ABSTRACTS

OF

ORAL AND POSTER CONTRIBUTIONS TO THE INTERNATIONAL

CHR-Workshop – Expert Consultation

‘Extreme Discharges’

Bregenz, Austria, 18 and 19 April 2005

International Commission for the Hydrology of the Rhine Basin (CHR)

Internationale Kommission für die Hydrologie des Rheingebietes (KHR)

KHR
CHR

Extreme Hochwasser im Elbeeinzugsgebiet

Uwe Grünewald
BTU Cottbus, Lehrstuhl Hydrologie und Wasserwirtschaft
Postfach 101344, D-03013 Cottbus, Deutschland
uwe.gruenewald@tu-cottbus.de

Die Elbe hat eine Länge von rd. 1 094 km von der Quelle im Riesengebirge bis zur Mündung bei Cuxhaven in die Nordsee und ist mit einem **Gesamteinzugsgebiet** *von 148 268 km²* das *viertgrößte Flussgebiet in Mitteleuropa* (zum Vergleich: A_E - Donau: 817 000 km²; A_E - Weichsel: 194 112 km²; A_E - Rhein: 183 800 km²).

Klima, **Geländehöhe** und **Relief** haben entscheidenden Einfluss auf die Niederschlags- und Abflussverhältnisse.

Das Einzugsgebiet befindet sich im Übergangsbereich vom *feuchten ozeanischen Klima* Westeuropas zum *trockenen kontinentalen Klima* Osteuropas.

Im Gesamteinzugsgebiet der Elbe liegen rd. 50,5 % der Fläche unter 200 m ü. NN und rd. 29 % über 400 m ü. NN Höhenlage.

Die *höchsten mittleren Jahresniederschlagshöhen* wurden auf dem Brocken im Harz mit 1 800 mm, in den Kammlagen des Isergebirges und des Riesengebirges mit 1 700 mm sowie mit 1 150 bzw. 1 250 mm im Böhmerwald bzw. Thüringer Wald ermittelt.

Die *höchsten bisher gemessenen Tagesniederschläge* wurden am 29.07.1897 mit 345 mm in Nová Louka im Isergebirge sowie mit 312 mm am 12.08.2002 in Zinnwald-Georgenfeld im Osterzgebirge registriert (Zahlenangaben aus: IKSE, 2004).

Im **Abflussregime** ist die Elbe dem *Regen-Schnee-Typ* zuzuordnen, d. h. das Abflussverhalten wird überwiegend durch Schneespeicherung und Schneeschmelze geprägt und über 60 % des mittleren Jahresabflusses fließen im Winterhalbjahr ab. Größere bis extreme Winter- und Frühjahrshochwasser entstehen hauptsächlich in Folge intensiver Schneeschmelze bis in die Kammlagen der Mittelgebirge verbunden mit großflächigem ergiebigen Regen. Wie der März 2005 erneut zeigte, löst aber die Schneeschmelze allein - trotz teilweise erheblicher gespeicherter Schneemengen in den Mittelgebirgen - keine größeren, geschweige extreme Hochwasserereignisse aus.

Damit Hochwasser mit extremen Abflüssen und Wasserständen an der Oberen Elbe z. B. im Raum Dresden entstehen können, bedarf es entsprechender **Bildungsbedingungen im tschechischen Teil des Einzugsgebietes**, in dem sich rd. 73 % der Flächen in Höhenlagen über 400 m NN befinden. Insbesondere vom Einzugsgebiet der Moldau gehen hier die entscheidenden Einflüsse aus. Hochwasser-Längsschnittbetrachtungen (IKSE, 2004) zeigen, dass allein aus den deutschen Elbeteileinzugsgebieten Mulde, Saale, Schwarze Elster und Havel im Bereich der mittleren Elbe keine Extremhochwasserereignisse entstehen können, während sich extreme Hochwasserereignisse von Prag über Děčin bis Dresden ausprägen. D. h. **sehr große Elbhochwasser in Dresden sind in der Regel mit großen Moldauhochwassern verknüpft**. Für die Pegel im Bereich der Mittleren Elbe (z. B. Neu Darchau) sowie weiter unterhalb gilt das aus unterschiedlichen Gründen nicht mehr.

Bezüglich des **Zustandekommens extremer Hochwasserregimes** an der Elbe müssen bei den *Winterhochwassern* neben solchen durch plötzlich eintretendes Tauwetter verknüpft mit starkem Regen auch noch deren Verstärkung durch Eisaufbruch bzw. Eisstau hervorgehoben werden. Christian Gottlieb Pötsch (1732-1805) erlebte und schilderte als Verfasser der *„Chronologischen Geschichte der großen Wasserfluten des Elbstromes seit tausend und mehr Jahren"* die diesbezüglich im Verlauf der gesamten Elbe besonders schadbringenden Frühjahrshochwasser von 1784 und 1799 eindringlich. Die Chronologie wird in Fachkreisen als außerordentlich gründlich recherchierte historische Dokumentation anerkannt und versetzt uns heute in die Lage, zeitlich weit zürückreichende Informationen zu extremen Hochwassern, deren unterschiedliche Ballungen, jahreszeitliche Verteilung und Ausprägung in unsere heutigen Analysen einfließen zu lassen. Darüberhinaus liegen seit 1806 lückenlos tägliche Beobachtungen der Wasserstände am Pegel Dresden vor.

Unter Zugrundelegung dieser „**Hochwasserchronologie**“ lassen sich orientierende bzw. quantifizierende Aussagen sowohl über die Klimaschwankungen als auch über *jahreszeitliche Muster des Auftretens von Extremhochwasser* der Elbe ableiten. So entstanden im Zeitraum des sogenannten *„mittelalterlichen Klimaoptimum“* (1000 - 1300) offensichtlich mehr als 90 % der großen Hochwasser im Sommerhalbjahr, während der Zeitraum 1300 bis 1400 durch mehrere harte Winter geprägt war, die zu entsprechenden katastrophalen Hochwasserereignissen führten. *88 % dieser* waren mit *„starken Eisfahrten und Tauwetter im Frühjahr“* verknüpft.

Im folgenden Jahrhundert (1400 - 1500) entstanden dagegen *80 %* der bekannten extremen Hochfluten in den *Sommermonaten*, während in der Zeit der *„kleinen Eiszeit“* (1550 - 1850) wiederum die *„winterlichen Hochfluten“* (um 80 %) dominierten. Zwischen 1775 und 1850 wird am Elbstrom für 37 Winter eine geschlossene Eisdecke angegeben, wovon in 27 Jahren eine Dauer von vier bis 14 Wochen eingetreten sein soll.

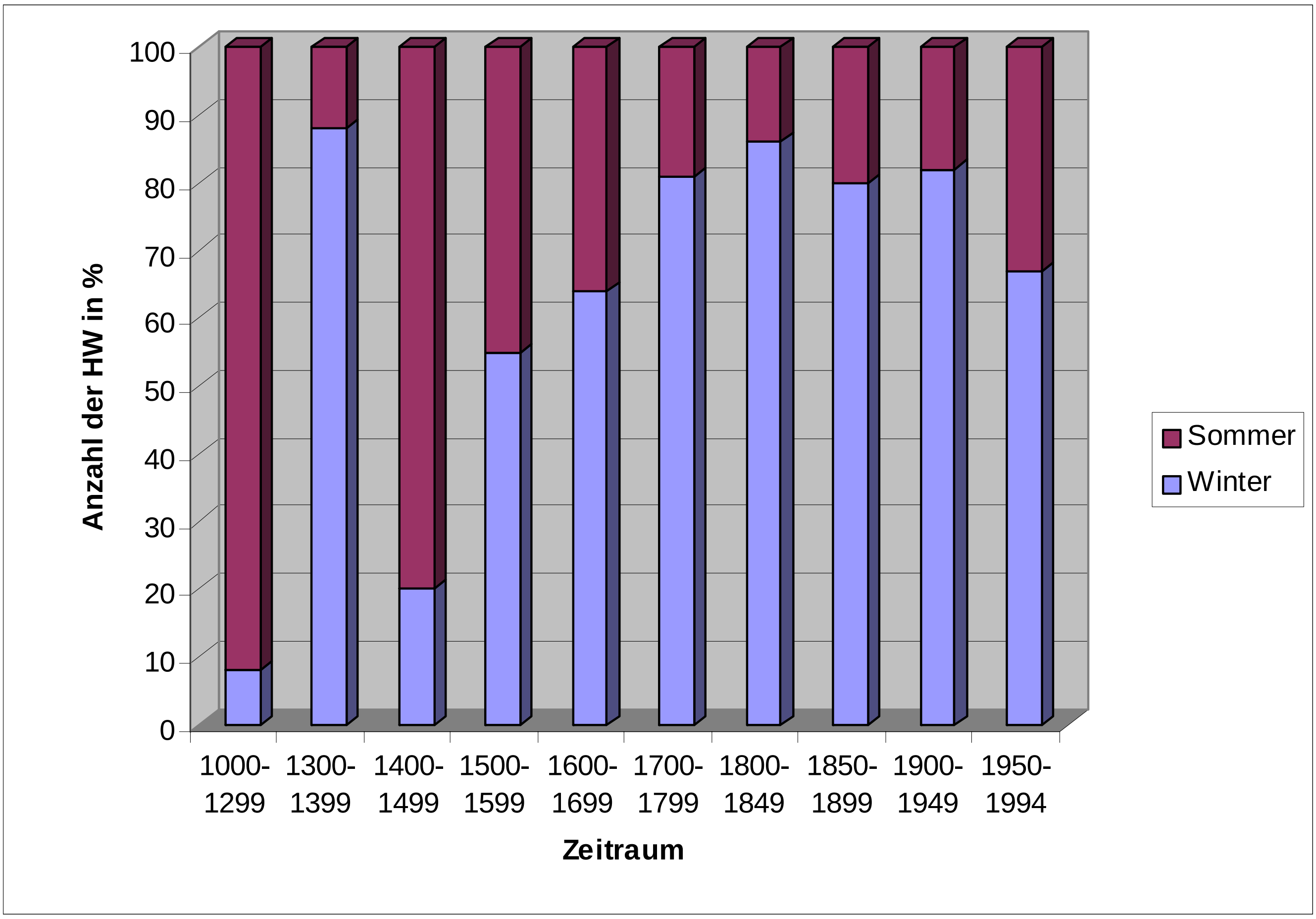


Abb. 1: Jahreszeitliche Verteilung der Elbe-Hochwasser innerhalb der letzten 1000 Jahre (FÜGNER, 1995).

(GLASER, 2001) zeigt, dass sich diese klimatisch bedingten jahreszeitlichen Muster des Auftretens von Extremhochwassern im Einzugsgebiet der Elbe auch in anderen mitteleuropäischen Flussgebieten wiederfinden.

In der Jahresreihe 1900 bis 2002 traten am Pegel Dresden im Bereich der Oberen Elbe 73 % der jährlichen Hochwasser im hydrologischen Winterhalbjahr auf, wobei mit 29 % der **Monat März der hochwasserreichste Monat** ist. Im Bereich der mittleren Elbe am Pegel Neu Darchau traten sogar rd. 83 % der jährlichen Hochwasser in diesem Zeitraum im Winterhalbjahr auf. Die seit ca. 1950 zu beobachtende winterliche Erwärmung schlägt sich in einer Zunahme des Anteils sommerlicher Hochwasser (ca. 35 % am Pegel Dresden) nieder.

Das extremste Ereignis des 19. Jahrhunderts war das **Märzhochwasser** von **1845**, was vom **Spitzenabfluss** (5 700 m³/s) her immer noch als **größtes Ereignis am Pegel Dresden** gilt, obwohl mit 8,77 m ein Wasserstand beobachtet wurde, der weit unterhalb dem vom Augusthochwasser 2002 mit 9,40 m am Pegel Dresden lag. Hier bedarf es für beide Ereignisse noch sorgfältiger hydraulischer, hydrologischer und historischer Analysen. An der Moldau in Prag überschritt dagegen das Hochwasser vom August 2002 das von 1845 sowohl in den Scheitelwasserständen als auch im Scheitelabfluss erheblich.

In seiner Genese und dem angegebenen Spitzenabfluss in Dresden von 4 350 m³/s kommt das **Sommerhochwasser vom September 1890** dem des extremen Augusthochwassers 2002 (Scheitelabfluss in Dresden: 4 580 m³/s) sehr nahe. Vom 02. bis 04.09.1890 lieferte aufgleitende feuchte Warmluft im Südosten Mitteleuropas langanhaltende ergiebige Niederschläge. Im Bereich der oberen Elbe fielen großflächig 150 bis 200 mm Regen und die Elbe wuchs am Pegel Dresden innerhalb 24 Stunden um 2,30 m auf einen Scheitelwert von 8,37 m. Dieser Wasserstandswert wurde bis zum Sommer 2002 - also im gesamten 20. Jahrhundert - am Pegel Dresden nicht mehr erreicht. An der Moldau in Prag lieferte dagegen das im September 1890 allein durch extreme Regenniederschläge ausgelöste Hochwasser einen um ca. 1 200 m³/s geringeren Scheitelabfluss als das vom August 2002.

Kleinräumigere, aber ähnlich extreme Sommerniederschläge lieferten in den Julimonaten der Jahre 1897, 1927 und 1957 „sintflutartige“ Hochwasserereignisse insbesondere in den Tälern der Osterzgebirgseinzugsgebiete. Insbesondere im Jahr 1927 hatte das Hochwasser katastrophale Wirkungen mit allein 152 Toten im Gottleubatal.

Obwohl die damit in Beziehung stehenden Großwetterlagentypen („TM - Tief Mitteleuropa“, „TRM - Trog Mitteleuropa“) in den Sommermonaten in ihrer relativen Häufigkeit gering sind, liefern sie immer wieder - mit sogenannten „Vb-Zugbahnen-Tiefs“ verknüpft - schadbringende Hochwasserereignisse in den betroffenen Teileinzugsgebieten der Elbe.

Insgesamt lässt sich zum Hochwasserregime im Einzugsgebiet der Elbe feststellen, dass **vieles dafür spricht**, dass es in der **Vergangenheit extremere Hochwasserereignisse gegeben hat**, als z. B. in den letzten beiden relativ gut mit kontinuierlichen Beobachtungen belegten Jahrhunderten. Wir sollten alle Anstrengungen unternehmen, sowohl die jüngere als auch die fernere „Extremhochwasser-Vergangenheit“ durch **systematische interdisziplinäre Forschungsarbeit** besser aufzuhellen.

