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Extension of the Flood Forecasting Model FloRIJN

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Extension of the Flood Forecasting Model FloRIJN

Final report of the IRMA-SPONGE project no 12

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Preface

This report and the IRMA-SPONGE Umbrella Program

In recent years, several developments have contributed not only to an increased public interest in flood risk management issues, but also to a greater awareness of the need for improved knowledge supporting flood risk management. Important factors are:

- Recent flooding events and the subsequently developed national action plans.
- Socio-economic developments such as the increasing urbanisation of flood-prone areas.
- Increased awareness of ecological and socio-economic effects of measures along rivers.
- Increased likelihood of future changes in flood risks due to land use and climate changes.

The study leading to this report aimed to fill one of the identified knowledge gaps with respect to flood risk management, and was therefore incorporated in the IRMA-SPONGE Umbrella Program. This program is financed partly by the European INTERREG Rhine-Meuse Activities (IRMA), and managed by the Netherlands Centre for River Studies (NCR). It is the largest and most comprehensive effort of its kind in Europe, bringing together more than 30 European scientific and management organisations in 13 scientific projects researching a wide range of flood risk management issues along the Rivers Rhine and Meuse.

The main aim of IRMA-SPONGE is defined as: "*The development of methodologies and tools to assess the impact of flood risk reduction measures and scenarios. This to support the spatial planning process in establishing alternative strategies for an optimal realisation of the hydraulic, economical and ecological functions of the Rhine and Meuse River Basins.*" A further important objective is to promote trans-boundary co-operation in flood risk management. Specific fields of interest are:

- Flood risk assessment.
- Efficiency of flood risk reduction measures.
- Sustainable flood risk management.
- Public participation in flood management issues.

More detailed information on the IRMA-SPONGE Umbrella Program can be found on our website: *www.irma-sponge.org*.

We would like to thank the authors of this report for their contribution to the program, and sincerely hope that the information presented here will help the reader to contribute to further developments in sustainable flood risk management.

Ad van Os and Aljosja Hooijer
(NCR Secretary and IRMA-SPONGE project manager)

Summary

After the floods of 1993 and 1995 in the Rhine basin, the ICPR Action Plan on Flood Defence (ICPR, 1998) was drawn up, after which the environmental affairs ministers of the Rhine riparian states agreed on several measures on the subject of improvement of flood forecasting and warning systems in the Rhine basin. One of the targets of this action plan is the extension of the forecasting period for reliable flood forecasts in the entire Rhine basin. For the Dutch gauging station Lobith on the German-Dutch boarder the forecasting period should be extended from two days to three days in the year 2000 and to four days in the year 2005.

Water level forecasts for Lobith are made by the Institute for Inland Water Management and Waste Water Treatment (RIZA). Under normal conditions this is done every morning, mainly for the benefit of navigation. In times of flood, forecasts are made at least twice a day, again for navigation but also for river management authorities, crises centres and population.

Until 1999 water level forecasts for Lobith were made with a simple statistical model based on multiple linear regression technique. The model uses present and antecedent water levels of the Rhine and its main tributaries, observed and forecasted precipitation for the German part of the Rhine basin. In most cases the forecasts for the first two days were within the desired accuracies. The three and four-day forecast however were not suitable for publication.

To achieve the goal of the Action Plan for the year 2000 a new forecasting system called FloRIJN was developed in the period between 1995 and 1998. This system consist of a combination of a hydrodynamic model of 250 km of the German Rhine from Andernach to Lobith, two rainfall-runoff models for the tributaries Sieg and Lippe and a sub model, computing lateral exchange between river and groundwater. The FloRIJN system proved to be capable of producing a reliable three-day forecast during some minor floods at the end of the last century.

To meet the demands for a four-day forecast, the system was further improved and transformed into a Flood Early Warning System (FEWS) for the Rhine. The hydrodynamic model of the Rhine was extended in upstream direction with another 250 km of the Rhine up to the gauging station of Karlsruhe/Maxau. A hydrodynamic model of the lower part of the River Moselle was made and connected to the Rhine model. The two rainfall-runoff models were replaced by new hydrological models based on the Swedish HBV software. The remaining part of the Rhine basin between Maxau and Lobith was modelled with HBV as well. The new FEWS Rhine will increase the available time for water management authorities and local decision makers to prepare and take measures such as the reinforcement of flood protection works, evacuation of people and life stock and deployment of retention areas. Therefore less people will be endangered and damages can be reduced.

1 Introduction

Operational flood management is an essential part of integrated flood protection. Information on expected water levels is important base information for flood management Since absolute safety against floods does not exist, it is important to indicate potential problem situations in an early stage and to take measures to prevent people from drowning and reduce damages as much as possible. In the Netherlands the potential damage in the part of the country that is endangered by rivers is roughly estimated at 1,200 billion Euro [Moll et al., 1996]. The flood event of 1995, during which over 200,000 people in the Dutch part of the Rhine basin had to be evacuated, showed again the importance of reliable forecasts with a sufficient forecast period.

