Proceedings of ERAD (2002): 144–149 © Copernicus GmbH 2002

ERAD 2002

# Assessment of storm return periods based on radar data

**T. Einfalt and M. Jessen**

einfalt & hydrotec GbR, Wakenitzmauer 33, D-23552, Lübeck, Germany

**Abstract.** Damage caused by overloading of urban drainage systems frequently occurs. Relevant for the operators of the drainage system is the assessment of the storm frequency in order to produce a statement of liability or of natural disaster. The city of Luebeck in Northern Germany faced reported flooding at three events in summer 2001. Radar data combined with raingauge data from two origins and traditional frequency statistics were used to assess a spatially detailed image of the rainfall return periods for the three events.

The rainfall amounts were spatially very variable: in presence of more than 50% event rainfall volume difference between neighbouring radar pixels, a straight comparison between radar pixel and raingauge measurement was not possible. Therefore, a methodology for estimating the uncertainty of the obtained rainfall values and the resulting storm return periods was applied.

The results showed a very heterogeneous rainfall pattern over the different subcatchments of the city which was supported by the reported flooding cases.

## 1 Introduction

In the case of flooding due to overloading of the urban drainage system communities have to determine the reason for the encountered problems. One possibility for such floodings are unusual rainfall events, another one is the too low capacity of the urban drainage system. Problems with low capacity of an urban drainage system arise if new pipes from residential areas are connected to the existing drainage network. For the long-term investment planning, it is in such cases necessary to know if there is enough transport capacity for the future.

The data from the raingauges are not sufficient for a statement on the rainfall volume in the affected areas. The reason is the missing spatial proximity of the raingauges to these areas. In those cases radar data give more detailed results in combination with raingauges data.

*Correspondence to:* T. Einfalt (thomas@einfalt.de)

## 2 Case study

### 2.1 The problem

The volume of three heavy rainfall events in June and July 2001was analysed for the waste and water disposal utility of Luebeck. In ten catchments of the city the rainfall of the three events was compared with the design situation of the drainage system.

The used data for this task were:

- Radar data from the German Weather Service - DWD (radar station Hamburg-Fuhlsbuettel)
- Raingauge data of Eutin and Hahnheide (state authority for nature and environment of Schleswig-Holstein)
- Raingauge data of Luebeck-Blankensee (DWD)
- Extreme rainfall statistics of Luebeck (DWD)

#### 2.1.1 Weather radar

The radar data from the German Weather Service (DWD) were based on the DX-product (DWD, 1997) which is characterized by

- 5 minute time step,
- 1 km $\times$ 1° spatial resolution,
- 256 intensity classes,
- 128 km range

For the events of 15 June, 30 June and 8 July 2001 the radar station Hamburg-Fuhlsbuettel was used.

#### 2.1.2 Raingauge locations

For the same period the raingauge data of the above mentioned three locations were available. The time step of these continuous data was 1 minute (Eutin, Hahnheide) or 10 minutes (HL-Blankensee).

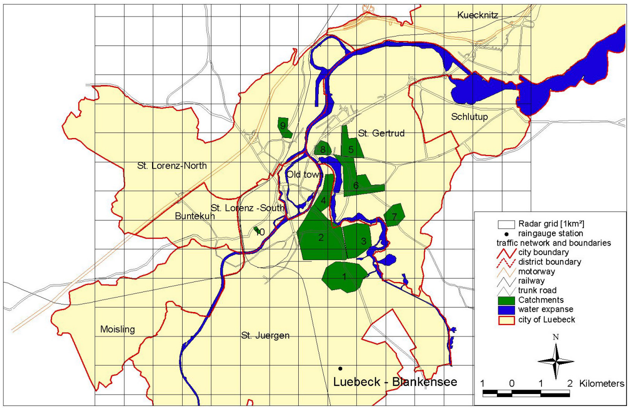


**Fig. 1.** Predetermined catchments with radar grid.

### 2.1.3 Geographical data

Before the radar precipitation data can be evaluated, they have to be put into a relation with the area of interest. The client defined ten catchment in Luebeck, for which an areal precipitation should be calculated. Therefore, the boundaries of the ten catchments were intersected with the $1 \times 1$ km radar grid (Fig. 1). In this way, an allocation of radar pixels for these areas was found.