Hochwasser waren und sind das Resultat des **zufallsbehafteten Zusammenwirkens** einer **großen Anzahl** von Kombinationen verschiedenartiger *klimatologischer Bedingungen*, *meteorologischer Ereignisse* und *hydrologischer Gebietszustände* (GRÜNEWALD, 1995). Je vielfältiger beispielsweise sich diese Überlagerungen im Laufe der vieltausendjährigen Landschaftsgenese und Klimageschichte erkennen oder/und mit Hilfe rechner- und modellgestützter Monte-Carlo-Simulations- bzw. Szenarioanalysen nachvollziehen lassen, desto besser sollte es gelingen, den Bereich der extremen Hochwasserereignisse zuverlässiger auszuloten. Neben dem damit verknüpften wissenschaftlichen Gewinn dürften sich daraus erhebliche Verbesserungen für die Praxis des Hochwasserrisikomanagements und der Bemessung wasserwirtschaftlicher Anlagen ergeben.

Literatur:

FÜGNER, D., 1995: Hochwasserkatastrophen des Elbstromes in Sachsen. In: Odborný seminar Povodňová ochrana na labi. Usti nad Labem.

GLASER, R., 2001: Klimageschichte Mitteleuropas - 1000 Jahre Wetter, Klima, Katastrophen, Primus-Verlag, 227 S.

GRÜNEWALD, U., 1995: Rapporteursbericht zum Themenbereich Landnutzung und Versiegelung. In: „Hochwasser in Deutschland unter Aspekten globaler Veränderungen“, PIK-Report Nr. 17, Potsdam, S. 37-45.

IKSE, 2004: Internationale Kommission zum Schutz der Elbe: Dokumentation des Hochwassers vom August 2002 im Einzugsgebiet der Elbe. Magdeburg, 207 S.

PÖTSCH, C. G., 1784, 1786, 1800: Chronologische Geschichte der großen Wasserfluten des Elbstromes seit tausend und mehr Jahren. Bände I, II, III, Dresden.

Extreme discharges in the Meuse basin

Marcel de Wit [1)]
Robert Leander [2)]
Adri Buishand [2)]
[1)] Institute for Inland Water Management and Waste Water Treatment (RIZA)
P.O. Box 9072, NL 6800 ED Arnhem, the Netherlands
[2)] Royal Dutch Meteorological Institute (KNMI)
P.O. Box 201, NL 3730 AE De Bilt, the Netherlands

m.dwit@riza.rws.minvenw.nl

Introduction

Over the last years the frequency and magnitude of floods of the river Meuse have been relatively large. These floods have caused a lot of trouble and triggered the design of national and international flood action plans. The recent floods have also generated many valuable observations of extremes. This presentation consists of i) a description of the river Meuse basin, ii) an impression of observed extremes, iii) an overview of ongoing research to derive the design discharge and scenarios for future extreme discharges of the river Meuse, and iv) a brief overview of the ongoing measures in the Meuse basin that aim at a reduction of flood risk.

The Meuse basin

The Meuse basin (Figure 1) covers an area of approximately 33,000 km^2, including parts of France, Luxembourg, Belgium, Germany, and the Netherlands. The Meuse basin has a temperate climate, with rivers that are dominated by a rainfall-evaporation regime, which produces low flows during summer and high flows during winter. The Meuse basin can be subdivided into three major geological zones: i) the Lotharingian Meuse (upstream of Charleville-Mézières). This part of the Meuse basin mainly consists of consolidated sedimentary Mesozoic rocks, ii) the Ardennes Meuse (between Charleville-Mézières and Liège). Here the river transects the Paleozoic rock of the Ardennes Massif, and iii) the lower reaches of the Meuse (downstream of Liège). The Dutch and Flemish lowlands are formed by Cenozoic unconsolidated sedimentary rocks. The average annual precipitation amounts 800 to 900 mm·year^{-1} in the southern part of the basin, around 700 to 800 mm·year^{-1} in the northern part of the basin and up to 1500 mm·year^{-1} in the central part of the basin. The annual average discharge of the Meuse at the outlet is approximately 350 m^3·s^{-1}.

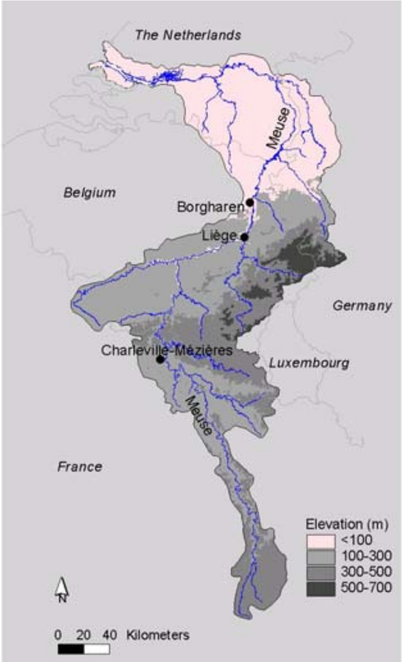


Fig. 1 Location of the Meuse basin

Observations

The longest discharge record available for the Meuse is that of Borgharen (upstream area 21,000 km^2). From Figure 2 it can be observed that even the average annual discharge of the Meuse shows strong fluctuations. The average discharge in 1966 is about 6 times larger than the average discharge in 1976. The Borgharen record also shows that five out of the seven largest floods in the Meuse have occurred during the last decade. Tu et al. (2004) detected long term changes in precipitation and discharge in the Meuse basin. They showed that both the annual maximum daily discharge and the k-day extreme precipitation depths (e.g. over 5 days and 10 days) have significantly increased since the early 1980s. Floods in the Meuse are typically preceded by a wet period with basin average 10-day precipitation depths of around 100 mm. The January 1995 flood was even accompanied by a basin average (upstream of Borgharen) 10-day precipitation depth of 164 mm (Leander & Buishand, 2004). During the recent flood events large differences have been observed in area specific runoff. Observed area specific runoff ranges from almost 30 $l \cdot s^{-1} \cdot km^{-2}$ for tributaries in the northern part of the basin to almost 600 $l \cdot s^{-1} \cdot km^{-2}$ in some tributaries in the central and southern part of the basin. Moreover, it appears that maximum discharges in the different tributaries are often observed during different flooding events. The ratio between 10-day precipitation volume and the discharge volume at Borgharen strongly depends on initial moisture conditions. For example: a relatively low 10-day precipitation depth, but very wet initial conditions accompanied the floods of February 2002, whereas the floods of 1993 and 1995 were characterized by less wet initial conditions but much larger 10-day precipitation depths. Almost all floods in the Meuse basin have been observed during the winter season. One exception is the flood of July 1980 during which a peak discharge of about 2,000 $m^3 \cdot s^{-1}$ was measured at Borgharen. The 30-day precipitation value (244 mm) that preceded this flood was very exceptional for the Meuse basin (Leander & Buishand, 2004).

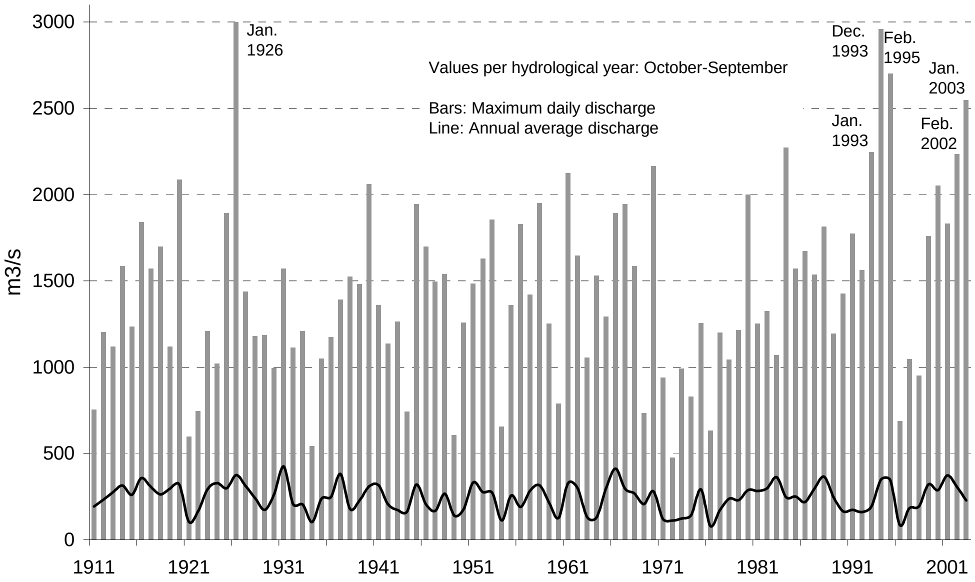


Fig. 2 Discharge record Meuse at Borgharen Source: Rijkswaterstaat

Design discharges and extreme scenarios

Along the embanked part of the river Meuse in the Netherlands, an average annual exceedance frequency of 1/1250 holds for the design discharge and the corresponding design water levels. This design discharge is obtained by analysing annual maximum discharges and peak over threshold data. For the Meuse the Borgharen record is used for this analysis. Several theoretical distributions have been fitted and used to make an extrapolation to the required exceedance frequency. The average value from the fitted distributions has been taken as the final estimate of the design discharge (at present 3800 $m^3 \cdot s^{-1}$). A detailed description of the procedure is given in Parmet et al. (2002). Recently a new methodology is being developed by KNMI and RIZA to provide a better physical basis for the design discharge of the Meuse. The first component of this new methodology is a stochastic multivariate weather generator, which generates long simultaneous records of daily rainfall and temperature over the basin. The second component is a hydrological model (HBV) for the Meuse basin, which transforms the generated rainfall into a discharge series at Borgharen. The first results obtained with this new methodology are described in Aalders et al. (2004) and Leander et al. (2005). The weather generator reproduces the distribution of the extreme 10-day rainfall quite well. Also the distributions of the maximum 1 day and 10 days discharges simulated with the generated meteorological data resemble those from the HBV simulations with observed meteorological data. Possible improvements of the methodology include the coupling with a hydraulic model for flood routing. The methodologies described above do not account for the possible impact of climate change. Several authors (e.g. Gellens & Roulin, 1998; Booij, 2005) have addressed the impact of climate change on the occurrence of floods in the Meuse basin. The general picture that evolves from these studies is that human-induced climate change will increase the risk of flooding in Northwest Europe. At present KNMI and RIZA are analysing the possibilities to apply the rainfall generator for the Meuse to the output of Regional Climate Model (RCM) simulations from the EU funded project PRUDENCE.

Policy

Over the last decade many measures have been taken or are being prepared to reduce the flood hazard and vulnerability to flooding in the Meuse basin (WHM/GTIM, 2002). The discharge levels that have been used to design those measures differ in the different regions of the Meuse basin. Like for most rivers, the flood protection level and the corresponding design discharge generally increase in downstream direction, where the effects of floods are potentially most devastating. This difference in design discharges complicates a supra regional tuning of measures.

Conclusion

The analysis of observed flood events as well as the first results of the rainfall generator for the Meuse reveal that there is no reason to assume that the observed floods in the Meuse are the most extremes that can occur. This motivates the need for a supra regional analysis of extreme conditions for the Meuse basin. The recently published and ongoing activities presented in this paper can support such an analysis.

References

Aalders, P., Warmerdam, P.M.M. & Torfs, P.J.J.F. (2004). Rainfall generator for the Meuse basin. 3,000 year discharge simulations in the Meuse basin. Wageningen University, sub-department Water Resources. Report nr. 124. Wageningen, The Netherlands.

Booij, M.J. (2005). Impact of climate change on river flooding assessed with different spatial model resolutions. Journal of Hydrology 303, 176-198

Gellens, D. & Roulin, E. (1998). Streamflow response of Belgian catchments to IPCC climate change scenarios. Journal of Hydrology 210, 242-258.

Leander, R. & Buishand, T.A. (2004). Rainfall generator for the Meuse basin. Development of a multi-site extension for the entire drainage area. KNMI-publication; 196-III, KNMI, De Bilt.

Leander, R., Buishand, A., Aalders, P. & de Wit, M. (2005). Estimation of extreme floods of the river Meuse using a stochastic weather generator and a rainfall-runoff model. Submitted to Hydrological Sciences Journal.

Parmet, B.W.A.H., Langemheen, W. van den, Chbab, E.H., Kwadijk, J.C.J., Lorenz, N.N. and Klopstra, D. (2002). Analyse van de maatgevende afvoer van de Maas te Borgharen. Onderzoek in het kader van het randvoorwaardenboek 2001. RIZA rapport 2002.013. Arnhem, The Netherlands.

Tu, M., Hall, M.J., de Laat, P.J.M. & de Wit, M.J.M. (2004) Detection of long-term changes in precipitation and discharge in the Meuse basin. GIS and Remote Sensing in Hydrology, Water Resources and Environment (Proceedings of ICGRHWE held at the Three Gorges Dam, China, September 2003). IAHS Publ. 289, 169-177.

WHM/GTIM (2002). Actieplan Hoogwater Maas. Voortgangsrapportage 1995-2001. Plan d'Action Inondations Meuse. Rapport d'avancement 1995-2001. Werkgroep Hoogwater Maas (WHM). Groupe de Travail pour la prévention des Inundations dans le bassin de la Meuse (GTIM). Namur, Belgium.

Does the perception of extremity change? An ongoing case study in the Sure river basin

Hugo Hellebrand
G. Drogue
P. Matgen
C. Schmitz
J. Juilleret
E. Vansuypeene
L Hoffmann
L. Pfister
Centre de Recherche Public Gabriel Lippmann
Av. de la Faiencerie 162A, L 1511 Luxembourg
hellebra@crpgl.lu

Introduction

In the last twelve years the Grand Duchy of Luxembourg experienced its three largest flood events of the past five decades, causing considerable economic damage. From the layman's point of view this high frequency of floods seems unacceptable and gives the hydrologist to answer the following important question: did the frequency of extreme flood events change? The answer to this question lies mainly in the field of two major topics, which are presently of high interest: climate change and land use change.