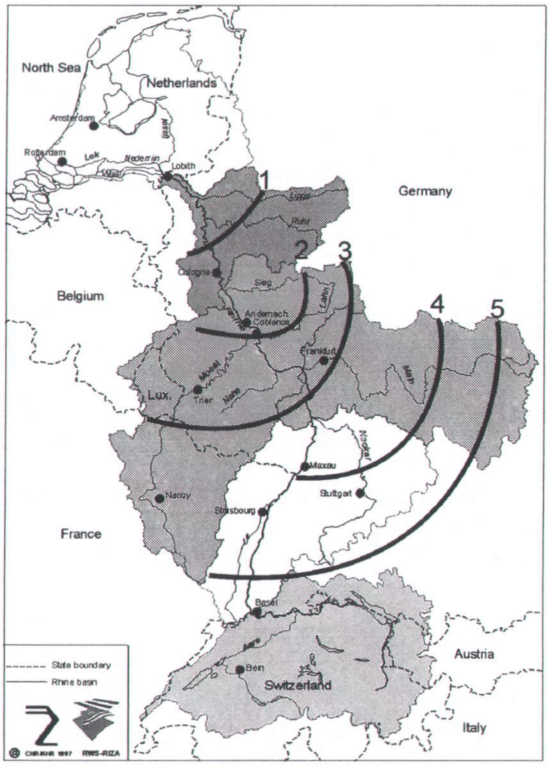

Figure 1.1 Rhine basin with travel times to Lobith

In periods of flood, river authorities and decision makers see themselves confronted with lots of questions dealing with organisation and communication. Which preventive measures must be taken? How many personnel should be brought in? What water levels can be expected? How is the stability of the river dikes? What should be done when evacuation is necessary? In such a crisis situation a large variety of inspective, executive and administrative institutions are active, all thinking and acting out of their own knowledge and experience. This can lead to complex situations. Technical judgements must be translated into administrative measures, e.g. evacuation or not. These kind of far-reaching measures ask for careful and expert deliberation. But time for consideration of decisions is limited.

Preventive measures will be taken on the basis of expected water levels. After the flood of 1995 water boards that are responsible for the stability of river dikes, as well as municipal and provincial authorities expressed the need for water level forecasts with a lead-time of more than 48 hours. An extension of the lead-time for flood forecasting should increase the available time for large-scale operations, like the evacuation of the densely populated area that is endangered by the River Rhine branches. Therefore less people will be endangered and damages can be reduced.

In addition to the safety precautions, flood forecasts will become more and more important for the steering of flood management, e.g. for the use of flood retention areas. The moment a retention area should be deployed, depends highly on expected water levels. If an area is deployed too early or too late, the measure has no effect on the top of the flood wave. Deployment of the retention areas in the Upper Rhine basin for an effective protection of the Middle and Lower Rhine area is e.g. only possible when the top of the flood wave can be forecasted 3½ to 4½ days ahead [Engel et al., 1994].

Water level forecasts for the Dutch gauging station Lobith on the German–Dutch border (see fig. 1.1) are made by the Institute for Inland Water Management and Waste Water Treatment (RIZA) that is part of the Dutch Ministry for Transport and Public Works. Under normal conditions this is done every morning, mainly for the benefit of navigation. In times of flood, forecasts are made at least twice a day, again for navigation, but also for river management authorities, crisis centres and population. Flood forecasts are made when the water level at Lobith is above 14.00 m +NAP[1] and expected to rise above 15.00 m +NAP (the mean level at Lobith is approximately 10.00 m +NAP).

[1] NAP: 'Normaal Amsterdams Peil' is the Dutch reference system for altitudes and corresponds approximately to the mean sea level near Amsterdam

One of the goals of the Action Plan on Flood Defence [ICPR, 1998] that was drawn up after the 1995 flood on the Rhine, is the extension of the forecasting period for reliable flood forecasts in the entire Rhine basin. For the gauging station Lobith it was decided to expand the forecasting period with 50% from two to three days in the year 2000 and with 100% to four days in the year 2005.

Until 1999 water level forecasts for the Lobith gauging station were calculated with a simple statistical model based on multiple linear regression technique. The model uses present and antecedent water levels of 12 gauges on the Rhine and its main tributaries, observed precipitation of eight stations in the Rhine basin and precipitation forecasts for the coming days as input. It computes water levels for Lobith up to four days ahead. In most cases for the first two days the required accuracies of 10 and 15 cm can be met. For the third and fourth day inaccuracies are larger than the desired 20 and 40 cm. Therefore only the forecast for the first two days were released for publication. The model was used for daily forecasts as well as for flood forecasts.

To achieve the goals of the Action Plan, efforts were made to improve the statistical forecasting model [Parmet & Sprokkereef, 1997]. After some studies (re-calibration, introduction of neural networks) it was concluded that the goals could not be achieved through improvement of this model. Another important reason for choosing a different approach were the expected anthropogenic influences in the Rhine basin, like river restoration and flood retention measures. These influences cannot easily be incorporated in a statistical model. Therefore a new physically based forecasting system, called FloRIJN, was developed.

At present the FloRIJN system consists of a 1-dimensional hydrodynamic (Sobek) model of 250 km of the German Rhine from Andernach to Lobith, two rainfall-runoff models for the northern tributaries Sieg and Lippe and a sub model, computing lateral exchange between river and groundwater. The system uses water level input of nine gauging stations, observed precipitation of five stations and precipitation forecasts for the northern part of the Rhine basin and is used when the discharge at Lobith exceeds 6,000 m^3/s. First semi-operational use of the FloRIJN system showed little improvement for the first and second-day forecast compared to the former statistical model. For the third and fourth day however FloRIJN performed substantial better. With this system it is assumed that the achieved 50% extension of the lead-time for accurate forecasts for the year 2000 is realized [Sprokkereef, 2001].

For the aimed 100% extension of the lead-time the present system was further improved and transformed into a Flood Early Warning System for the Rhine. The hydrodynamic backbone, the Sobek-model, was extended in upstream direction with another 250 km of Rhine stretch, to the gauging station of Karlsruhe/Maxau. The two existing rainfall-runoff models of the northern tributaries Sieg and Lippe were replaced by a new type of hydrological models, based on the Swedish HBV-software. These models allow a better physical description of the basin. Other tributaries downstream of Maxau and sub-catchments draining on the Rhine were also incorporated as HBV-models.