### 2.1.4 Extreme value statistics

There were two extreme value statistics of the German Weather Service (DWD) available for Luebeck:

- one of the year 1973, the basis for design of a large part of the current drainage system (DWD,1973), and
- the extreme value statistics of Luebeck-Blankensee of KOSTRA-90 (DWD, 1990).

Both were included in the evaluation and thus provided information for the range definition of the results.

## 2.2 Data preparation

### 2.2.1 Data quality control

First an intensive quality control of the input data took place (Maul-Kötter, Einfalt, 1998; Maul-Kötter et al., 2001). For the periods which were important for the events no implausibilities were noticed.

### 2.2.2 Adjustment of radar data

Radar measurements are measurements with an indirect method. Therefore it is compulsory to include point measurements for the exact determination of the precipitation volume.

On the basis of the DX-product of the DWD for the radar location Hamburg the precipitation volume was adjusted using the three raingauges mentioned above.

Precipitation data of the radars used in Germany today show the precipitation events with high spatial precision - the volume of the precipitation is more reliably detected by raingauges. Therefore it is necessary to adjust the spatial precipitation structure to the point values of the raingauges. Details of different measurement and further adjustment techniques, measurement errors etc. can be found in the specialized literature (e.g. Collier, 1989).

The radar adjustment was executed separately for each of the three events based on the comparison of precipitation sums of all three raingauges with the precipitation sums of the corresponding radar pixels. The adjustment technique chosen was the minimization of the root mean square error of the rainfall volume of all three locations. The resulting radar correcting factor was able to reproduce the raingauge values in a satisfactory way.

## 2.3 Methodology

The following work steps were undertaken:

– *Determination of the spatial rainfall for each catchment*

  For the ten catchments and the single points of the raingauge locations time series were created in 5-minute time steps using the SCOUT radar data processing software.

– *Classification of the precipitation intensities by means of the extreme value statistics of the DWD*

  The continuous levels were determined as having a return period of x years, if the values obtained by the radar data were above the table values of this x-year return period in the statistics. One exception is the determination of the frequency of twice a year: there a limit of 70% of the table value was chosen to obtain a separation between the hydrologically relevant and the irrelevant events.

– *Presentation of the return intervals for each area*

  On the one hand the return intervals were presentated in a table by taking the return periods from the tables of both extrem value statistics and presenting them in a similar way. On the other hand a graphic presentation was chosen, which shows the return periods for each duration class and the respective bandwidth.

– *Determination of the bandwidth of the results*

  The method of this determination will be described in the following section.

## 2.4 Uncertainties

To consider the spatial uncertainty of the measured data for the adjustment - the raingauge measures on the ground on an area of 200 cm$^2$, the radar in a height of a few hundred meters a volume of approximately $1 \times 1 \times 1$ km - the adjustment factor was calculated in different ways: firstly only with the

**Table 1.** Measured values of the radar at the raingauge locations (dark), the second nearest pixels (grey) and the other surrounding points

| location | Eutin | | | Hahnheide | | | Luebeck-Blankensee | | |
|---|---|---|---|---|---|---|---|---|---|
| radar measurement (without adjustment) | 0.97 | 0.97 | 5.17 | 6.14 | 4.79 | 10.78 | 18.68 | 13.27 | 13.63 |
| | 0.97 | 0.48 | 0.73 | 5.68 | 6.30 | 6.76 | 15.75 | 14.29 | 14.21 |
| | 0.65 | 0.65 | 0.50 | 6.43 | 7.25 | 5.63 | 8.21 | 17.77 | 19.11 |
| **median (mm)** | 1.23 | | | 6.64 | | | 14.99 | | |
| **standard deviation (mm)** | 1.49 | | | 1.71 | | | 3.37 | | |
| **standard deviation (%)** | **120.9** | | | **25.7** | | | **22.5** | | |
| **raingauge station (mm)** | 0.54 | | | 11.71 | | | 29.50 | | |

pixel of the raingauge location, secondly with the neighbouring pixel, thirdly with the mean of both pixels, fourthly with the mean of the nearest four pixels at the raingauge location and fifthly with the mean of the nine closest pixels. All obtained adjustment factors were used for the calculation of the spatial precipitation. The minimum, the maximum and the median value were further evaluated.