Concerning climate change several studies have pointed out that there is an actual change in the climate of the Rhine and Meuse basins. Pfister et al. (2004) demonstrated an increase of westerly atmospheric fluxes leading to an increase in winter rainfall duration and intensity. In another study climatological observations through the 19th and 20th century for the Grand Duchy of Luxembourg have shown a clear trend towards higher rainfall totals as a consequence of changes in the dominating atmospheric circulation patterns (Pfister et. al., 2004). An increase of average discharge rates and flood frequency in the Rhine during the last century has been attributed to the increase of winter rainfall (Engel, 1997). Concerning micro- and mesoscale basins in the Grand Duchy of Luxembourg the observed climate change signal of the last 50 years has had very contrasted consequences on maximum stream flow, mainly due to the orientation of the westerly fluxes and the influence of the topography (Pfister et al., 2004). However in the same study it was concluded that an increase in number of days with rainfall and/or in rainfall event duration could lead to a higher overall basin humidity, thus creating favourable conditions for high surface runoff rates.

During the last century considerable changes in land use have occurred, mainly consisting in an increase in urbanisation, in a change in forest cover and in an increase in drained agricultural lands. However, no clear evidence exists of the impact of land use changes on flood frequency and magnitude in the main channels of the Rhine and Meuse basins (Pfister et al., 2004). Land use change may nevertheless have a significant impact on the hydrological behaviour in micro- or mesoscale river basins and particularly urbanisation can have significant local effects in small basins (headwaters) with respect to flooding, especially during heavy local rainstorms (Pfister et al., 2004).

Another cause of discharge regime change is the straightening of the rivers by reducing the floodplain with dykes and other structures. For the Rhine and Meuse basins Ebel and Engel (1994) have evaluated the loss in floodplain areas to as much as 70% of the initial 1400 km^2. The frequency of bank overtopping for the Geer (Belgium) increased 16 fold from 1965 to 1980 and was mainly attributed to river straightening (Mabille and Petit, 1987).

The above-mentioned natural and/or anthropogenic changes in climate, land use and river morphology and their interaction make it difficult to predict changes in discharge regimes on every scale. This holds especially for extreme flood events, since they are very rare and their statistical properties are extremely difficult to determine via existing observation periods (Pfister et al., 2004). In order to point out these difficulties we tried to assess the discharge regime of the Sure river located in the Grand Duchy of Luxembourg for two different periods, one from 1870-1920 and the other from 1966-2003, at the village of Steinheim.

Study area

The study area comprises a stretch of the river Sure, its floodplain and the village of Steinheim. The stretch is 1.2 km long and has an average river width of 40 metres and the floodplain width varies between 320 and 110 metres. The village is located on the right side of the river. The Sure river basin has a surface area of about 4280 km^2 and it confluences with the Moselle River.

Methodology

For the flood frequency and flood risk analysis three hydro-climatological data series were at our disposal: one series ranging from 1870-1920, which provides only peak discharges for events higher than 450 m^3/s, one series ranging from 1966-1996, which provides daily rainfall data from six rain gauges located throughout the Sure basin and one series ranging from 1996-2003, which provides discharge data at an hourly time step. The exact location of measuring the historical discharge series (1870-1920) is not known anymore. The more recent hourly discharges are recorded at a bridge near Rosport, located 2.5 km downstream of Steinheim.

To create a long daily discharge data series from 1966-2003 we used a version of the HBV model (Bergström, 1995) that has been adapted to the particular environment of the Sure basin. Eight years of hourly readings from the 1996-2003 data series in combination with a rating curve were used for calibration, which gave a Nash-Sutcliffe performance measure of 0.9 and a bias close to zero. The rainfall series of 1966-2003 served as input data to the previously calibrated model in order to obtain the daily discharges for this period.

To calculate flood extension the HEC-RAS model (U.S. Army Corps of Engineers) in combination with ARC-GIS was used. The widely used one-dimensional HEC-RAS model was used for river flow computations. The model was calibrated with discharge and water level data from the floods of 1995 and 2003. After defining a threshold value of 585 m^3/s (below this value no significant flooding occurred), the inundation model was applied to create flood maps for the peak discharges of the series of 1870-1920 and 1966-2003.

For monitoring the rate of urbanisation in the study area we used several maps of the Grand Duchy of Luxembourg ranging back to 1775, digitised in GIS. These maps were crossed with the flood extension maps.

To assess the Flood Risk (FR) of the study area during the two periods both the Flood Hazard (FH) and Vulnerability (V) were considered. The FH was expressed as a function of flood frequency, water velocity and water height. V was expressed as the area of flooded buildings. In our study we defined FR as the ratio between flooded and non-flooded buildings, thus ranging from 0 (no buildings flooded) to 1 (all buildings flooded). For each period we calculated the FH for a return period of 30 years and a return period of 10 years.

Preliminary results

The FH maps for a return period of 30 years turned out to be the most relevant. This return period is associated to a discharge of 1145 m^3/s for the 1870-1920 period and a discharge of 1210 m^3/s for the 1966-2003 period. So the potential flood extension of the new period is larger. This could be linked to an increase of extreme events.

Regarding the number of medium sized floods that are characterized with discharges ranging from 585 to 750 m^3/s a decrease was observed between the 1870-1920 period and the 1966-2003 period: ten floods for the former period and only five for the latter period. This decrease could presumably be attributed to the construction of a dam in the upper Sure river.

From 1775 to 2002 the urban area in the stretch increased almost six fold. Until the 1950's most of the urbanisation took place in the floodplain. This is clearly reflected by the ratio between the area of flooded buildings and total building area, which is 0.95 in 1775 and 0.8 in 1953. In 1993 this ratio decreased to 0.69, which implies that urbanisation took place outside of the floodplain. However, in 2003 the ratio increased to 0.72, a result from constructing mainly in the floodplain during the last 10 years.

Discussion and conclusion

According to our assessment the flood risk for the urban area of 2003 in the 1966-2003 period is larger than in the 1870-1920 period. The construction of a dam in the upper Sure River at the beginning of the 1960's as a drinking water reservoir restricts medium floods, which is plainly reflected by the data: only five floods with discharges between 585 m^2 and 750 m^2 for the period 1966-2003 compared to ten floods for the period of 1870-1920. This is an example of the interaction between climate change and land use change. Although higher rainfall totals are measured during the last 50 years, their effect on generation on medium floods is in this case mitigated by the construction of a retention dam.

References

Bergström S., 1995. The HBV model. In *Computer Models of Watershed Hydrology*, Singh V.P. (ed.), Water Resources Publications, Highlands Ranch, Colorado, 443-476.

Ebel U., Engel H. 1994. *The Christmas Floods in Germany 1993/1994.* Bayerische Rückversicherung, Special Issue 16: Munich.

Engel H. 1997. Die Ursachen der Hochwasser am Rhein - natürlich oder selbstgemacht? In *Hochwasser, Natur im Überfluss*?, Immerdorf R (ed.). Verlag CF. Müller: Heidelberg; 9-30.

Mabille G., Petit F. 1987. Influence des aménagements du cours d'une rivière de moyenne Belgique et de son bassin hydrographique sur le comportement hydrologique de la rivière. In *Actes du colloque Crues et inondations (Genèse, méthodes d'étude, impacts et prévention)*, Humbert J., Cloots AR, Maire G (eds). Strasbourg: France; 279-294.

Pfister L., Drogue G., El Idrissi A., Iffly J-F., Matgen P., Poirier C., Hoffmann L. 2004. Hydrological impacts of climate change at catchment scale: A case study in the Grand Duchy of Luxembourg. *Geological Acta*, **2**: 135-145.

Pfister L., Drogue G., El Idrissi A., Iffly J-F., Poirier C., Hoffmann L. 2004. Spatial variability of trends in the rainfall-runoff relationship: A mesoscale study in the Mosel basin. *Climatic Change* **66**: 67-87.

Pfister L., Kwadijk J., Musy A., Bronstert A., Hoffmann L. 2004. Climate change, land use change and runoff prediction in the Rhine-Meuse basins. *River Research and Applications* **20**: 229-241.

Extreme Scenarios and Flood Risk Management

Bruno Merz
Annegret Thieken
Engineering Hydrology, GeoForschungsZentrum Potsdam
Telegrafenberg, D-14473 Potsdam, Germany
bmerz@gfz-potsdam.de
thieken@gfz-potsdam.de

This contribution looks at the quantification of extreme flood scenarios and how such scenarios are used in flood risk management. In order to stimulate the discussions on extreme discharges several questions are addressed:

Which extreme scenarios are of interest?

Different users are interested in extreme flood scenarios. Examples are people living in flood-prone areas, authorities responsible for flood design or re-insurance companies. Different users have different needs regarding flood scenarios. For example, direct insurers need to know the flood risk of their clients. To this end, they have to estimate the flood hazard of single land parcels. Flood hazard zoning, e.g. showing a few zones from the 10-year to the 100-year flood, fits this need. In contrast, re-insurers need to know the Probable Maximum Loss of their insurance portfolio. For this purpose large-scale scenarios with a constant return period throughout the whole catchment may not be suitable. Large-scale scenarios are needed that resemble real flood events.

How should extreme scenarios be considered in flood risk management?

Flood risk is usually defined as expected damage, i.e. the product of probability and damage, integrated over the damage (or discharge). However, the expected damage tends to undervalue the significance of extreme events. Their contribution to the expected damage may be very small due to their low probability. This effect may be a consequence of the usual negligence of indirect and intangible effects of floods. Therefore, the use of the expected damage as risk indicator has to be questioned. Even if extreme scenarios contribute insignificantly to the expected damage they may be highly important for flood risk management.

How can extreme scenarios be quantified?

Usually, the quantification of extreme flood scenarios is based on several far reaching assumptions. Examples are the assumptions of homogeneity and stationarity in flood frequency analysis, the assumption that the return period of the input rainfall corresponds to the return period of the discharge in the design storm method, or the negligence of failure mechanisms such as blockage of dam outlets during extreme discharge situations. In many cases it is not clear how such assumptions affect the results. We have to expect that in extreme situations processes occur that are not observed during less extreme situations. Therefore, the quantification of extreme events requires the understanding of the processes that may differ under extreme and less extreme situations.

How can extreme scenarios be validated?

Usually, observations and data about extreme flood scenarios are rare or missing. Therefore, common validation methods that compare the predicted variable, such as discharge or flood damage, against measurements are hardly applicable. Such methods are sometimes termed first order validation. Due to the lack of data it is necessary to apply a second or third order validation. This includes the use of expert knowledge or methods for evaluating the process of model construction.

Extreme Niederschläge in Deutschland
(Extreme Precipitation in Germany)

Gabriele Malitz
Deutscher Wetterdienst (DWD), Abt. Hydrometeorologie
Lindenberger Weg 24, D-13125 Berlin, Deutschland
gabriele.malitz@dwd.de

Extremwertstatistisch ermittelte Starkniederschlagshöhen dienen zur Berechnung von Abflusshöhen für verschiedene Belange der hydrologischen Praxis. Es fehlt auch nicht an wissenschaftlichen Arbeiten, die sich mit den Änderungen im Starkniederschlagsgeschehen auseinander setzen. Starkniederschlag ist ein natürlicher oder definierter Niederschlagsabschnitt, der im Verhältnis zu seiner Dauer eine hohe Niederschlagsintensität aufweist und dementsprechend relativ selten auftritt. Was unter "relativ selten" zu verstehen ist, definieren viele Autoren entweder selbst (z. B. viermal pro Jahr), oder sie beziehen sich auf die DIN 4049, nach welcher der Niederschlag beispielsweise dann mit dem Adjektiv "stark" versehen wird, wenn er einmal in fünf Jahren (jährliche Eintrittswahrscheinlichkeit von 20 %) oder einmal in zwanzig Jahren (jährliche Eintrittswahrscheinlichkeit von 5 %) auftritt.

Extreme Hochwasser resultieren i.d.R. jedoch nicht aus starken, sondern aus extremen Niederschlägen. Derartige Niederschläge haben Eintrittswahrscheinlichkeiten von - zum Teil deutlich - weniger als 1 %. Im Spannungsfeld zwischen den punktuellen, extremwertstatistisch ermittelten Starkniederschlagshöhen einer Jährlichkeit von 100 Jahren und den - naturgemäß ohne Bezug zur Jährlichkeit - auf unterschiedliche Weise erzielten Schätzwerten der vermutlich größten Niederschlagshöhen (PMP) bedarf es weiterer Anstrengungen, praxistaugliche Bemessungsniederschläge zu quantifizieren. Dabei muss die variable Niederschlagsdauer berücksichtigt werden. Von großer Bedeutung ist auch der Schritt vom Punktwert zum Gebietswert - in Abhängigkeit von der Größe und der Lage des Gebietes.

Der vorliegende Beitrag zeigt - unter Hinweis auf den jeweiligen methodischen Hintergrund - Beispiele für

- extremwertstatistisch ermittelte Starkniederschlagshöhen einer Jährlichkeit von 100 Jahren,
- Werte der vermutlich größten Niederschlagshöhe,
- extreme Niederschlagshöhen kleiner Eintrittswahrscheinlichkeit, wie sie im Ergebnis einzelner Untersuchungen berechnet wurden,
- gemessene Niederschlagsextremwerte

in Deutschland.

Das Augusthochwasser 2002 im Osterzgebirge und dessen statistische Bewertung

Andreas Schumann
Ruhr-Universität Bochum
Lehrstuhl für Hydrologie, Wasserwirtschaft und Umwelttechnik
Universität Str. 150, D-44801, Bochum, Deutschland
Andreas.schumann@ruhr-uni-bochum.de

Das Augusthochwasser 2002 war für das Flussgebiet der Mulde und die Einzugsgebiete der linksseitigen Elbenebenflüsse das bisher höchste, durch Messungen belegte Hochwasserereignis. Niederschläge, die langfristige Rekordwerte der Vergangenheit überschritten, führten zu extremen Hochwasserwellen und gravierenden Schäden in den Flusstälern. Dieses Ereignis hat auf Grund seiner extremen Ausprägung eine besondere Bedeutung für die regionale Hydrologie. Nicht nur, dass die Hochwasserstatistik stark korrigiert werden musste, die Analyse der Ursachen und des Verlaufs dieses Ereignisses lieferte eine Reihe von Erkenntnissen hinsichtlich der Entstehung derart extremer Hochwasserereignisse in dieser Region.