In chapter 2 of this report the development of the FloRIJN forecasting system that was carried out immediately after the flood of 1995 and is presently used for operational forecasting in the Netherlands, is briefly described. This chapter contains information on the development of the Sobek model Andernach-Lobith, the rainfall-runoff models for two main tributaries and the user interface of the forecasting system. Chapter 3 describes the extension of the FloRIJN system into the new FEWS Rhine system. Main parts of this chapter are the introductory definition study, the extension of the hydrodynamic model, the hydrological modelling of the German part of the Rhine basin and the development of the forecasting system itself. Chapter 4 deals with data flows and chapter 5 with dissemination of forecasts, whereas chapter 6 contains the main conclusions and recommendations.

2 Development of the FloRIJN forecasting system

2.1 Introduction

After several studies it was concluded that the improvements of the statistical forecasting model for the gauging station Lobith on the Rhine that was used since 1980, have been insufficient to produce a reliable forecast for a period of more than two days. After three re-calibrations, the implementation of a new sub model for high discharges, investigations on correction for the hysteresis effect and introduction of neural networks as a non-linear error corrector, the possibilities for improvement of this model are more or less exhausted [Parmet & Sprokkereef, 1997].

Another important reason to abandon the statistical concept is the expected changes in the catchment area and the river system. After the floods of 1993 and 1995 plans for flood protection have accelerated. For the Rhine basin the Action Plan on Flood Defence was drawn up [ICPR, 1998]. As a result of this plan the storage capacity of the catchment area will be expanded and the river will be given more space. Retention areas will be created along the river that will significantly affect flood waves. In a statistical model that is calibrated with observed discharges, this kind of human influences can only be implemented subsequently, when a new series of discharges has been collected. In the mean time uncertainties of flood forecasting will be large. Given the great importance of flood forecasts for the Netherlands, these uncertainties are unacceptable. Changes in the river system must be implemented immediately. Therefore a new physically based forecasting system called FloRIJN was developed in the period between 1995 and 1998.

2.2 Hydraulic modelling

The basis of the current flood-forecasting system FloRIJN is a 1-dimensional hydrodynamic flow model of the German Rhine between Andernach (Rhine km 613.8) and Lobith (Rhine km 862.2). The hydraulic model with a length of 248.8 km is based on the modelling system Sobek. Gauging stations are located at more or less regular intervals (nine in total). In order to enable simulations per river reach between main gauging stations, it was decided to divide the river reach of 248.4 km into seven reaches varying from 23.4 to 56.2 km of length. In addition it was agreed not to model the main tributaries as separate branches, but to include them as lateral inflows. Minor tributaries (in some cases unmeasured) were neglected.

Main objective was to construct a calibrated and verificated 1-dimensional flow model, suitable for making accurate operational water level predictions. This model should fulfil the following requirements:

- the calculated top water levels must deviate less than 0.10 metres from the measured water levels at the gauging stations;
- the difference between the calculated and the measured travel time of the top level on the reach Andernach-Lobith should not exceed six hours;
- the model must connect to the existing operational Sobek model of the Dutch Rhine branches.

The construction of the Andernach-Lobith model was carried out in three phases [Barneveld & Meijer, 1997]. In the first phase data was collected for two representative test reaches of the River Rhine. These two reaches have been schematised and roughly calibrated for a series of permanent discharges. The aim of this first phase was to assess which schematisation routines were most suitable for the German Rhine and which adaptations should be made. In the second phase data for the remaining reaches between Andernach and Lobith have been collected and processed. Based on experiences of the first phase, the most appropriate schematisation routines have been applied to generate the Sobek cross sections for the complete river reach. In the third and final phase the cross sections generated in first two phases have been used to construct, calibrate and verify a Sobek model for the complete river reach between Andernach and Lobith. Calibration and verification have been carried out using measured water levels during periods with approximately permanent flow and measurements during recent flood events.

The results of the steady state calibration runs are presented in table 2.1 This table shows the differences between calculated and measured water levels at the gauging stations in metres.

Table 2.1 Differences between calculated and measured water levels (in metres) for steady state calibration runs.

	NW91	GLW92	MW89	MHW93	HW88	HW93	HHW95
Bonn	0.01	0.05	-0.01	0.01	0.06	0.02	0.12
Cologne	0.04	0.03	0.05	0.04	-0.11	0.02	0.00
Düsseldorf	0.01	-0.02	-0.05	-0.05	-0.06	-0.09	-0.02
Ruhrort	0.02	-0.03	-0.03	-0.05	-0.05	-0.03	0.03
Wesel	0.00	-0.01	-0.09	-0.04	0.05	-0.07	0.07
Rees	0.04	0.05	0.05	0.06	-0.08	-0.01	0.07
Emmerich	-0.05	-0.03	-0.04	0.03	0.00	-0.05	-0.01
Lobith	0.00	0.00	0.00	0.00	0.00	0.00	0.00

The results show that especially for the four lowest permanencies (NW91 to MHW 93) simulation results agree very well with the measurements. For the three higher permanencies (HW88, HW93 and HHW95) differences are larger.

In addition to the steady state simulations, the flood wave of 1995 is used for calibration. Downstream of Bonn this flood wave produced the highest water levels since 1926. Upstream of Bonn the water levels were slightly lower than the ones observed one year earlier during the flood wave of December 1993. The simulated water levels for the 1995 flood wave were compared with measured water levels at the gauging stations. The results for the gauging stations downstream of Ruhrort are presented in figure 2.1. Table 2.2 shows the differences between observed and simulated peak water levels for the different gauging stations.