In addition to this, the standard deviation of the event volumes of the nine pixels for each event was determined. The uncertainties of the extreme value evaluation of the radar data were now deduced from the variability of the adjustment factors and the spatial standard deviation.

### 2.5 Results

As an example, the results for the event of 8 July 2001 are presented here. The analyses of the other events were undertaken in a similar way.

#### 2.5.1 Description of the event of 8 July 2001

From the southeast, a precipitaion area moved over the area of interest with a speed of about 50 km/h. The precipitation band included cells of heavy rain. The most affected regions were located southwest of the Old Town and northwest of Luebeck outside of the urban area (Fig. 2).

#### 2.5.2 Analysis of the spatial variability

The spatial variability of the precipitation is described using the neighbouring radar pixels at the raingauge location. Figure 3 shows the time series of the eight radar pixels surrounding the locations of the three raingauges and the time series of the raingauge pixels themselves. By analysing the event sums (Table 1) it became obvious,

– that almost no precipitation occurred in Eutin and only light precipitation in Hahnheide,

– that the spatial variability of the precipitation is high (at all stations over 20% standard deviation in the event sums of the nine pixels),

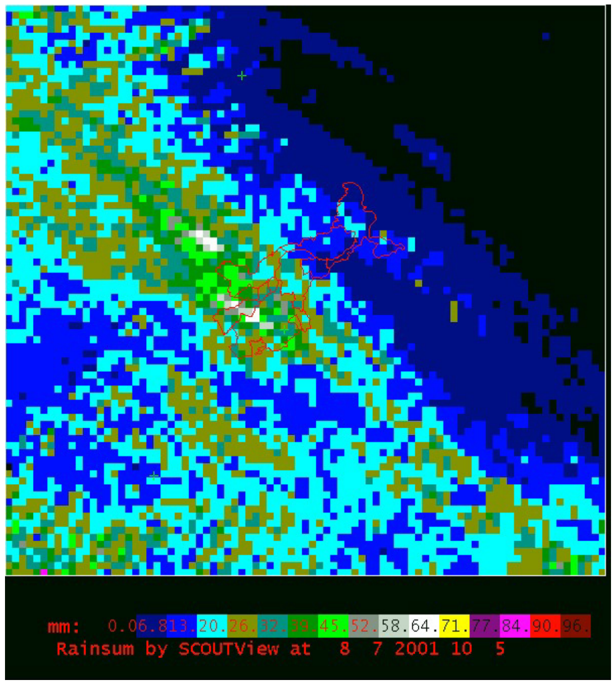


**Fig. 2.** Precipitation sum of the 8 July 2001.

– that the radar had measured less precipitation than the raingauges.

The comparison with the radar measurements shows additionally, that the measurements of the raingauges at the locations Hahnheide and Lübeck-Blankensee is spatially very variable and therefore not very representative for the area. The calculated standard deviation of the radar data was used as estimation of the spatial uncertainty for the measurement of raingauges.

#### 2.5.3 Adjustment of the radar data

First the adjustment parameters were determined. The bandwidth of factors of this event is presented in Fig. 4. In this