Bedingt durch eine Vb-Wetterlage fielen in den ersten dreizehn Augusttagen extreme Niederschläge über weiten Teilen Österreichs, der Tschechischen Republik, der Slowakei und Ostdeutschlands. Das Tief blieb nahezu stationär über dem Osten Deutschlands stehen und erhielt immer wieder Nachschub an sehr feuchter Luft vom Mittelmeer. Es führte zu lang andauernden ergiebigen advektiven Niederschlägen. Zusätzlich gab es vereinzelt Starkniederschläge kürzerer Dauer durch eingelagerte Gewitterzellen. Rudolf und Rapp (2003) schätzen für den Bereich des Erzgebirges die ursächlichen Anteile von advektiven zu konvektiven Niederschlägen wie 2 zu 1 mit einer Verdopplung der Niederschlagsmengen durch orographische Effekte ab. Die höchsten Tagesniederschläge wurden an der Station Zinnwald-Georgenfeld mit 312 mm/d für die Zeitspanne vom 12.08.2002, 7:00 MEZ bis 13.08.2002, 7:00 MEZ gemessen. Dies ist der absolut höchste jemals in Deutschland gemessene Tagesniederschlag. Bisher galt als Rekordniederschlag eine Tagessumme von 260 mm/d, beobachtet am 6.07.1906 in Zeithain. Neben den Rekordhöhen war die zeitliche Struktur des Niederschlages besonders problematisch. Infolge der konvektiven Komponente kam es in vielen Flussgebieten zu mehrgipfligen Niederschlagsganglinien. Durch die Sättigung des Bodens in der Folge der ersten Niederschlagsspitze führte die zweite Spitze oftmals zu einem weiteren, besonders raschen Anstieg des Hochwasserabflusses. Somit traten extrem hohe Scheitelabflussspenden und Abflussbeiwerte auf. Von 51 analysierten Einzugsgebieten der Mulde und der linksseitigen Elbenebenflüsse mit Einzugsgebietsflächen unter 200 km^2 wiesen 53% der Gebiete Scheitelabflussspenden über 1000 l/skm^2 auf, bei 25% der Gebiete lagen die Scheitelabflussspenden sogar über 2000 l/skm^2. Der Gesamtabflussbeiwert lag bei 59% aller analysierten Einzugsgebiete über 0,5, für 23% der Gebiete über 0,6.

Das extreme Hochwasser im August 2002 stellte im Flussgebiet der Mulde ein sehr seltenes Ereignis dar, dessen hochwasserstatistische Einordnung in Hinblick auf die Veränderungen, die sich für die hochwasserstatistischen Aussagen in den betroffenen Einzugsgebieten ergeben, von besonderer Bedeutung sind. Eine Überprüfung bzw. Neufestlegung von Hochwasserbemessungswerten erfolgte auf der Grundlage einer regional konsistenten pegelstatistischen Analyse. Erstmalig wurden dabei die Besonderheit des saisonal unterschiedlichen Auftretens von Katastrophenhochwasserereignissen im Muldegebiet bei der hochwasserstatistischen Analyse beachtet. Die Einbeziehung des Augusthochwassers 2002 erfolgte in mehreren Schritten. Zunächst wurde die Hochwasserstatistik der Reihen bis 2001 berechnet. Der Scheitelabfluss des Augusthochwassers 2002 wurde hinsichtlich seiner Jährlichkeit eingeordnet. Daraufhin wurden die Reihen um den Wert des Augusthochwassers verlängert und die Verteilungsfunktionen neu angepasst. Die Jährlichkeiten des Hochwassers 2002 wurden entsprechend neu ermittelt. Mit der saisonalen Differenzierung wird es hier möglich, die selteneren Sommerereignisse, die besonders hohe Hochwasserscheitelwerte aufweisen, besser zu berücksichtigen.

Bei einer statistischen Bewertung des Augusthochwassers 2002 anhand der Beobachtungsreihen der Pegel bis 2001 ergaben sich für das Erzgebirge äußerst hohe Jährlichkeiten. Um dies zu verdeutlichen sind in Tabelle 2 die Häufigkeiten der Jährlichkeiten für 33 Pegel der Mulde zusammengestellt. Diese Jährlichkeiten beruhen auf der Anwendung der Allgemeinen Extremwertverteilung mit wahrscheinlichkeitsgewichteten Momenten. Rein rechnerisch ergaben sich an 6 von 33 Pegeln Jährlichkeiten von über 100.000 Jahren, an weiteren 3 Pegeln von Jährlichkeiten zwischen 10.000 und 100.000. An 5 Pegeln liegt die Jährlichkeit zwischen 5.000 und 10.000 Jahren. Wenn diese Beobachtungsreihen um den Wert des Jahreshöchstabflusses 2002 (Augusthochwasser) verlängert und die Verteilungsfunktionen neu angepasst werden, verringern sich die Jährlichkeiten des Hochwassers 2002 drastisch (Tab. 2, rechte Seite).

Tabelle 2 Jährlichkeit des Augusthochwassers 2002 für 33 Pegel im Flussgebiet der Mulde bei Verwendung der Jahresreihen bis 2001 bzw. bis 2002 (d.h. unter Einbeziehung des Augusthochwassers 2002)

	HQ- Reihen bis 2001		HQ- Reihen bis 2002	
Jährlichkeit	Statistik der Jahres-HQ- Werte	Saisonale Statistik	Statistik der Jahres-HQ- Werte	Saisonale Statistik
>100.000	6	0	0	0
10.001 bis 100.000	3	0	0	0
5.001 bis 10.000	4	2	0	0
1.001 bis 5.000	5	8	0	0
501 bis 1000	7	7	5	0
401 bis 500	1	3	5	1
301 bis 400	0	1	5	3
201 bis 300	1	4	3	10
101 bis 200	2	4	9	10
51 bis 100	3	3	5	7
unter 51	1	1	1	2
Gesamtzahl	**33**	**33**	**33**	**33**

Bei Anwendung der saisonalen Differenzierung in der Hochwasserstatistik, die auf Grund der historischen Analyse der Katastrophenhochwasser im Muldegebiet begründet erscheint, ergaben sich insbesondere im Gebiet der Freiberger Mulde wesentlich höhere Quantilwerte. Demzufolge liegt die Jährlichkeit des Augusthochwassers im Einzugsgebiet der Freiberger Mulde bei ca. 200 Jahren falls die saisonal differenzierende Verteilung angewandt wird oder bei 400 – 500 Jahren, wenn die Jahres-Höchstwerte verwendet werden. Generell wurde aus den Untersuchungen die Problematik der hochwasserstatistischen Analyse infolge der beschränkten Beobachtungsreihen deutlich. So hätten z.B. Daten zum Hochwasser 1897 in Sachsen wesentlich zur Verbesserung der Hochwasserstatistik in der Vergangenheit beitragen können (zumindest war dieses Ereignis jedoch der äußere Anlass ein hydrometrisches Messnetz in Sachsen aufzubauen). Deutlich wurde auch die Variabilität hochwasserstatistischer Aussagen, die durch den Stichprobeneffekt stark beeinflusst werden. Die Entfernung von Ausreißerwerten aus den Beobachtungsreihen kann in diesem Zusammenhang nicht empfohlen werden.

Im Rahmen der hochwasserstatistischen Analyse wurden neue Erkenntnisse zu der regionalen Verteilung von Extremhochwassern im Einzugsgebiet der Vereinigten Mulde gewonnen, die in zukünftigen Regionalisierungsansätzen Berücksichtigung finden sollten.

Tab.12a Relation zwischen den HQ(T)- Werten ermittelt aus den Hochwasserwerten des Sommer- und Winterhalbjahres und den entsprechenden Werten aus Jahres-HQ- Werten für Reihen bis 2002

Vereinigte, Zwickauer und Freiberger Mulde

Pegel	Gewaesser	Ae in km^2	Reihe von	bis	HQ2	HQ5	HQ10	HQ20	HQ25	HQ50	HQ100	HQ 200	HQ 300	HQ 500	HQ 1000
Golzern1	Mulde	5442	1911	2002	0.982	0.955	0.956	0.973	0.982	1.026	1.095	1.192	1.262	1.364	1.526
Bad_Dueben1	Mulde	6170.8	1961	2002	0.983	0.942	0.937	0.948	0.954	0.982	1.023	1.078	1.116	1.172	1.261
		Mittel			**0.983**	**0.948**	**0.947**	**0.960**	**0.968**	**1.004**	**1.059**	**1.135**	**1.189**	**1.268**	**1.394**
		Min			0.982	0.942	0.937	0.948	0.954	0.982	1.023	1.078	1.116	1.172	1.261
		Max			0.983	0.955	0.956	0.973	0.982	1.026	1.095	1.192	1.262	1.364	1.526
Schoenheide3	Zwickauer_Mulde	152	1972	2002	0.971	0.982	0.989	1.001	1.007	1.029	1.060	1.099	1.126	1.163	1.218
Niederschlema	Zwickauer_Mulde	759.4	1928	2002	0.991	0.972	0.973	0.981	0.984	0.997	1.013	1.031	1.042	1.058	1.080
Zwickau_P.	Zwickauer_Mulde	1029.7	1928	2002	0.988	0.964	0.969	0.982	0.988	1.009	1.035	1.065	1.085	1.111	1.150
Wechselburg1	Zwickauer_Mulde	2107	1910	2002	0.999	0.966	0.963	0.973	0.978	1.003	1.040	1.088	1.122	1.170	1.246
Sachsengrund	Große_Pyra	6.6	1971	2002	0.967	0.964	0.979	1.001	1.010	1.041	1.076	1.117	1.143	1.179	1.231
Aue1	Schwarzwasser	362.5	1928	2002	0.968	0.969	0.980	0.994	0.999	1.016	1.035	1.054	1.066	1.082	1.104
Markersbach1	Große_Mittweida	30	1974	2002	0.961	0.913	0.917	0.937	0.946	0.982	1.027	1.081	1.116	1.164	1.235
Niedermuelsen1	Muelsenbach	49.9	1966	2002	1.041	1.010	1.013	1.023	1.027	1.042	1.058	1.077	1.088	1.103	1.125
Niederlungwitz	Lungwitzbach	137.6	1965	2002	0.996	1.016	1.025	1.032	1.035	1.043	1.052	1.062	1.068	1.076	1.088
Chemnitz1	Chemnitz	403.2	1918	2002	0.997	0.966	0.970	0.984	0.991	1.016	1.048	1.087	1.112	1.147	1.201
Goeritzhain	Chemnitz	532.3	1910	2002	0.977	0.949	0.955	0.977	0.987	1.031	1.097	1.186	1.251	1.345	1.497
Harthau	Wuerschnitz	135.7	1965	2002	0.890	0.892	0.924	0.975	0.996	1.075	1.177	1.305	1.394	1.521	1.722
		Mittel			**0.978**	**0.963**	**0.971**	**0.987**	**0.995**	**1.022**	**1.057**	**1.101**	**1.130**	**1.170**	**1.233**
		Min			0.890	0.892	0.917	0.937	0.946	0.982	1.013	1.031	1.042	1.058	1.080
		Max			1.041	1.016	1.025	1.032	1.035	1.075	1.177	1.305	1.394	1.521	1.722
Berthelsdorf	Freiberger_Mulde	244.4	1936	2002	1.024	0.920	0.849	0.812	0.811	0.852	0.938	1.048	1.120	1.221	1.373
Nossen1	Freiberger_Mulde	585.2	1926	2002	1.000	0.913	0.869	0.860	0.868	0.936	1.056	1.209	1.312	1.457	1.683
Erlln	Freiberger_Mulde	2982.5	1961	2002	0.943	0.927	0.939	0.970	0.985	1.052	1.150	1.283	1.377	1.510	1.719
Wolfsgrund	Chemnitzbach	37.2	1921	2002	0.987	0.964	0.956	0.956	0.959	0.981	1.032	1.124	1.200	1.315	1.501
Niederstriegis1	Striegis	283	1926	2002	0.978	0.923	0.899	0.903	0.914	0.990	1.122	1.289	1.402	1.561	1.810
		Mittel			**0.986**	**0.930**	**0.902**	**0.900**	**0.908**	**0.962**	**1.060**	**1.191**	**1.282**	**1.412**	**1.617**
		Min			0.943	0.913	0.849	0.812	0.811	0.852	0.938	1.048	1.120	1.221	1.373
		Max			1.024	0.964	0.956	0.970	0.985	1.052	1.150	1.289	1.402	1.561	1.810

Tab. 12b Relation zwischen den HQ(T)- Werten ermittelt aus den Hochwasserwerten des Sommer- und Winterhalbjahres und den entsprechenden Werten aus Jahres-HQ- Werten für Reihen bis 2002

Flöha/ Zschopau

Pegel	Gewaesser	Ae in km^2	Reihe		HQ2	HQ5	HQ10	HQ20	HQ25	HQ50	HQ100	HQ 200	HQ 300	HQ 500	HQ 1000
			von	bis											
Tannenberg	Zschopau	90.6	1960	2002	1.052	0.991	0.938	0.902	0.896	0.911	0.970	1.052	1.107	1.180	1.288
Hopfgarten	Zschopau	528.8	1911	2002	0.989	0.973	0.968	0.970	0.972	0.985	1.008	1.044	1.070	1.110	1.175
Lichtenwalde	Zschopau	1574.6	1910	2002	0.961	0.942	0.953	0.977	0.988	1.028	1.081	1.148	1.193	1.258	1.361
Kriebstein_UP	Zschopau	1756.8	1933	2002	0.982	0.953	0.961	0.984	0.994	1.036	1.092	1.165	1.215	1.287	1.399
Annaberg1	Sehma	48.6	1968	2002	1.039	1.002	0.957	0.919	0.911	0.907	0.951	1.044	1.116	1.221	1.386
Wiesa	Poehlbach	86.3	1961	2002	1.017	0.998	0.988	0.980	0.978	0.972	0.968	0.966	0.966	0.968	0.974
Streckewalde	Preßnitz	205.9	1921	2002	1.009	0.964	0.955	0.962	0.968	0.999	1.051	1.120	1.169	1.236	1.340
Joehstadt1	Joehst.Schwarzwasser	35.9	1968	2002	1.037	0.978	0.966	0.970	0.974	0.997	1.037	1.101	1.150	1.227	1.360
Pockau1	Floeha	384.6	1921	2002	0.955	0.936	0.957	0.992	1.007	1.061	1.128	1.209	1.264	1.342	1.464
Borstendorf	Floeha	643.8	1929	2002	0.979	0.956	0.965	0.987	0.995	1.029	1.070	1.120	1.152	1.197	1.266
D.Georgenthal2	Rauschenbach	9.6	1967	2002	1.024	0.946	0.904	0.885	0.886	0.916	0.983	1.079	1.144	1.235	1.373
Neuwernsdorf	Wernsbach	6.8	1968	2002	1.015	1.006	1.005	1.008	1.010	1.019	1.032	1.048	1.059	1.074	1.096
Rauschenbach2	Rauschenfluss	7.4	1966	2002	1.031	0.985	0.942	0.910	0.902	0.892	0.903	0.932	0.957	0.995	1.055
Rothenthal	Natzschung	75	1929	2002	1.007	0.972	0.978	0.999	1.008	1.043	1.088	1.141	1.177	1.226	1.300
Zoeblitz	Schwarze_Pockau	129.2	1937	2002	1.006	0.959	0.945	0.960	0.971	1.019	1.081	1.149	1.191	1.246	1.326
		Mittel			**1.007**	**0.971**	**0.959**	**0.960**	**0.964**	**0.988**	**1.029**	**1.088**	**1.129**	**1.187**	**1.278**
		Min			0.955	0.936	0.904	0.885	0.886	0.892	0.903	0.932	0.957	0.968	0.974
		Max			1.052	1.006	1.005	1.008	1.010	1.061	1.128	1.209	1.264	1.342	1.464