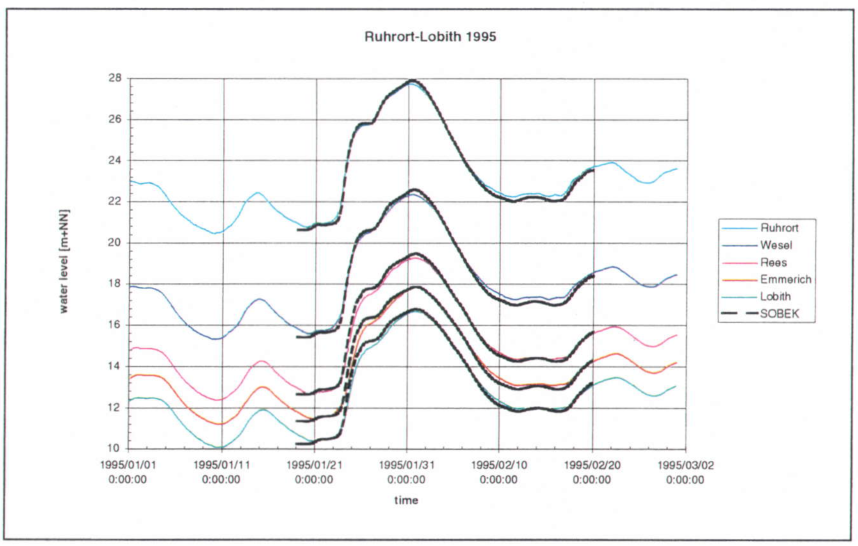

Figure 2.1 Observed and simulated water levels on the reach Ruhrort-Lobith for the 1995 flood event

It can be seen that calculated and observed water levels are in good agreement for the reach Andernach-Düsseldorf. The differences between measured and observed peak levels never exceed 10 cm, which was one of the objectives of the calibration. For the reach downstream of Düsseldorf larger differences are found. The calculated peak water levels are generally higher (up to 20 cm) than the observed ones. Calculated and observed travel times of the flood wave are also in good agreement. The difference between calculated and observed travel time between Andernach and Lobith is about one hour.

Analysis of the differences between calculated and observed water levels and discharges shows an overestimation of model results in the rising limb and an underestimation in the falling limb of the flood wave. These differences could be caused by a number of factors:

- unreliability of stage-discharge relations;
- hysteresis effect or looped rating curve;
- backwater effects in the tributaries during high water levels on the Rhine;
- loss of water between gauging stations due to flooding of cities;
- temporary storage of water in the groundwater.

It was concluded that the exchange between river and groundwater likely is the main cause of the differences between observed and calculated water levels. For incorporating this groundwater effect in the Sobek simulations an analytical model has been developed during the project. This model calculates – in a simple way – for every river reach the water losses and supplies as a function of the water level time series at Andernach.

With the calculated lateral exchange between river and groundwater the Andernach-Lobith model was recalibrated. Table 2.2 shows the differences between observed and calculated water levels for the peak of the 1995 flood after recalibration and incorporation of the groundwater model.

Table 2.2 Differences between observed and simulated peak water levels (in metres) on the reach Andernach-Lobith for the 1995 flood event. Calibration without and with groundwater model.

Station	Andernach	Bonn	Cologne	Düsseldorf	Ruhrort	Wesel	Rees	Emmerich	Lobith
peak without groundwater model	-0.05	-0.01	0.05	0.06	0.16	0.21	0.20	0.00	0.10
peak with groundwater model	0.00	0.01	0.01	0.03	0.06	0.06	0.03	-0.06	-0.06

The differences between calculated and observed water levels between Andernach and Lobith are small. The calculated peak is reached one hour before the measured peak. For verification of both flow model and groundwater model, three additional flood waves were simulated. The differences for the peak levels never exceed the required 10 cm. Table 2.3 shows the differences in metres between computed and measured water levels for the two peaks of the 1993 flood event, one of the events used for model validation.

Table 2.3 Differences between observed and simulated peak water levels (in metres) on the reach Andernach-Lobith during the flood of 1993. Verification with groundwater model.

station	Andernach	Bonn	Cologne	Düsseldorf	Ruhrort	Wesel	Rees	Emmerich	Lobith
peak 1	0.00	0.03	0.10	0.08	0.07	0.01	0.03	0.02	0.00
peak 2	0.00	-0.04	-0.04	-0.04	-0.05	-0.02	0.02	0.06	0.03

2.3 Hydrological modelling

To provide lateral input to the Sobek model of the Rhine stretch Andernach-Lobith, rainfall-runoff models for the northern Rhine tributaries Sieg and Lippe were developed [Van Mierlo & Passchier, 1998]. Both models distinguish between surface flow and base flow. The volume that is available for surface flow is calculated with a Horton type infiltration module, whereas the temporal distribution of the surface flow is determined with the Nash Unit Hydrograph method (also called Nash cascade method). Base flow is calculated with an ARIMA-model that considers actual base flow to be a function of preceding base flows only.

Both the Sieg and the Lippe model are calibrated for one flood period and validated for three other flood periods. The models produced satisfactory results for most of the flood events. All the model parameters stay within physically acceptable ranges. Figures 2.2 and 2.3 show model results for both the Sieg and the Lippe model for one of the validation periods.