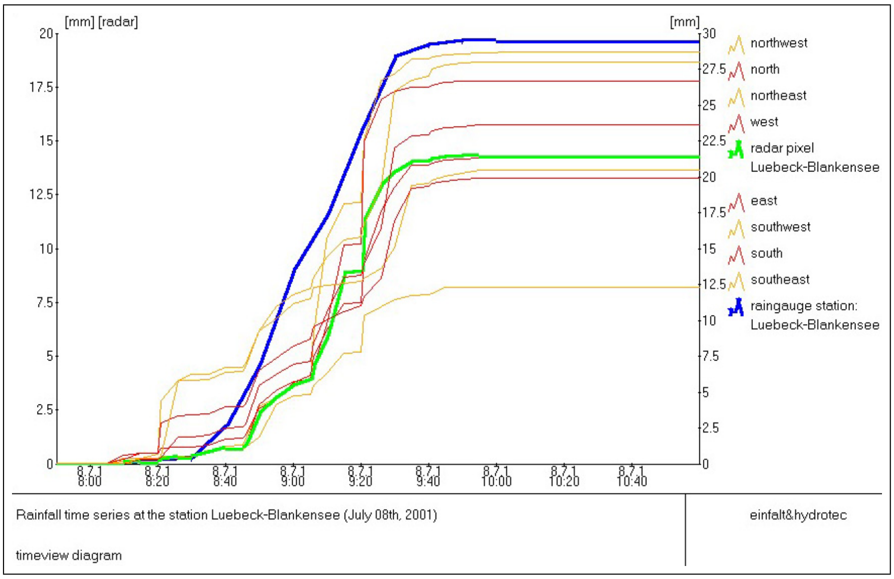


**Fig. 3.** Rainfall time series of the raingauge station Luebeck-Blankensee and the surrounding radar pixels.

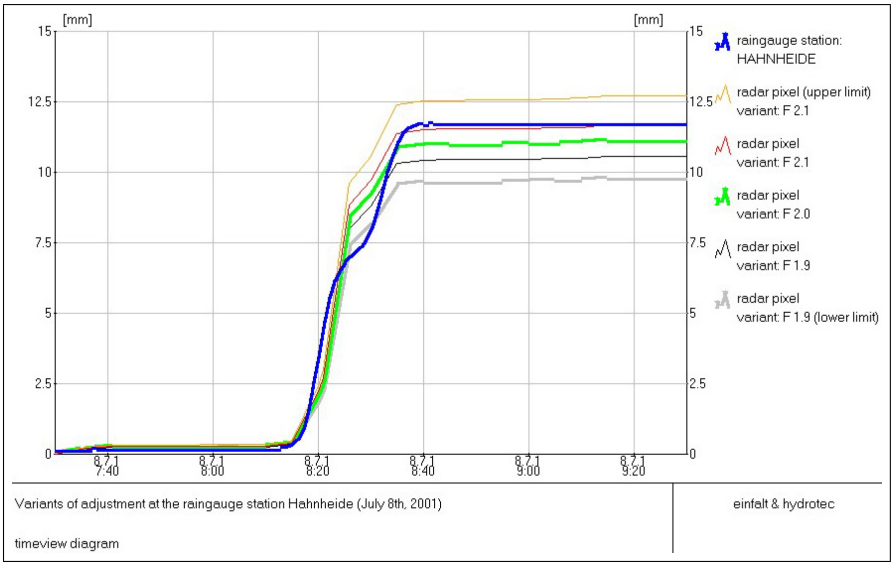


**Fig. 4.** Alternatives for adjustment at the raingauge station Hahnheide.

case, a correction factor for the radar data of 2.0 was calculated as the most plausible value - the lower and upper alternative were the use of the factors 1.9 and 2.1. The deviation from the lower and upper class boundary was smaller than the obtained spatial standard deviation of the data - therefore the latter was used here as bandwidth for the uncertainty of the values.

### 2.5.4 Results for the ten catchments

Based on the adjustment factor of 2.0 the precipitation of the ten catchments was calculated and compared with the extreme value statistics of Luebeck from 1973. For the uncertainty bandwidth the value 22,5% was used.

The precipitation of this event is very variable in the catchments – from moderate to very heavy precipitation. In all catchments the maximum return period was reached for a duration of 90 or 120 minutes. (Table 2).

In the catchments 1 and 2 it was a decennial rainfall event (durations 90, 120 minutes), in the catchment 10 it was quinquennial (durations 90, 120 minutes), in catchments 3 and 4 it was biennial (duration at least 120 minutes), in the catchments 5, 6 and 8 it was annual (duration at least 90 minutes) and in the catchments 7 and 9 it was a half yearly event (durations 60, 90, 120 minutes). Figure 5 shows the bandwidth of the results. In comparison to the DWD report of 1973, the KOSTRA 90 tables evaluated the event up to two return period classes lower.