Tab. 12c Relation zwischen den HQ(T)- Werten ermittelt aus den Hochwasserwerten des Sommer- und Winterhalbjahres und den entsprechenden Werten aus Jahres-HQ- Werten für Reihen bis 2002
Weisse Elster, Pleisse, Wyhra

Pegel	Gewaesser	Ae in km^2	Reihe von	bis	HQ2	HQ5	HQ10	HQ20	HQ25	HQ50	HQ100	HQ 200	HQ 300	HQ 500	HQ 1000
Adorf	Weiße_Elster	171	1926	2002	1.010	0.979	0.977	0.987	0.993	1.019	1.055	1.101	1.133	1.179	1.248
Oelsnitz	Weiße_Elster	328	1961	2002	0.982	0.992	1.014	1.042	1.051	1.083	1.118	1.154	1.176	1.205	1.245
Magwitz	Weiße_Elster	376	1939	2002	1.012	0.949	0.938	0.951	0.960	1.005	1.079	1.186	1.265	1.381	1.571
Straßberg	Weiße_Elster	610.8	1966	2002	1.053	1.008	0.994	0.988	0.988	0.994	1.007	1.029	1.046	1.072	1.116
Hasenmuehle	Trieb	99.6	1968	2002	1.020	0.962	0.954	0.986	1.004	1.067	1.135	1.207	1.251	1.310	1.396
Mylau	Goeltzsch	155	1921	2002	0.984	0.972	0.976	0.987	0.991	1.008	1.030	1.055	1.071	1.093	1.125
		Mittel			**1.010**	**0.977**	**0.976**	**0.990**	**0.998**	**1.029**	**1.071**	**1.122**	**1.157**	**1.207**	**1.284**
		Min			0.982	0.949	0.938	0.951	0.960	0.994	1.007	1.029	1.046	1.072	1.116
		Max			1.053	1.008	1.014	1.042	1.051	1.083	1.135	1.207	1.265	1.381	1.571
Regis_Serbitz	Pleiße	769	1964	2002	1.043	1.015	1.030	1.059	1.071	1.112	1.162	1.219	1.256	1.305	1.379
Boehlen1	Pleiße	1359	1959	2002	1.061	0.993	0.972	0.967	0.968	0.983	1.017	1.077	1.124	1.197	1.315
Streitwald	Wyhra	177.9	1930	2002	0.997	0.985	1.012	1.054	1.069	1.126	1.192	1.269	1.319	1.388	1.492
Leipzig_Thekla	Parthe	314.8	1942	2002	1.054	1.019	1.020	1.029	1.032	1.046	1.063	1.081	1.093	1.110	1.133
		Mittel			**1.039**	**1.003**	**1.009**	**1.027**	**1.035**	**1.067**	**1.108**	**1.162**	**1.198**	**1.250**	**1.330**
		Min			0.997	0.985	0.972	0.967	0.968	0.983	1.017	1.077	1.093	1.110	1.133
		Max			1.061	1.019	1.030	1.059	1.071	1.126	1.192	1.269	1.319	1.388	1.492

Climate Change and Hydrological Extremes

Christoph Schär
Atmospheric and Climate Science, ETH Zürich
Winterthurerstr.190, CH-8057 Zürich, Switzerland
schaer@env.ethz.ch

The estimation of flood and drought frequencies is a delicate and difficult task, even in a stationary climate. Modern estimation methods utilize some probabilistic methodology and thus provide a probability density function (PDF), for instance of the frequency of a certain event category. Climate change will further complicate the task of estimation, as the assumption of a stationary climate system is rejected. The most immediate effect of climate change in this context is thus to increase the uncertainty in flood and drought estimation (corresponding to a widening of the PDF). Such an increase in uncertainty in essence implies an increase in safety margins and thus costlier protection for the same level of security. It is important to realize that this kind of effect takes place, irrespective of whether climate change will actually increase or decrease the frequency of the respective event category (corresponding to a shift of the PDF).

In the long run, however, appropriate estimation methodologies should rely on a combination of past observations and climate change scenarios. Climate models have made rapid progress in recent years. Yet the projection of regional climate changes – and in particular of catchment-scale extreme events – is associated with large uncertainties.

Here results of climate change scenarios will be discussed with reference to European-scale summer droughts. Anthropogenic climate change is usually perceived as a comparatively slow trend towards higher temperatures, with attendent shifts in precipitation distribution and hydrological conditions. Associated changes in interannual (year-to-year) variability are usually considered small. In a recent paper (Schär et al. 2004, see also Vidale et al. 2005), we have proposed that climate change may give rise to a pronounced increase in interannual variability during the extratropical summer season. Such an increase in variability would have important repercussions for the frequency of extreme summer heat waves and droughts, and would also represent a challenge to adaptive response strategies designed to cope with climate change.

We utilize regional climate models (RCMs) from the European project PRUDENCE and provide a detailed analysis of physical processes implicating on the frequency of heat waves and droughts over Europe. RCM simulations suggest that interannual summer temperature variability may increase considerably, by up to a factor two towards the end of the current century. The main region of enhanced variability is the temperate climate zone in Central and Eastern Europe. Analysis of the simulated water cycle shows that the increase in variability is at least partly related to land-surface processes, and associated with an increasing frequency of summer droughts. The representation of the associated non-linearities requires a realistic description of the continental-scale water cycle in the coupled atmosphere / land-surface system. Intercomparison of model simulations suggests that there is considerable agreement between different models regarding the occurrence of the effect, but there are large differences regarding its geographical distribution, seasonal evolution and amplitude. These differences are related to a wide range of model characteristics, among them the representation of the soil hydrology and the simulation of large-scale circulation anomalies. A particularly important uncertainty in climate models relates to the seasonal cycle of terrestrial water storage.

The study was motivated by the extreme European summer 2003. In much of Central Europe, mean summer temperatures exceeded their long-term mean by more than 4 standard deviations, leading to an extreme heat wave. A brief analysis of this event will also be presented. It will be argued that the frequency of extreme heat waves and droughts is more sensitive to an increase in temperature variability (i.e. a widening of the statistical distribution), than to a mere warming (i.e. a shift of the distribution towards warmer and dryer conditions).

References:

Frei, C., H.C. Davies, A. Gurtz and C. Schär, 2000. Climate Dynamics and Extreme Precipitation and Flood Events in Central Europe. *Integrated Assessment*, **1**, 281-299

Frei, C., and C. Schär, 2001. Detection probability of trends in rare events: Theory and application to heavy precipitation in the Alpine region. *J. Climate*, **14**, 1568-1584

Frei, C., R. Schöll, J. Schmidli, S. Fukutome and P.L. Vidale, 2005: Future change of precipitation extremes in Europe: An intercomparison of scenarios from regional climate models. *J. Geophys. Res.*, submitted.

Hirschi, M., S.I. Seneviratne and C. Schär, 2005: Seasonal variations in terrestrial water storage for major mid-latitude river basins. *J. Hydrometeorol,* submitted

Kleinn, J. C. Frei, J. Gurtz, D. Lüthi, P.L. Vidale, and C. Schär, 2005: Hydrologic Simulations in the Rhine Basin driven by a Regional Climate Model, *J. Geophys. Res. – Atmos.*, **110**, D04102

Schär, C., D. Lüthi, U. Beyerle and E. Heise, 1999: The Soil-Precipitation Feedback: A Process Study with a Regional Climate Model. *J. Climate*, **12**, 722-741

Schär, C., P.L. Vidale, D. Lüthi, C. Frei, C. Häberli, M.A. Liniger and C. Appenzeller, 2004: The role of increasing temperature variability for European summer heat waves. *Nature*, **427**, 332-336

Schär, C. and G. Jendritzky, 2004: Hot news from summer 2003. *Nature*, **432**, 559-560

Schmidli, J., C. Schmutz, C. Frei, H. Wanner and C. Schär, 2002. Mesoscale precipitation variability in the Alpine region during the 20th century. *Int. J. Climatol.*, **22**, 1049-1074

Schmidli, J. and C. Frei, 2005: Trends of heavy precipitation and wet and dry spells in Switzerland during the 20th century. *Int. J. Climatol.,* in press

Seneviratne, S. I., P. Viterbo, D. Lüthi and C. Schär, 2004: Inferring changes in terrestrial water storage using ERA-40 reanalysis data: The Mississippi River basin. *J. Climate*, **17**, 2039-2057

Van den Hurk, B., M. Hirschi, C. Schär, G. Lenderink, E. van Meijgaard, A. van Ulden, B. Röckel, S. Hagemann, P. Graham, E. Kjellström and R. Jones, 2005: Soil control on runoff response to climate change in regional climate model simulations. *J. Climate*, in press

Vidale P.L., D. Lüthi, R. Wegmann, C. Schär, 2005: Variability of European climate in a heterogeneous multi-model ensemble. *Clim. Change*, submitted

Regional Flood Process Types

Ralf Merz
Günter Blöschl
Institut für Wasserbau und Ingenieurhydrologie
Technische Universität Wien
Karlsplatz 13, A-1040 Vienna, Austria
merz@hydro.tuwien.ac.at
bloeschl@hydro.tuwien.ac.at

Understanding the physical processes giving rise to floods of a given probability of occurrence is among the most intriguing areas of catchment hydrology. Not only are these processes complex and controlled by a range of variables including rainfall regime, snowmelt, state of the catchment and catchment characteristics but also their interaction is intricate and has so far defied detailed analyses at the regional scale. In this paper we propose an approach for identifying types of causative mechanisms of floods on the entire flood peak sample of all catchments in a region. The types are long-rain floods, short-rain floods, flash-floods, rain-on-snow floods and snow-melt floods. We adopt a catchment perspective, i.e. the focus is on the catchment state and the atmospheric inputs rather than on atmospheric circulation patterns. We use a combination of a number of process indicators including the timing of the floods, storm duration, rainfall depths, snow melt, catchment state, runoff response dynamics and spatial coherence. Table 1 gives a summary of the envisaged characteristics of the indicators for each of the process types.

Flood indicators such as the seasonality of floods the spatial extent of catchments that are covered by the same flood were extracted from the maximum annual flood peaks data of 490 Austrian catchments, with observation periods from 5 to 44 years. Daily precipitation data from 1029 stations as well as air temperature data were regionalized to estimate catchment rainfall and to simulate the snow water equivalent and soil moisture state of each catchment using a conceptual water balance model. In addition, a data set consisting of the depths and durations of extreme rainstorms in Austria was used as an indicator to storm type. Catchment response times of flood events were inferred from the ratio of the maximum annual flood peak and the average daily runoff on the day the flood peak occurred. All observed flood peaks were classified manually on a flood event basis with the help of diagnostic maps (Merz and Blöschl, 2003). For each flood event, maps contained the information of all indicators in a way that grasping the essence of the flood processes was a matter of a few minutes for the analyst. Each map covered all of Austria and consisted of different layers, representing the different flood indicators discussed above.

Table 1 Indicators for identifying flood process types at the regional scale.

Process type	Long-rain floods	Short-rain floods	Flash floods	Rain-on-snow floods	Snow-melt floods
Timing of floods	No pronounced seasonality	No pronounced seasonality	Floods and extreme rainfall mainly in summer or late summer	Often occur during transition between cold and warm periods	Floods in spring to summer
Storm duration	Long duration (>1-day)	Duration of several hours to 1 day	Short duration (<90 min), high intensities	Moderate rainfall events can cause large floods	Rainfall unimportant
Rainfall depths, snow melt	Substantial rainfall depths	Moderate to substantial rainfall	Small to moderate rainfall depths	Snow melt and rainfall	Snow melt, no or minor rainfall
Catchment state (SWE, soil moisture)	Wet due to persistent rainfall	Wet for large flood events	Any	Wet, snow covered	Wet, snow covered
Runoff response dynamics	Slow response	Fast response	Flashy response	Responses range from fast to slow	Medium or slow response
Spatial coherence	Large spatial extent of storms and floods (>10^4 km²)	Local or regional extent	Limited spatial extent of storms and floods (<30 km²)	Limited to areas of snow cover	Medium spatial extent of floods

Table 2 Results of the flood type classification of maximum annual floods in 490 Austrian catchments, 1971-1997. *MAF* is the mean annual flood.

Process type	Long-rain floods	Short-rain floods	Flash floods	Rain-on-snow floods	Snow-melt floods	All types
Number of events	783	597	302	430	154	2266
Number of flood peaks <*MAF*	2511 (50.6%)	1281 (39.7%)	274 (50.3%)	1398 (57.4%)	248 (71.5%)	5712 (49.6%)
Number of flood peaks >*MAF* and < 10yr flood	2051 (41.3%)	1541 (47.8%)	225 (41.3%)	957 (39.3%)	94 (27.1%)	4868 (42.3%)
Number of flood peaks > 10 yr flood	404 (8.1%)	403 (12.5%)	46 (8.4%)	80 (3.3%)	5 (1.4%)	938 (8.1%)
Total number of flood peaks	4966 (100%)	3225 (100%)	545 (100%)	2435 (100%)	347 (100%)	11518 (100%)

Based on these indicators and diagnostic maps we identify the process types of 11518 maximum annual flood peaks in 490 Austrian catchments. Results indicated that 43% of the flood peaks are long-rain floods, only 3% are snow-melt floods and the relative contribution of the types changes with the flood magnitude (Table 2). It should be noted that these process interpretations are applicable to the scale of the gauged catchments examined with a median of about 150 km². In smaller catchments flash floods, for example, may be more important than these statistics indicate.