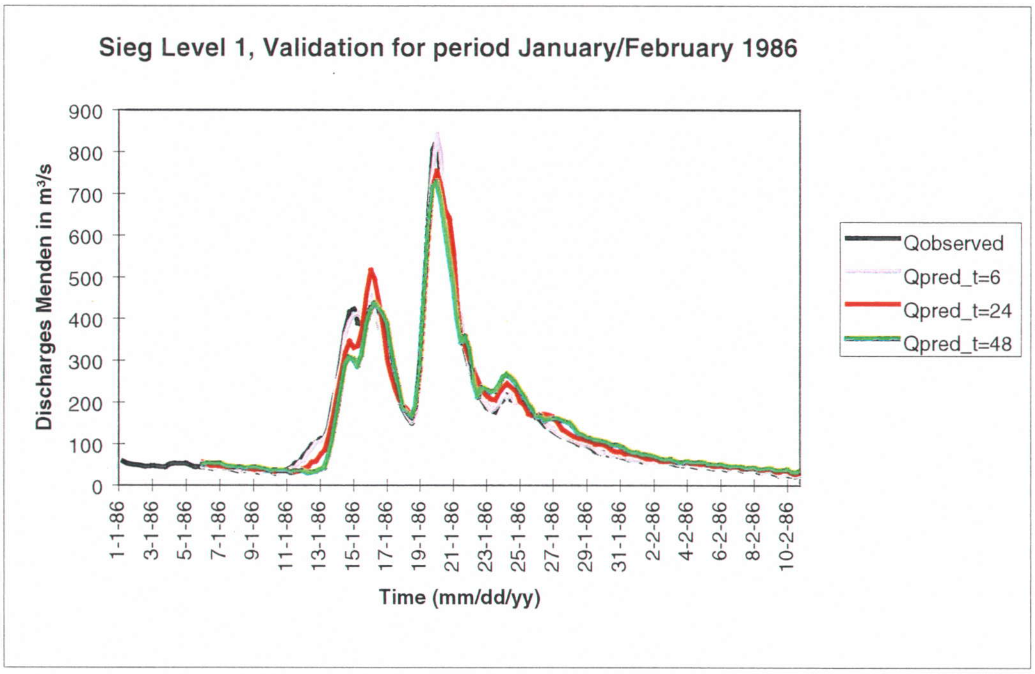

Figure 2.2 Observed and calculated discharges 6, 24 and 48 hours ahead for the gauging station Menden/Sieg for the validation period January/February 1986

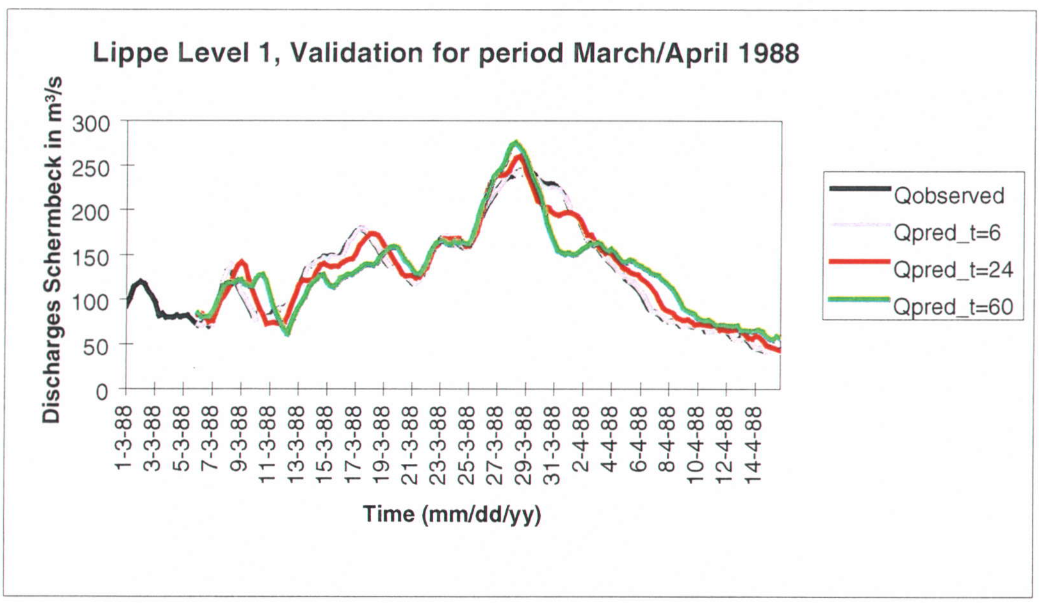

Figure 2.3 Observed and calculated discharges 6, 24 and 60 hours ahead for the gauging station Schermbeck/Lippe for the validation period March/April 1988

2.4 FloRIJN User Interface

Mid 1998 the FloRIJN system consisted of a 1-dimensional hydrodynamic model of 250 km of the German Rhine between Andernach and Lobith, two separate precipitation-runoff models for the tributaries Sieg and Lippe and a groundwater component for the simulation of the exchange between river and groundwater.

The backbone of the forecasting system, the Sobek model Andernach-Lobith is fed with the following information:

- a German water level forecast for the gauging station Andernach;
- the results of the groundwater model for 7 reaches between Andernach and Lobith;
- the results of the precipitation-runoff models for the Sieg and the Lippe;
- a German discharge forecast for the tributary Ruhr;
- on-line recordings for the tributaries Ahr, Sieg, Wupper, Ruhr, Emscher and Lippe.

Before the development of the user interface, the FloRIJN system consisted of a collection of sub modules combined with input and output files. To make the system suitable for operational use, the input and output of the various modules had to be connected and the system was provided with a user-friendly interface [Vermetten, 1998] [Vermetten & Van den Akker, 1998].

The user interface takes care of the conversion of input, originating of various sources to a suitable format for the sub modules and conversion of the output of the sub modules to a suitable format for the Sobek model. Communication between the Sobek model and the groundwater and precipitation-runoff components is invisible. A module was created, allowing the user to optimise the parameters of the precipitation-runoff models online. The interface makes it possible to present input and output graphically as well as alphanumerically. Last but not least the interface provides possibilities for adequate archiving and backup of input data and calculation results.

Figure 2.4 shows the connection between the required data, the models and the model results.