**Table 2.** Results of one rainfall event

| time slice | areal precipitation [mm] | | | | | | | | | | Luebeck-Blankensee |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| **5** | 10.5 | 6.4 | 6.5 | 4.3 | 4.1 | 5.7 | 2.4 | 5.9 | 6.6 | 8.1 | - |
| **15** | 13.5 | 13.7 | 8.3 | 7.2 | 6.9 | 7.6 | 4.6 | 8.9 | 7.3 | 9.8 | 8.8 |
| **30** | 14.3 | 14.7 | 8.9 | 11.7 | 8.2 | 11.2 | 5.7 | 11.2 | 8.4 | 15.3 | 16.3 |
| **60** | 24.1 | 23.1 | 13.9 | 18.4 | 15.3 | 16.2 | 9.8 | 17.7 | 13.8 | 23.3 | 28.0 |
| **90** | 35.9 | 33.7 | 21.7 | 25.5 | 17.9 | 18.7 | 13.2 | 20.2 | 15.6 | 31.6 | 29.2 |
| **120** | 38.2 | 37.4 | 24.4 | 27.8 | 18.8 | 19.7 | 14.4 | 21.2 | 16.2 | 32.5 | 29.5 |

tolerance of the stated values: 22,5 %

| values based on the DWD (Kostra 90) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **time slice** | **return periods of the catchments [a]** | | | | | | | | | | **Luebeck-Blankensee** |
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | |
| **5** | 10 | 2 | 2 | 0.5 | 0.5 | 1 | 0.25 | 1 | 2 | 2 | - |
| **15** | 5 | 5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1 | 0.5 | 1 | 1 |
| **30** | 2 | 2 | 0.5 | 1 | 0.5 | 1 | 0.5 | 1 | 0.5 | 2 | 5 |
| **60** | 10 | 10 | 1 | 2 | 1 | 2 | 0.5 | 2 | 1 | 10 | 20 |
| **90** | 50 | 50 | 2 | 5 | 2 | 2 | 0.5 | 2 | 1 | 20 | 20 |
| **120** | 50 | 50 | 5 | 5 | 1 | 2 | 0.5 | 2 | 1 | 20 | 10 |
| values based on the DWD (report 1973) | | | | | | | | | | | |
| **time slice** | **return periods of the catchments [a]** | | | | | | | | | | **Luebeck-Blankensee** |
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | |
| **5** | 5 | 1 | 1 | 0.5 | 0.5 | 1 | 0.25 | 1 | 1 | 2 | - |
| **15** | 2 | 2 | 0.5 | 0.5 | 0.5 | 0.5 | 0.25 | 0.5 | 0.5 | 1 | 0.5 |
| **30** | 1 | 1 | 0.5 | 0.5 | 0.5 | 0.5 | 0.25 | 0.5 | 0.5 | 2 | 2 |
| **60** | 2 | 2 | 0.5 | 1 | 0.5 | 1 | 0.5 | 1 | 0.5 | 2 | 5 |
| **90** | 10 | 10 | 1 | 2 | 1 | 1 | 0.5 | 1 | 0.5 | 5 | 5 |
| **120** | 10 | 10 | 2 | 2 | 0.5 | 1 | 0.5 | 1 | 0.5 | 5 | 2 |

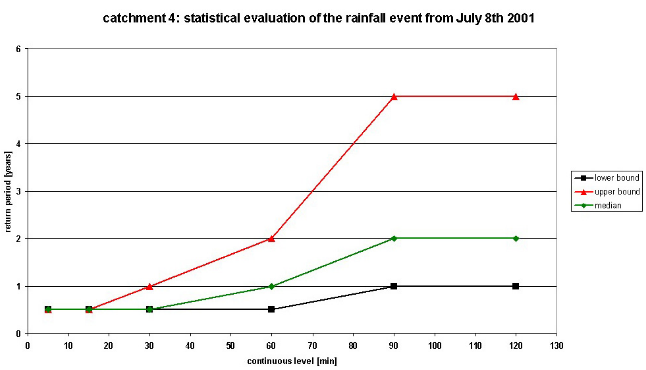


**Fig. 5.** Bandwidth of the results for one catchment.

### 2.5.5 Evaluation of the results

Only in the catchments 1, 2 and 10 the measured precipitation of the radar was higher than the measured value at the raingauge station Luebeck-Blankensee. In the remaining catchments the precipitation was lower than the value from Luebeck-Blankensee. Figure 6 shows the maximum return periods for the ten catchments. In all areas the maximum return period were obtained for a duration of 90 or 120 minutes.

In one sentence, the rainfall event can be summarized as strong precipitation with a frequency of less than once a year, in three catchments (1, 2, 10) as heavy precipitation with a frequency of less than once in ten years.