There are pronounced spatial patterns in the frequency of flood type occurrence. In catchments at the northern fringe of the high Alps, long-rain floods are particularly common. The high Alps tend to act as a topographic barrier to north-westerly airflows, and orographic enhancement often produces persistent rainfall which can result in floods. The regions of the highest relative importance of long-rain floods are identical with the regions of the highest mean annual rainfall in Austria. Short-rain floods occur more frequently in southern Austria than north of the Alps. This is likely due to two mechanisms. The main ridge of the Alps tends to block weather systems approaching from the northwest which reduces the advection of moist air and hence the persistence of the rainfall. Also, south of the Alps southern airflows may produce floods that are associated with high-intensity short-duration storms. Flash-floods occur significantly less frequently than long-rain and short-rain floods. Flash-floods are mainly important in eastern Austria, specifically in the hilly region of Styria and the southern Burgenland. The hilly terrain appears to increase the instability of the boundary layer and hence the likelihood of convective storms. Rain-on-snow floods are important in the catchments of medium altitude in the north of Austria. A rapid increase in air temperature in early winter or spring appears to occur quite frequently as a result of the inflow of warm and moist air. Relatively low rainfall depths on an existing snow cover appear to produce a significant portion of maximum annual floods in these catchments. Snow-melt floods are occur only in the high Alps where both snow and glacier melt can be important and snow-melt floods rarely produce the maximum annual flood.

REFERENCES

Merz, R. & Blöschl, G. (2003) A process typology of regional floods. *Water Resources Research*, VOL. 39, NO. 12, 1340, doi:10.1029/2002WR001952

Derived frequency methods for estimating flood from rainfall frequencies

Günter Blöschl
Ralf Merz
Dieter Gutknecht
Institute for Hydraulic and Water Resources Engineering, Vienna University of Technology
Karlsplatz 13, A-1040 Vienna, Austria
M. Sivapalan, Centre for Water Research, Department of Environmental Engineering, University of Western Australia, 35 Stirling Highway, Crawley, WA 6009, Australia
bloeschl@hydro.tuwien.ac.at

Derived flood frequency models can be used to study climate and land use change effects on the flood frequency curve. Inter-annual climate variability strongly impacts upon the flood frequency characteristics in two ways, in a direct way through the seasonal variability of storm characteristics, and indirectly through the seasonality of rainfall and evapotranspiration, which affect the antecedent catchment conditions for individual storm events. In this paper we propose a quasi-analytical derived flood frequency model that is able to account for both types of seasonalities. The model treats individual events separately. It consists of a rainfall model with seasonally varying parameters. Increased flood peaks, as compared to block rainfall, due to random within-storm rainfall time patterns are represented by a factor that is a function of the ratio of storm duration and catchment response time. Event runoff coefficients are allowed to vary seasonally and include a random component. Their statistical characteristics are derived from long term water balance simulations. The components of the derived flood frequency model are integrated in the probability space to derive monthly flood frequency curves. These are then combined into annual flood frequency curves. Comparisons with Monte Carlo simulations using parameters that are typical of Austrian catchments indicate that the approximations used here are appropriate. We perform sensitivity analyses to explore the effects of the interaction of rainfall and antecedent soil moisture seasonalities on the flood frequency curve. When the two seasonalities are in phase there is resonance, which increases the flood frequency curve dramatically. We are also able to isolate the contributions of individual months to the annual flood frequency curve. Monthly flood frequency curves cross over for the parameters chosen here, as extreme floods tend to mainly occur in summer while less extreme floods may occur throughout the year.

Estimating design river discharges using generated series and Bayesian statistics

E. Houcine Chbab
Hendrik Buiteveld
Ministery of Public Works and Water Management, Institute for Inland Water Management and Waste Water Treatement, RIZA, Lelystad
P.O. Box 17, NL 8200 AA Lelystad, the Netherlands
h.chbab@riza.rws.minvenw.nl
h.buiteveld@riza.rws.minvenw.nl

I. INTRODUCTION

In the Netherlands, the design discharge for the river Rhine (and the other large rivers) is defined as an extreme discharge with an average return period of 1,250 years (Parmet et al. 1999). Extreme quantiles, such as the design discharges are currently estimated by fitting various probability distributions to the available observations (DH &EAC-RAND 1993, Castillo 1998 and van Gelder 1999). Probability plots and goodness-of-fit tests such as chi-square and Kolomogorov-Smirnov, are commonly used to select an appropriate probability distribution. The maximum likelihood method has been recognized as one of the best fitting method (Castillo 1998, Galambos et al. 1994). A major difficulty in fitting probability distributions is that there is often a limited amount of observations for determining extreme events. The associated return periods are very large and as a result of it, the representativeness of the observations may be questioned. For example, in the Netherlands, observed discharges for the river Rhine are available for a period of about 100 years only. Consequently, there is a large statistical uncertainty involved in estimating extreme discharges when using these observations.

Another punt of uncertainty concerns the choice of the appropriate probability distribution. Since the observed period is relatively short, more than one probability distribution seems to fit the observed discharges and only a few can be rejected. The un-rejected distributions usually lead to different extrapolated values and the goodness-of-fit tests for selecting an appropriate distribution function are often inconclusive. The fact that the series of records are short and the physical knowledge about river dynamics is limited, contributes to this inconclusiveness.

2. EXTRAPOLATION METHODS

2.1 Maximum Likelihood method

The maximum likelihood method has been recognized as one of the best estimation methods, due to its statistical properties (see for example, Grigoriu 1984, Castillo 1988, Goda, 1988, Galambos et al. 1984). The likelihood function gives the relative likelihood of the obtained observations as a function of the parameter of the probability distribution concerned. Therefore, it represents the inherent uncertainty or variability in nature. With this method one chooses that values of the parameter for which the likelihood function is maximized. The maximum likelihood method gives asymptotically unbiased parameter estimations and of all unbiased estimators it has the smallest mean squared error. Furthermore, the maximum likelihood estimators are invariant, consistent, fully sufficient and normally distributed, all of them in asymptotical sense. For the definitions we refer to van Gelder (1999).

The maximum likelihood method is extremely useful since it is often quite straightforward to evaluate the maximum likelihood estimators. Nonetheless it is an approximation, and should only be trusted for large number of observations. The maximum likelihood estimators may not exist, and when they do, they may not be unique or give a bias error. Another drawback of the maximum likelihood method is that it is more suitable when there is a large number of observations. Furthermore the method has the disadvantage that statistical uncertainties cannot be taken into account.

2.2 Hypotheses testing and Bayes weights

The Bayesian method (van Gelder 1999) can be used to estimate extreme events while statistical uncertainties are taken into account. This uncertainty can be subdivided into parameter uncertainty and model or distribution-type uncertainty. Bayesian parameter estimates and so-called Bayes weights can then be used to account for parameter uncertainty and distribution-type uncertainty, respectively. Using Bayes weights, it is possible to discriminate between different probability distributions and to quantify how well a distribution fits the observations. This approach was successfully applied for estimating extreme river discharges (van Noortwijk et al. 2001, Chbab et al. 2002).

Assume a data set $\boldsymbol{x} = (x_1, x_2, ..., x_n)$ and two possible probability distributions or hypotheses H_1 and H_2. In the traditional approach we would determine a test statistics T and compute its p-value according to model H_1 or H_2. If the test statistic of the data results in a smaller value than the calculated p-value, then we would reject H_1 or H_2. To this aim, goodness-of-fit tests such as chi-square and Kolmogorov-Smirnov tests can be used. This traditional way of model testing has a lot of disadvantages. To this purpose, we refer to van Gelder (1999). In the Bayesian approach, we apply Bayes theorem to the data that each of the hypotheses is supposed to predict and compute the posterior probability that a certain hypothesis is correct.
In practice, the procedure is as follow: assume two hypothetical models with corresponding prior weights $w(H_1)$ and the $w(H_2) = 1 - w(H_1)$. Applying Bayes theorem, the observations produce posterior weights $w(H_1 \mid \boldsymbol{x})$ and $w(H_2 \mid \boldsymbol{x}) = 1 - w(H_1 \mid \boldsymbol{x})$. More details can be found in (Kass & Raftery 1995, David 1999, van Noortwijk et al. 2002). This method can finally easily be extended to higher dimension.

The maximum likelihood method can be used to deal with the inherent uncertainty (variability in nature), while the Bayesian method is especially useful to account with both the inherent uncertainty and statistical uncertainty. Nevertheless, these methods are rather empirical. More physical knowledge about river dynamics, including water genesis and water input from different tributaries, should also be taken into account.

3. GENERATED SERIES

3.1 Stochastic Rainfall generator

Daily rainfall and temperature are simultaneously simulated at 36 stations in the Rhine basin using nearest-neighbour resampling. A major advantage of a non-parametric resampling technique is that it preserves both the spatial association of daily rainfall over the drainage basin and the dependence between daily rainfall and temperature without making assumptions about the underlying joint distributions.
For each day the simulated values (i.e. the observed data of the selected day) may also include the observed data of the selected day from stations that are not used in the feature vector or include the area-average precipitation data from subcatchments of the selected day. The simulation of such additional data is designated as *passive* simulation. More details about nearest-neighbour resampling can be found in Rajagopalan and Lall (1999), Wójcik et al. (2000) and Buishand and Brandsma (2001). The performance of the rainfall generator is described by Beersma and Buishand (2004).

3.2 Precipitation runoff modelling of the river basin

The tributaries of the river Rhine upstream of Lobith are modelled with the precipitation-runoff model HBV on a daily basis. HBV is a conceptual semi-distributed precipitation-runoff model. It was developed at the Swedish Meteorological and Hydrological Institute (SMHI) in the early 1970s (Lindström et al., 1997 - e.g. Lidén, Harlin, 2000 and Eberle et al., 2002). HBV describes the most important runoff generating processes with simple and robust structures. In the "snow routine" storage of precipitation as snow and snow melt are determined according to the temperature. The "soil routine" controls which part of the rainfall and melt water forms excess water and how much is evaporated or stored in the soil. The "runoff generation routine" consists of one upper, non-linear reservoir representing fast runoff components and one lower, linear reservoir representing base flow. Flood routing processes can be simulated with a simplified Muskingum approach.
The setup and performance of the HBV model of the Rhine is given by Eberle et al. (2002) and in Eberle et al (2005).

The flood routing in the Rhine from Maxau till Lobith is done with the 1-d hydrodynamic model SOBEK on a hourly basis (refs). A description of this SOBEK model is given by Lammersen (2002,2001). The boundary conditions are provided by the discharge calculated by HBV for the tributaries and the part upstream of Maxau.

4. CASE STUDY AND RESULTS

The discharge of the river Rhine at Lobith with an average return period of 1250 year has been examined using both the observed and generated annual maximum discharges. The maximum likelihood and Bayesian methods have been used.

The maximum likelihood estimation method, applied to observed discharges at Lobith during the period 1901-2002, resulted in seven probability distributions which could not be rejected. On the other hand, the analysis based on generated annual maximum series lead up to four distributions which could not be rejected.

The Bayesian method applied to observed annual maximum discharges resulted in a reasonable fit. Nevertheless, The Bayes weights computed are meagre. As a matter of fact, the highest Bayes weight is about 23 % at most corresponding to the Weibull distribution. Moreover, applying this estimation method to generated annual maximum discharges for a period of 1000 years, more decisive Bayes weights are calculated. In that case the Gamma distribution fits excellent with a Bayes weight of 80 %. This suggests that the observed and generated series are not identically distributed.

5. DISCUSSION

The method consisting of a statistical rainfall generator combined with hydrological and hydraulic models is promising. The fact is that the method generates automatically more homogenous annual discharges. Also, we notice that the method provides opportunities to study the effects of different measures against flooding. On the other hand, the basic assumption of the method is rather empirical. Indeed, the method is based on observed and homogeneous rainfall data during a period of about 40 years.

Finally, With regard to the observed and generated annual maximum discharges, the remarkable things are that the calculated design discharges and Bayes weights are incoherent. All in all, at the moment it is not known whether the combined method consisting of a rainfall generator and hydrological and hydraulic calculations, generates annual maximum discharges reliably. Therefore, a decisive validation of the method is inevitable. It should be mentioned, though, that also series of generated maximum discharges are available for which flooding takes place in Germany (upstream from Lobith). These floods occur at extreme discharges larger then the observed ones, thereby yielding a lower design discharge. A further investigation of the problem whether the observed and the generated maximum discharges are identically distributed should also incorporate series with floods taking place in Germany.

6. ACKOUWLEDGEMENTS

The daily precipitation, temperature and sunshine duration data were made available by the following institutions: German Weather Service (DWD), Service de la météorolgie et de l'hydrologie de Luxemburg, Météo France and the Swiss Meteorological Institute through the international Commission for the Hydrology of the Rhine Basin (CHR/KHR). The generated time series with date from the rainfall generator were provided by the Royal Dutch Meteorological Office (KNMI) and the HBV model for the Rhine was supplied by the Federal Institute of Hydrology (BfG).

Improving the estimation of the magnitude of extreme floods by considering dominant runoff processes and historical floods

Felix Naef
Institut für Hydromechanik und Wasserwirtschaft - ETH Zürich
Schafmattstr. 6, CH-8093 Zürich, Switzerland
naef@ihw.baug.ethz.ch

The statistical analysis of discharge measurements is considered to be the most reliable method to determine recurrence interval and magnitude of large floods. However, several problems cannot be ignored, like:

- discharge measurements during extreme floods are not reliable and can contain large errors,
- recurrence intervals of 100, 300 and more years are of interest for flood protection measures. As systematic discharge measurements started only about 80 years ago, our knowledge on the relation between the 20 and 50-year flood and the 100 and 300-year flood is limited,
- this is reflected in the treatment of outliers in discharge record,. the information they contain cannot be extracted in a statistical analysis.