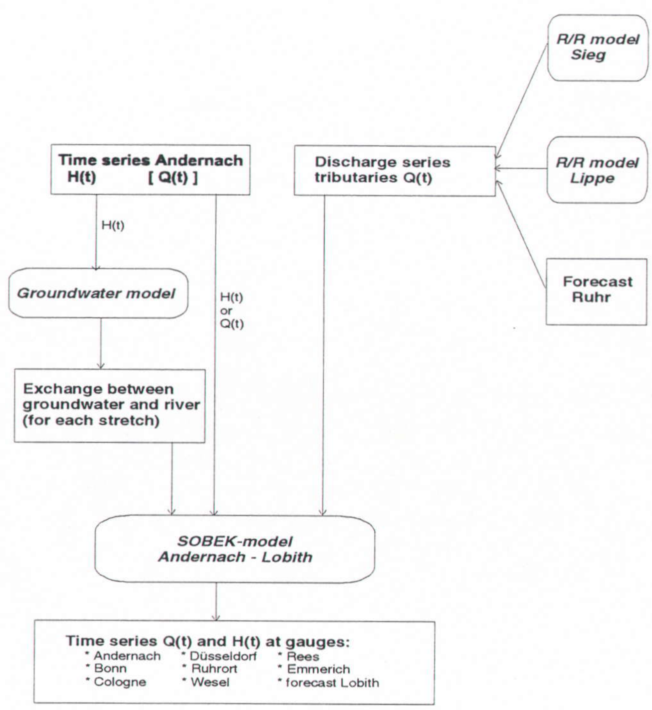

Figure 2.4 Schematic presentation of a flood simulation

In operational mode the FloRIJN forecasting system is used at RIZA's Information Centre (IC) for Inland Waters in Lelystad. Therefore the data-interfaces of the forecasting system had to be tuned to the data infrastructure of the IC. A complete redesign of this infrastructure, the project BC2000, has led to a central database for all activities within the IC. For the flood forecasting models this means that the required input files (water levels, precipitation and stage discharge relations) are provided by the central database in an agreed format at an agreed location.

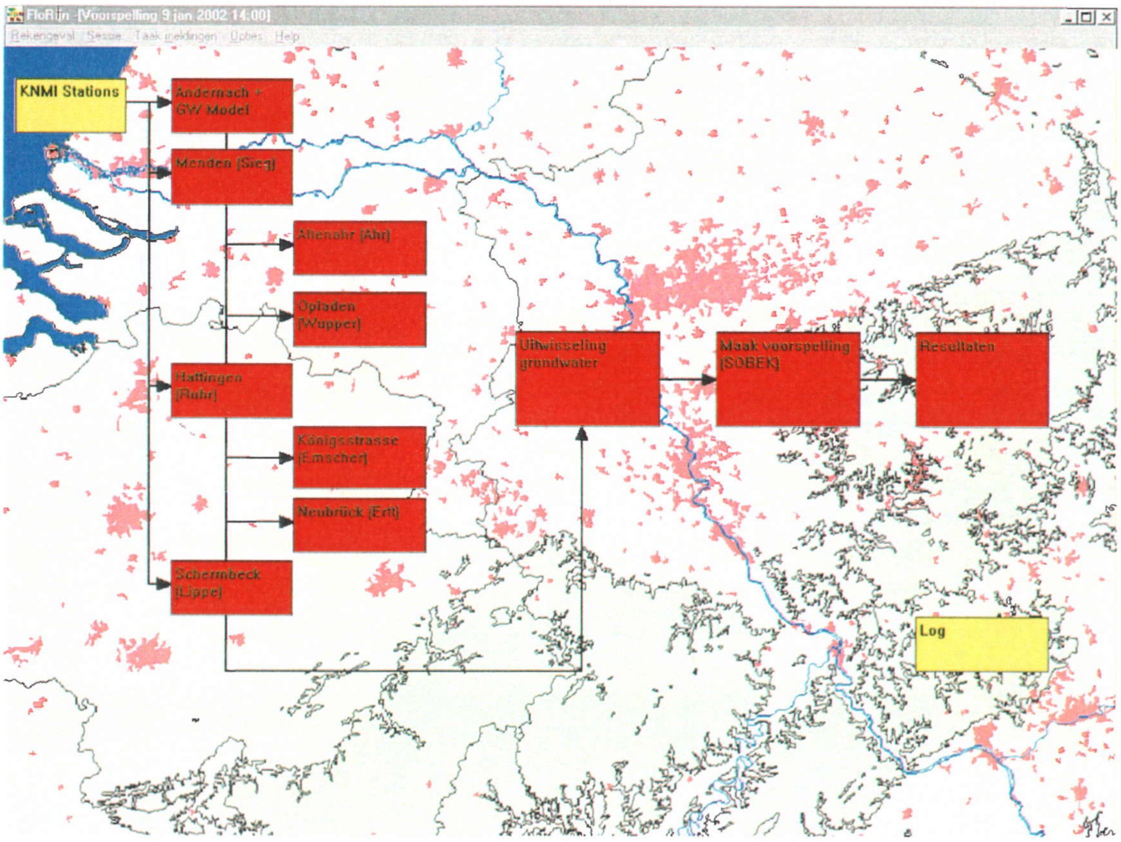

Figure 2.5 FloRIJN User Interface, start screen with the different modules

To ensure maximum reliability, it was decided that the FloRIJN forecasting system should not just depend on the IC database. FloRIJN can also use the (ASCII) files with water levels that are produced by the Multi Functional Presentation System (MFPS), a monitoring system for meteorological and hydrological data in the Netherlands With this option it is possible to run the forecasting system at any chosen location without a connection to the central database. When also the MFPS data are not available, all data can of course be typed in manually.