## 3 Conclusion

Using radar measured rainfall data, the return periods of the three rainfall events could be evaluated for ten catchments. In this connection large differences between the rainfall measurements at Luebeck-Blankensee and the precipitation in the different catchments became obvious.

Taking into account the spatial uncertainty of the raingauge data resulted in the determination of a bandwidth of the return periods for each catchment. In this way, an upper and a lower limit for the results could be obtained. One consequence of the report was that conditions were set for the retention of rain water in an urban area to be developed in the near future (during the first 15 minutes of an event the

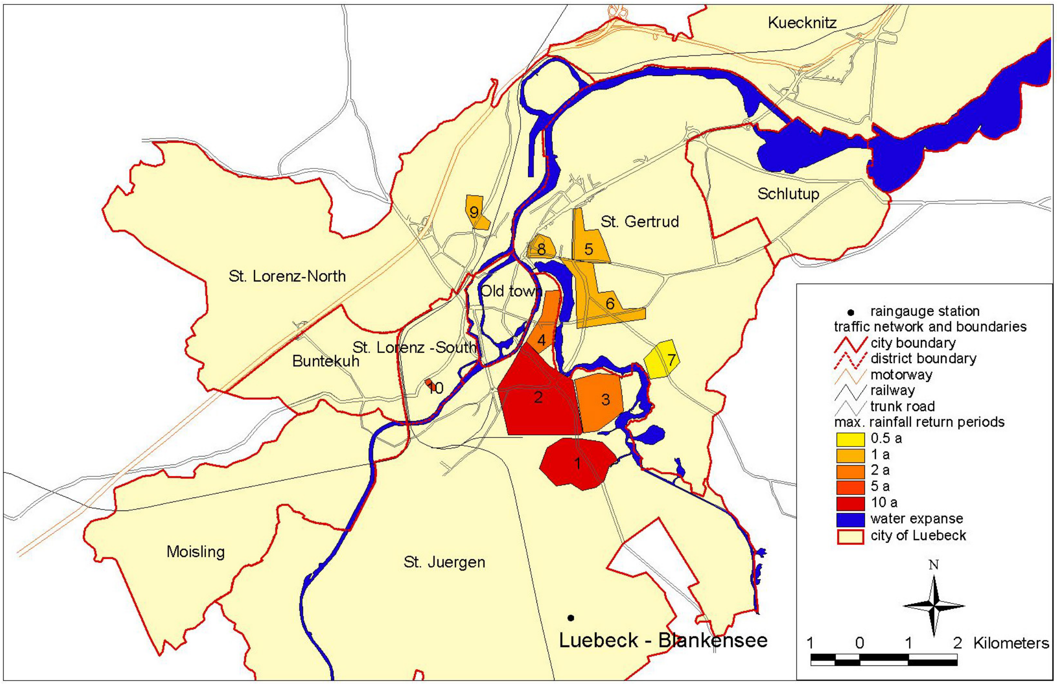


**Fig. 6.** Evaluation of the rainfall events in Luebeck-Blankensee.

rain water has to be completely retained in the area).

*Acknowledgement.* We are thanking Mr. Jörn Garbers of the Water and Waste Disposal Utility of Luebeck for many fruitful discussions and for his support to the project.

## References

Collier, C.G., 1989, ”Applications of Weather Radar Systems”, Ellis Horwood, London, 294 pp.

DWD, 1990: Starkniederschlagshöhen für die Bundesrepublik Deutschland Teile 1 und 2

DWD, 1997: “AKORD - Anwenderorientierte Organisation von Radardaten”, Deutscher Wetterdienst Produktkatalog, Offenbach.

Einfalt, T., Maul-Kötter, B. and Spies, S. (2000). “A radar data quality control scheme used in hydrology.” Physics and Chemistry of the Earth, Part B, Vol. 25, No. 10-12, pp. 1141-1146.

Maul-Kötter, B., Einfalt, T., 1998, “Correction and preparation of continuously measured raingauge data: a standard method in North Rhine-Westphalia”, Water Science and Technology, Vol.37, Issue 11, pp. 155-162.

Maul-Kötter, B., Spies, S., Einfalt, T., 2001, “Qualitätskriterien für Radardaten in der hydrologischen Simulation”, Hydrologie und Wasserbewirtschaftung, Volume 6, p. 236-244