In this presentation, possibilities are demonstrated, how statistical analyses can be enhanced with data from historical records and by considering runoff formation during extreme events. The procedures, which have been applied until now to over 50 catchments, consist of the following steps:

- evaluation of the accuracy of discharge measurement: during large floods, the flow regime at a gage might change (backwater effects, hydraulic jumps), resulting in considerable discrepancies between discharges derived from extrapolated rating curves and from hydrodynamic modelling,
- information from archives might allow the reconstruction of large floods in the past and the circumstances of their occurrence, enlarging the time window of the known flood history,
- extrapolation to floods with large recurrence intervals using maps of dominant runoff processes.

Extrapolations to very large floods are often based on rainfall scenarios and simulations with rainfall-runoff models. However, the important infiltration parameters of rainfall-runoff models are usually defined by calibration. In this process, uncertainties in the precipitation field are compensated with errors in the infiltration parameter. Runoff process maps allow a direct and independent definition of these parameters. The method is demonstrated on two examples. Simulations of the extreme 1984 event in the 1 km^2 Erlentobel catchment in the Alp valley, based on such maps were accurate. The computed discharge from the whole Alp catchment of 38 k m^2, however, depended critically on the timing of the chosen rainfall distribution over the different subcatchments. Comparing the discharge resulting from different rainfall distributions with historical floods allowed insights into the probability of the different rainfall scenarios and therefore on the recurrence interval of extreme floods.

An analysis of an extreme event in Schwarzenburg revealed a similar dependency on the rainfall distribution. In this event, the effect of the extraordinary precipitation was enhanced by a change in the runoff process in certain areas of the catchment: the saturation of the topmost layer of the otherwise quite permeable soils caused surface runoff in areas where it usually did not occur. This caused a decrease in the recurrence interval of this flood.

The correct assessment of the magnitude of extreme floods with defined recurrence intervals is of great practical importance. The presented methodology leads to more reliable assessments and shows also the potential of future research.

Modeling series of extreme flood events for (re)insurance purposes

Jens Mehlhorn,
Hans Feyen
Christoph Oehy
Swiss Reinsurance Company, Zürich
Mythenquai 50/60, P.O. Box 8022, Switzerland
jens.melhorn@swissre.com

Introduction

The assessability of risk is one of the most important principles of insurance. For a long time the risk of flooding was seen as almost uninsurable since no adequate flood risk assessment models were available. However, in the last 5-10 years investments from the (re)insurance industry and risk consultants in the development of such models have been substantially increased. As a result of these efforts now several flood risk assessment tools are available. The presentation, firstly, provides an overview on the different model types used for flood risk assessment and, secondly, explains by the means of an example used approaches and factors limiting the development of such models.

Flood risk assessment in (re)insurance industry

In general all flood risk assessment tools used in (re)insurance comprise of the same four elements. The first element contains of information about the flood hazard. Where (location) do we have to expect, how often (probability) a certain inundation water level (intensity)?

The second element describes the susceptibility of insured values to be damaged when they get in contact with water. So-called vulnerability curves provide mean damage degrees (percent of loss of insured value) in relation to water levels for different risk types e.g. residential buildings, residential contents, commercial buildings etc…

The distribution (location) of insured values and insurance conditions such as original deductibles or loss limits are elements number three and four.

It is needless to say that the result of a flood risk modeling exercise is strongly influenced by the weakest point in the chain of the four elements. In other terms it does not make very much sense to have detailed information about water levels in the range of centimeters if the resolution of insured values is low.

Based on the used hazard information flood risk assessment models in (re)insurance industry can be classified in two different types of models. The first group of models bases on zones which describe the flood risk along rivers. The risk zones depict the probability (e.g. on average once a 100 years) of each location in a country being flooded. Zone based tools are generally used by primary insurance companies for risk selection and premium calculation. Additionally, zoning models help to determine the flood exposure of entire portfolios by providing the proportions of risks located in the different flood risk zones. This information can then be used to calculate the annual expected loss of an insurance portfolio.

The second group of models calculate flood losses for a series of historic and/or probabilistic events. Their major objective is to reflect the correlation of larger river systems to have a flood event at the same time. These types of models are mainly used by reinsurance companies to determine possible aggregated peak losses (EML: estimated maximum loss or PML: possible maximum loss) of insurance portfolios or large industrial accounts. EML or PML values enable reinsurers to adequately structure catastrophe reinsurance programs. And in addition, by the means of the series of calculated expected losses the price of such catastrophe reinsurance programs can be determined.

The present abstract and the presentation will only focus on the hazard part of the second type of models.

Main feature of probabilistic flood risk models

In reinsurance terms probabilistic models are defined as risk assessment models which comprise of a set of probabilistic hazard events. A set of probabilistic hazard events consists of a large number of possible events which could happen in the region under study which are mostly countries up to entire continents. Probabilistic events are derived from statistics of historic records and help to enlarge the mostly insufficient number of historic events.

The main objective of a probabilistic flood event is to provide information on locations and inundation water levels which could be affected by one flood event. There are different ways to come up with such flood event food prints. One option is to model the whole process chain from precipitation and/or snowmelt to runoff generation to stream flow routing. In this case different flood events can be achieved by sampling rainfall distributions and intensities. The drawback of such a proceeding is the high complexity of the multiple processes involved which require a high amount of resources.

An alternative is to use already a set of flood hydrographs which are started at multiple points in different river systems and are routed through the river systems by the means of a hydraulic model. The size and shape of these initializing hydrographs depend on the catchment specific parameters and on the return period which should be represented by the hydrograph. Correlations of event intensities (initializing hydrograph return period) between the different hydrograph starting points are determined by a correlation analysis on the basis of stream flow data at evenly distributed head water gauging stations. The resulting covariance table of the correlations analysis is then used in a Monte Carlo process to create a set of return periods for each hydrograph starting point and per event.

The the successful implementation of the above describe proceeding will be presentated by the example of UK.

Validation of simulated flood flows

In the presented example the 973 largest flood events which possibly could occur in UK had been simulated. A comparison study showed a reasonable fit between the 100 year flood flows determined on the basis of simulated and measured flows at more than 100 gauging stations. It could also be shown that the uncertainties of the 100 year flood flows for the measured flows were in many cases high due to the shortness of underlying time series. In the study only gauging stations with data covering at least 25 consecutive years had been used. Extreme values had been determined by the POT method using the median annual flood QMED as threshold. Consecutively, the generalized pareto model was fitted to the POT values using the method of L-moments (FEH 1999).

Conclusions

It is possible to develop sophisticated flood risk assessment models for reinsurance purposes. A prerequisite for successful development of such models is the availability of detailed flow data and exact digital terrain models. Additionally, consistent studies on the estimation of flood flows from catchment descriptors are also needed on a country wide basis. However, newest approaches base only on flow and digital terrain data.

Uncertainty in flood quantiles from basin and river models

Ferdinand Diermanse
Henk Ogink
WL Delft Hydraulics
P.O. Box 177, NL 2600 MH Delft, the Netherlands
Hendrik Buiteveld, RIZA
Institute for Inland Water Management and Waste Water Treatment (RIZA)
P.O.Box 9072, NL 6800 ED Arnhem, the Netherlands
ferdinand.diermanse@wldelft.nl
henk.ogink@wldelft.nl
h.buiteveld@riza.rws.minvenw.nl

Introduction

Without adequate flood defence structures, almost two-thirds of the Netherlands would be regularly flooded. To prevent floods by the sea, rivers and lakes, an extensive system of river dikes and coastal-defence has been constructed in the past. In the design of the dikes a safety level is defined of the order of 10^{-3} to 10^{-4} “failures” per year. This frequency is based on both the economic value of the protected area and the extent of the threat. Related to this safety level, the design of the dikes must be based on extreme hydraulic conditions, i.e. extreme water levels, wave heights or wave periods. In practice these conditions are often derived in statistical form where some type of extreme-value distribution function is fitted to observed data of extreme conditions. When extrapolating to extreme events with a frequency of exceedance of 10^{-3} to 10^{-4} per year, the statistical uncertainties inevitably are substantial.

Extreme value analysis: traditional approach

Most commonly statistical methods are used in extreme value analysis and a parameterised probability distribution function is fitted to a set of observed extremes of the target variable. The distribution provides a one to one relation between probabilities of (non)exceedence (which are equivalent to return periods) and the associated level of the target variable (e.g. peak discharges). This relation can then be used for the prediction of extremes for recurrence times that are far beyond the length of the data record. The popularity of such strictly statistical methods is mainly due to the fact that they are easy to apply. For design purposes along the river Rhine the frequency analysis of extreme discharges uses no less than five distribution functions: Gumbel, log-normal, Pearson-III, general Pareto and exponential. An averaging procedure is applied to obtain a unified result.

The uncertainties in frequency analyses are generally expressed by confidence intervals. The traditional method to estimate these intervals is to assume a Gaussian shaped confidence band for the parameters of the distribution function. In this way the confidence intervals, or at least approximations, can be derived analytically. A problem with this assumption is that it sometimes results in suspiciously wide confidence intervals. Furthermore, confidence intervals can differ strongly for different distributions even if the goodness-of-fit is comparable. An example of this is shown in Figure 1 where two functions (general Pareto and exponential) are derived from a series of Peaks-Over-Threshold discharges for the Rhine at Lobith over the period 1901-2004. For a return period of 1,250 years (which is the design criterion along the non-tidal part of the Rhine in the Netherlands) the width of the confidence interval is 5,500 m^3/s for the exponential distribution and 9,000 m^3/s for the Pareto distribution. Since both underestimation and overestimation of flood dangers can prove to be very costly, these uncertainties are much larger than desired. Furthermore, these two numbers show that even the estimated uncertainties are highly uncertain!

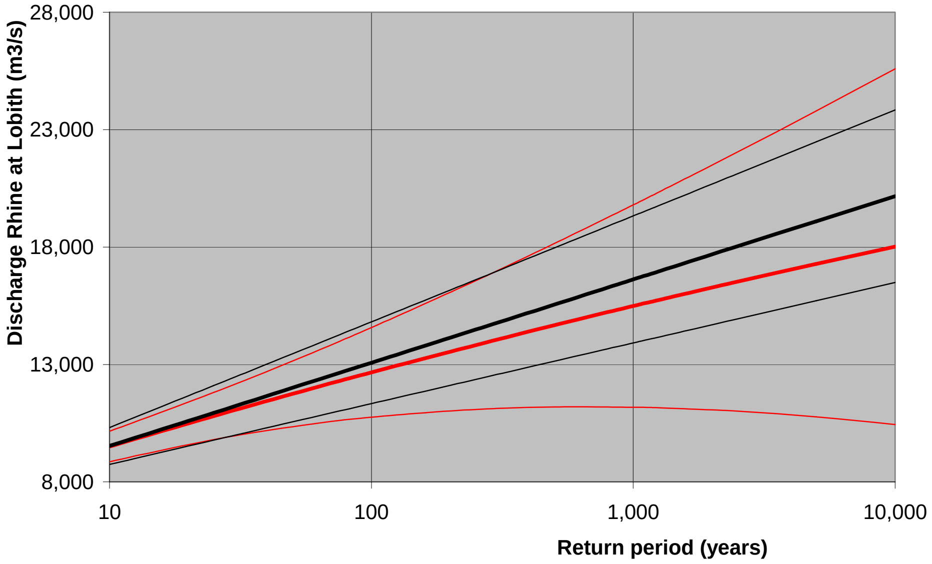


Figure 1 Frequency curves (thick lines) of Rhine discharges at Lobith and confidence intervals (thin lines) for the Pareto distribution (red) and the exponential distribution (black)

Alternative approach

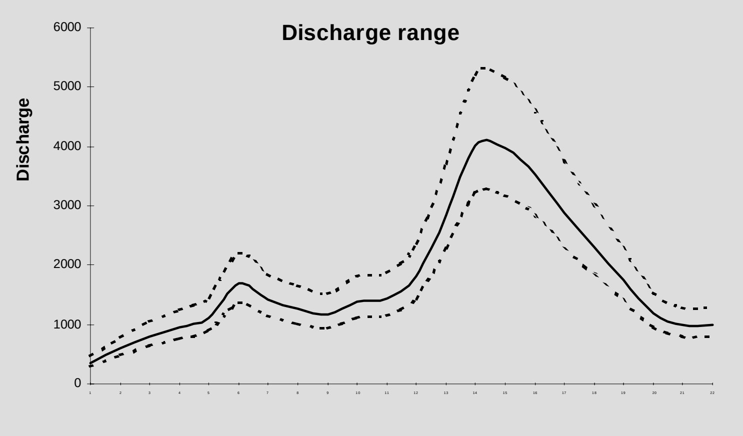


Figure 2 Flood hydrograph with uncertainty bounds.

The main cause for the large uncertainties in Figure 1 is the fact that relevant return periods are an order of magnitude larger than the length of the available series of measurements. Therefore, RIZA[1] has initiated the development of an alternative approach in which a stochastic rainfall generator is coupled with a conceptual rainfall-runoff model of the Rhine basin and a routing model for the main river systems. The rainfall generator is developed by the Royal Dutch Meteorological Institute (KNMI). It uses a nearest-neighbour resampling technique to generate daily rainfall and temperature series for the entire basin. This means that, in order to maintain the statistical characteristics of the observed series, the selection of a single sample is conditioned (in a probabilistic sense) on the characteristics of its predecessor(s). The hydrological model is developed by the German Federal Institute of Hydrology (BfG), using the well-known HBV-concept. With this model instrumentation it is possible to generate a series of synthetic discharges that is much longer than the available series of measurements.

Theoretically, this increase in series length will lead to a reduction in the uncertainties in the resulting frequencies. The problem, however, is that the application of the model instrumentation introduces new sources of uncertainties that will also affect the outcome of the frequency analysis. Some of these uncertainties are hard, if not impossible, to quantify. This is especially the case for the rainfall generator, since there is no reference situation to validate the outcome of this model for the extreme return periods of 1000 years or more. A verdict on the quality of predictions is therefore difficult to assess. A vital step in that respect is that the derived results should at least be realistic. Furthermore, the relevant statistical properties of the generated series should be in accordance with the statistics of the observed series. KNMI has done extensive research on this subject.