Output of the forecasting system is a water level and discharge forecast for the gauging station Lobith four days ahead. This output can be displayed graphically and alphanumerically (see fig. 2.6). Besides that it is possible to present hydrographs, meteorological time series and previous forecasts. Based on these data and the hydrological knowledge of the hydrologist in charge of the forecast, he or she can correct the model result manually into the forecast that will be published. The system generates a standard Flood Warning that can be imported and edited in every normal word processor.

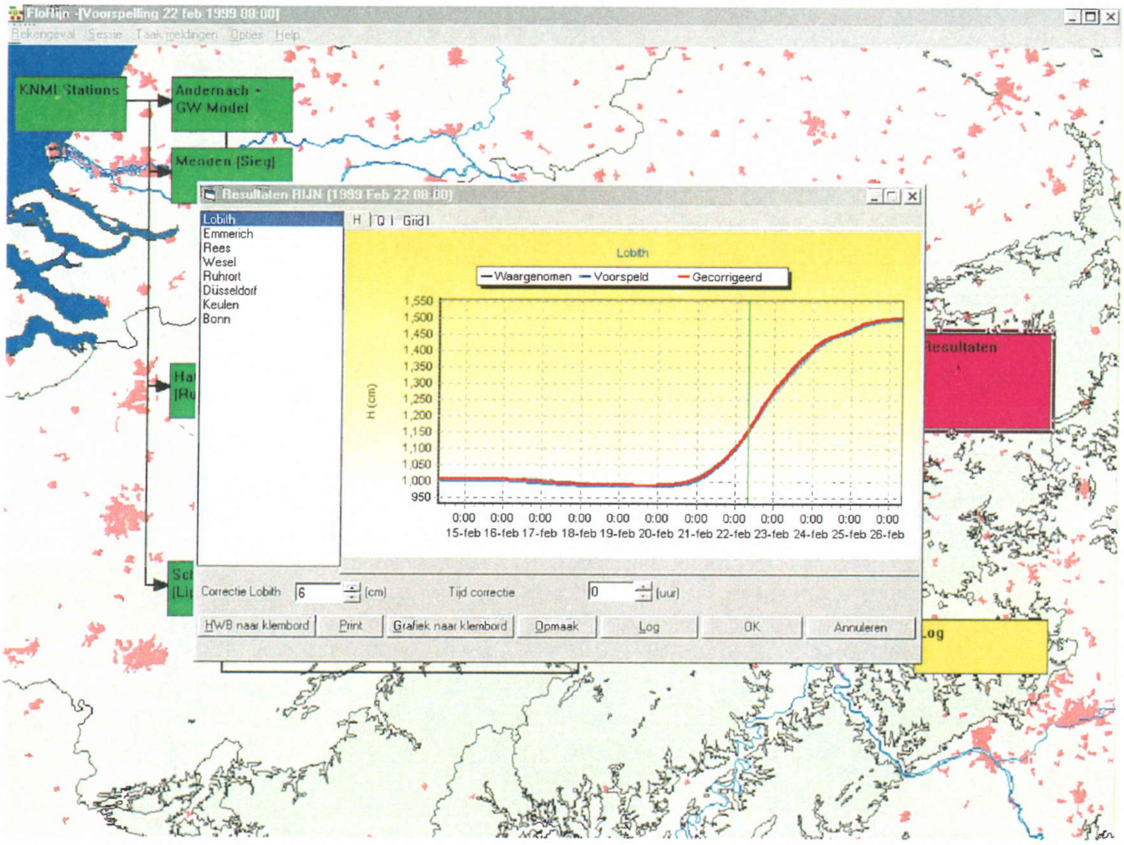

Figure 2.6 FloRIJN User Interface, screen forecasting results

2.5 Forecasting results of the FloRIJN system

There are four different components that may effect the accuracy of the FloRIJN forecasting system: the rainfall-runoff models, the groundwater component, the external forecasts for Andernach and the Ruhr and last but not least the weather forecasts of the Royal Dutch Meteorological Institute KNMI. The accuracy of the different model components were analysed for two floods at the end of the 90s [Sprokkereef, 2001].

It was concluded that the maximum error of the two rainfall-runoff models two days ahead could mount up to some 500 m^3/s. During a flood with a discharge at Lobith of about 10,000 m^3/s this could result in a forecasting error for Lobith of some 20 cm. There are two main reasons for the inaccuracy of the rainfall-runoff models. The first reason is that the chosen model concept probably is not capable to describe the physics of the precipitation-discharge process very accurately. A second and probably far more important reason can be found in the meteorological input of the models. For the Sieg model as well as for the Lippe model areal precipitation for the entire catchment is calculated based on observations of two stations. Also the precipitation forecast (one daily sum for the northern part of the Rhine basin) can hardly be translated into areal precipitation for a sub catchment. Besides the areal inaccuracy of the input data, the temporal resolution of the meteorological data is probably too coarse. The observed precipitation data are six-hourly sums and the precipitation forecast is a daily sum. These sums are equally divided by 6 and 24 respectively and used by the rainfall-runoff models as hourly data. It is clear that in most cases this will not be a correct reproduction of reality.

Due to lacking groundwater measurements on the stretch Andernach-Lobith, the results of the groundwater component cannot be compared to reality.

FloRIJN uses the German forecasts for the gauging station Andernach as upper precondition. The travel time from Andernach to Lobith is about 48 hours. For a 72-hour forecast for Lobith a 24-hour forecast for Andernach should be available. This forecast is essential for the reliability of the three-day forecast for Lobith. Table 2.4 shows the contribution of the different parts of the Rhine system to the total discharge at Lobith for the peak of the flood of 1995. The composition of this flood wave is representative for flood waves originating in the southern and middle part of the Rhine basin. At the upper boundary of the forecasting model 80% of the total discharge that was observed at Lobith was already in the system. That means that the observed water level at Andernach determines 80% of the two-day forecast for Lobith. The 24-hour forecast for Andernach has the same influence on the three-day forecast for Lobith.

Table 2.4 Contribution of the different parts of the Rhine system between Andernach and Lobith to the peak discharge at Lobith for the flood of 1995.

Discharge component	Contribution
Andernach	10,200 m^3/s (80%)
Sieg	730 m^3/s (6%)
Ruhr	850 m^3/s (7%)
Lippe	370 m^3/s (3%)
other tributaries	460 m^3/s (4%)

During the floods of 1995 and 1998 the German water level forecasts for Andernach were mainly to low in the rising limb and to high in the falling limb of the wave. Errors up to 50 cm were observed for the 24-hour forecast. A 50 cm error for Andernach leads to a discharge error of about 700 m^3/s, which means a forecast error for Lobith of some 30 cm in the top of the flood wave. 48-hour forecasts for Andernach that will be necessary for a four-day forecast for Lobith, presently are of rather poor quality. Here the forecast for the River Moselle becomes indicative. The mean error of the 48-hour forecasts for Andernach during the flood of November 1998 was about 60 cm, whereas the maximum underestimation was more than 1 meter (1.14 m). Such an error would lead to an error in the four-day forecast for Lobith of about one metre.

The local forecast for the gauging station Hattingen on the River Ruhr is made by the Ruhrverband in Essen. Within the FloRIJN project it was decided not to implement a separate model for the Ruhr. The discharge of the Ruhr depends highly on manipulations of the storage reservoirs in the basin. Because of the travel time from Hattingen to Lobith (about 24 hours) a 48-hour forecast for Hattingen would be required for a three-day forecast for Lobith. In practice a 12-hour forecast is the best the Ruhrverband can provide at this moment. The model that is used by the Ruhrverband covers only the downstream part of the Ruhr. A new model that covers the entire Ruhr basin is presently developed.

During the flood of November 1998 the FloRIJN model was used for the first time under semi operational conditions. The improvements for the forecasts with lead-times of two days and more were significant. Especially for the three and four-day forecasts the model results met the requirements in almost all cases. The results of both the old statistical model and the FloRIJN forecasting system for the flood of November 1998 are presented in figure 2.7.

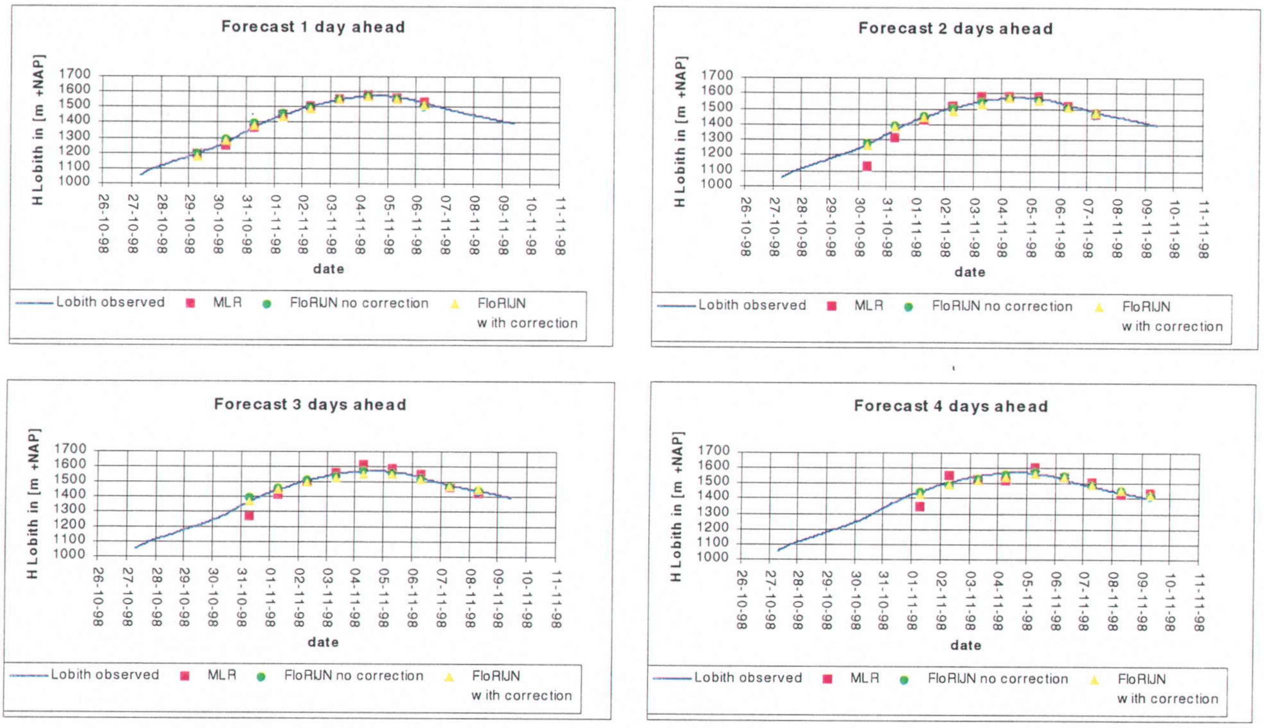

Figure 2.7 Observed and forecasted water levels one, two, three and four days ahead during the flood of October/November 1998. Forecasts made with the statistical (MLR) model and with the FloRIJN forecasting system, without and with model correction based on the mean difference between observation and model calculation in the last 24 hours before the forecast