In principle, the same problems exist in quantifying uncertainties in the rainfall-runoff model. Again, the model is used to simulate events that are more extreme than any one of the observed events. In this case, however, locally observed extreme events may come to the rescue. For example, the accumulated maximum discharges of

---

[1] RIZA: the Institute for Inland Water Management and Waste Water Treatment

the tributaries of the Rhine exceed the 1,250 year design discharge, i.e. 16,000 m^3/s, near the Dutch-German border at Lobith. So, even though at Lobith the maximum observed discharge is “only” 12.500 m^3/s, the relevant hydrological processes that occur during a 16,000 m^3/s event possibly have been observed on a more local scale. This means a relatively good estimate of model uncertainties can be obtained by comparing observed and simulated discharges. First enquiries were executed to do this quantification with the so-called “GLUE”-method in which uncertainties (likelihoods) in parameter estimates are based on the goodness-of-fit of observed and simulated hydrographs. In this method a large number of optional parameter sets are then used in model predictions, and model outcomes are weighted according to the associated likelihood. From this ensemble of weighted model outcomes the mean and uncertainty bounds can be evaluated (see e.g. Figure 2).

Special focus in this process is needed for the hydraulic component of the model. During design flood conditions long stretches of the river network are confronted with discharges that exceed the highest observed discharges by far. Therefore we need to know [a] at what stage floods will occur and [b] which amount of water will be lost. Even though no data on these type of extreme floods is available, the physical processes involved are quite well-known. Hydraulic model simulations can therefore provide valuable information. However, this requires detailed information on cross sections, dikes and flood plains along all stretches of the basin. This may still take a huge effort but it will pay off eventually. The physical boundaries of the river network may well reduce the effects of uncertainties of the rainfall generator and rainfall-runoff model on the final outcome.

Fuzzy logic approach for reducing uncertainty in flood forecasting

Shreedhar Maskey,
Raymond Venneker
Stefan Uhlenbrook
UNESCO-IHE Institute for Water Education, Delft, The Netherlands
P.O. Box 3015, NL 2601 DA Delft, the Netherlands
s.maskey@unesco-ihe.org

Extended abstract

The application of mathematical models for flood forecasting is increasingly common. Model types vary from physically-based distributed to lumped conceptual as well as data driven. The discussion in this paper is limited to the uncertainty and related issues in the first two categories of models. Uncertainty in flood forecasts from models results from the uncertainty in (i) input data, (ii) model parameters, (iii) model structure, (iv) calibration data, and (v) the initial state of the system. The uncertainty in rainfall data (observed as well as forecasted) is normally the dominant source of input data uncertainty in flood forecasting for both physically-based and conceptual models. The error/uncertainty in rainfall is comprised in the point estimates, and in the temporal distribution and spatial regionalization. Some studies show that the contribution of the uncertainty in the temporal distribution is predominant compared to that in point estimates. This conclusion is more valid for the catchments where the measuring frequency of available rainfall data is rather low (e.g. daily rainfall data).

The role of future precipitation for forecasting floods is also of importance (Fig. 1). Although there has been increasing progress in the quantitative precipitation forecast (QPF), the real-time coupling of QPF with operational flood forecasting models is still rare. Moreover, the dynamics of weather variables are such that the uncertainty in the QPF is substantial. Therefore, the uncertainty in QPF should be explicitly taken into account for flood forecasting and decision-making. In the absence of QPF, instead of assuming no future rainfall more plausible flood forecasts can be achieved using the rainfall time series extension by various methods such as assuming monthly average precipitation, monthly maximum precipitation, or stochastic generation of rainfall patterns based on average or maximum monthly precipitation, etc.

Calibration is an important step in the development of a model for specific catchment. The role of calibration is normally more vital for the accuracy of conceptual models. The dilemma of the model calibration is two-fold: (i) a set of parameters calibrated for some flood events may vary systematically to that for other flood events, (ii) the data against which the model is calibrated may also posses significant uncertainty. The latter problem, although the effect can be very pronounced, has not been widely discussed in the literature. The problem can be addressed in the framework of generalized likelihood uncertainty estimation (GLUE), but its applicability to models with large numbers of uncertain parameters is restricted due to computational requirements.

The main purpose of this paper is to propose a methodology to deal with the first problem of calibration mentioned above. The idea is not to develop a single model that will represent the catchment behaviour as closely as possible for all flow classes (e.g. high, medium or low flows), but various models each representing the optimal catchment response for a given range of flows. Ranges of initial conditions and input variables defined by fuzzy membership functions are used to qualify the given flow classes. Then, a set of fuzzy rules is defined as follows

> If flow class is $\mathbf{FC_1}$ then use model $\mathbf{M_1}$.
> …
> …
> If flow class is $\mathbf{FC_n}$ then use model $\mathbf{M_n}$.

The forecast or estimate of a flood for given flow conditions at each time step is based on the combined use of these models using fuzzy logic (Fig. 2). The rationale behind this approach is the basic fuzzy principle, i.e. *everything is a matter of degree*. In other words, each of the models can be applied for all flow conditions, but the degree of accuracy may vary from one flow condition to another. Therefore, there exists a fuzzy boundary area between two flow classes (the shaded area in Fig. 2), for which combination of two or more models may produce more accurate results.

One advantage of this approach is that each model can be optomized fully to the parameters for the given flow class without compromising other flow classes. On the other hand, it may give an extra weight to the calibration procedure possibly resulting in an over-parameterised (or over trained) model. There is also a danger that the model becomes very sensitive to the calibration procedure. Therefore, it needs a consistent and robust calibration procedure. An automatic calibration with manual intervention is proposed, which is described in following steps:

(i) Establish initial values and minimum and maximum limits for each of the parameters obtained from available data and knowledge about the characteristics of the model domain (catchment).
(ii) Finding of the optimum values for the parameters using automatic calibration procedures (with one or more algorithms and with one or more objective functions).
(iii) Manually adjust the optimized parameter values using expert judgement.
(iv) Re-adjust values of the parameters that are dependent on the values of the calibration parameters (if any); e.g. the feasible range of Muskingum *x* is dependent on the values of Muskingum *K*.
(v) Evaluate the adjusted set of parameters by running the model. If the result is unsatisfactory:
(vi) Re-adjust the parameter limits if necessary. For example, the automatic calibration may result in a parameter value close to its upper limit for all hydrological subunits, which means that the optimum value could be found at some higher value. If reasonable the upper limit of the parameter should be increased and the lower limit should be increased accordingly to narrow down the search space. Similar adjustment should be applied if the optimized parameter value is close to the lower limit.
(vii) Check if some of the parameters have the most appropriate values in the current calibration run. If confirmed, fix the values for these parameters and exclude from further calibration. This helps to reduce the next calibration time.
(viii) Repeat steps (ii) to (vii) until the satisfactory parameter set is found.

The proposed calibration method possesses the advantages of both automatic and manual calibrations.

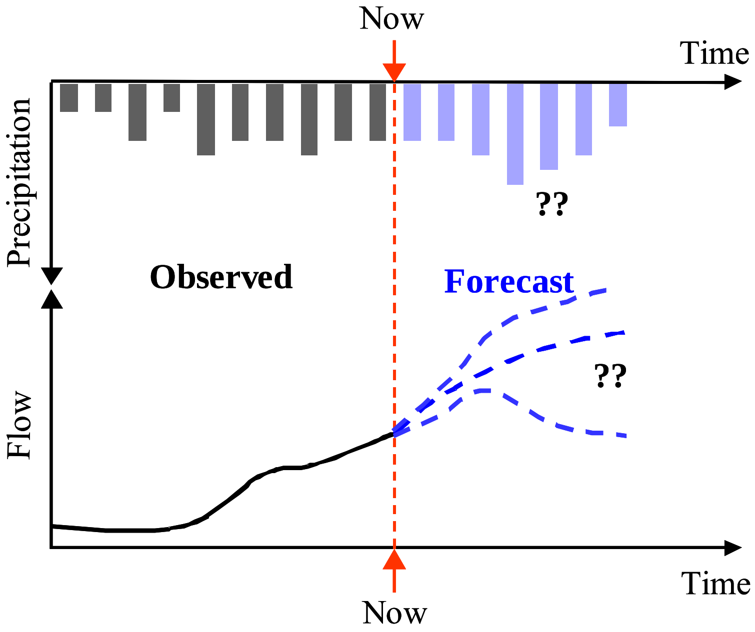


Figure 1: Role of future rainfall in flood forecasting.

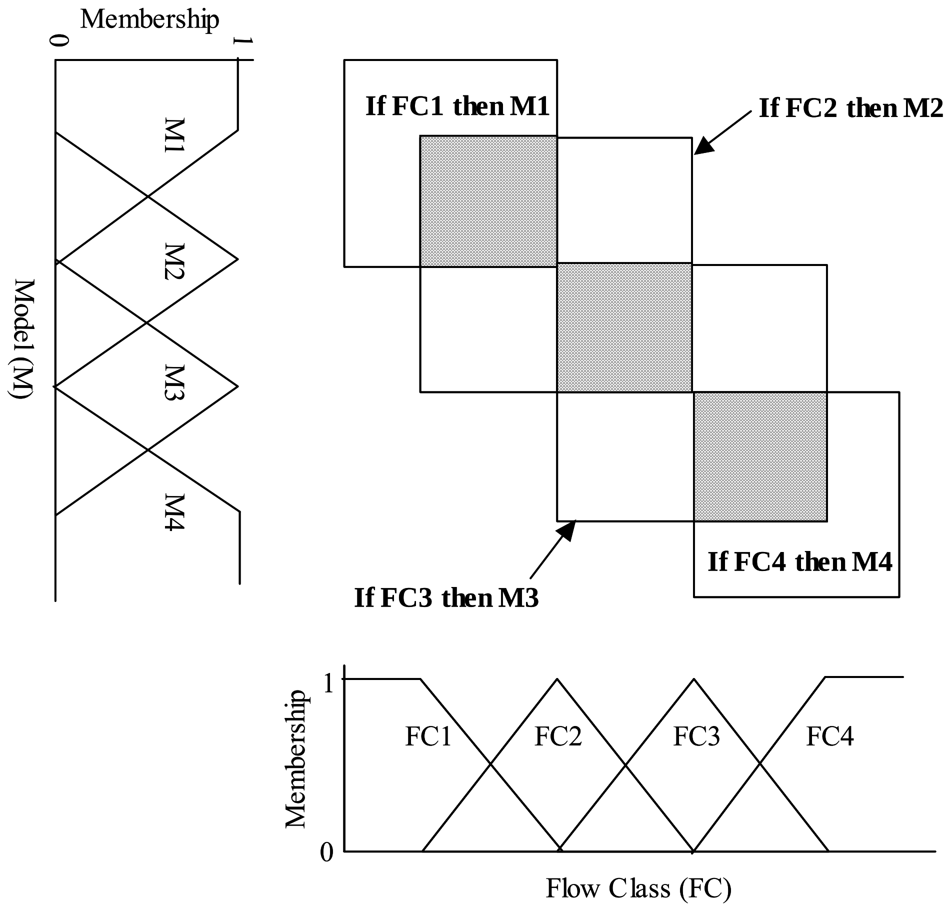


Figure 2: Illustration of fuzzy rules.

Extremwertstatistik für instationäre Verhältnisse – Methoden für die Berücksichtigung der Klimaänderung bei Bemessungsaufgaben

András Bárdossy
Institut für Wasserbau, Universität Stuttgart
Pfaffenwaldring 61, D-70550 Stuttgart, Deutschland
bardossy@iws.uni-stuttgart.de

Eines der Probleme der hydrologischen Bemessung liegt in der Tatsache, dass zukünftige Extreme aus Beobachtungen der Vergangenheit abzuschätzen sind. Beobachtungen der letzten Jahre und die Untersuchungen der Meteorologen zeigen, dass das Klima sich verändert hat. In einigen Gebieten sind ungewöhnliche Hochwasserereignisse häufiger auftreten und die mittlere Hochwasserscheitel sind ebenfalls angestiegen. Da diese Änderungen für unterschiedliche Gebiete sehr unterschiedlich ausfallen kann ein pauschales Vorgehen (z.B. eine Erhöhung der Bemessungswerte um einen festen Prozentsatz) nicht empfohlen werden.

In diesem Beitrag werden unterschiedliche Verfahren zur Berücksichtigung von Instationaritäten bei der Extremwertstatistik vorgestellt.

Das erste Verfahren ist die Beschränkung der Daten auf die letzten Jahre unter die Annahme das diese für die Zukunft repräsentativ sind. Dieses Verfahren hat zahlreiche Mängel, unter anderem kann es die Klimaentwicklung nicht berücksichtigen.

Das zweite Verfahren ist die Anwendung der Extremwertstatistik unter der Annahme das die Parameter zeitliche Änderungen aufweisen. Dieses Verfahren kann die Tendenzen der Vergangenheit gut nachbilden und ist statistisch korrekt formulierbar. Nachteilig ist dass es die aus Klimaszenarien stammende Informationen nicht berücksichtigen kann.

Das dritte Verfahren verwendet aus Reanalysen und aus Klimaszenarien stammende Niederschlagsindizes. Diese Indizes können mit den beobachteten Hochwasserereignisse in Verbindung gebracht werden. Der so bestimmte Zusammenhang ermöglicht die Berechnung möglicher zukünftiger Hochwasser. Die Zuverlässigkeit dieser Methode kann mit Hilfe eines Split-Sampling Verfahrens beurteilt werden.

Eine Kombination der beiden letzten Verfahren wird ebenfalls andiskutiert.

Die Verfahren werden anhand von Fallbeispielen im Reineinzugsgebiet demonstriert und die Ergebnisse werden ausführlich diskutiert.

Wirkungen weiträumig verteilter Rückhaltemaßnahmen auf den HW-Ablauf im Rhein

Heinz Engel
Bundesanstalt für Gewässerkunde, Koblenz
Postfach 200253, D-56002 Koblenz, Deutschland
engel@bafg.de

Am 22.01.1998 haben die Mitglieder der 12. Rheinminister-Konferenz den "Aktionsplan Hochwasser" für den Rhein beschlossen und versprochen, dass "Extremhochwasserstände nach Realisierung der Maßnahmen des Aktionsplans Rhein abwärts um bis zu 30 cm bis zum Jahr 2005 und um bis zu 70 cm bis zum Jahre 2020 reduziert werden".
In positiver Abweichung zu Verhaltensmustern früherer Jahre wurden zu realisierende Maßnahmen im Einzelnen benannt, in ihrer Wirkung quantifiziert, erforderliche Kosten politikseitig bereitzustellen versprochen, Kontrollgremien benannt und Zeithorizonte für Nachweise der bis dahin erbrachten Wirkungen festgelegt.

Inzwischen ist mit dem Jahr 2005 der erste Meilenstein des Aktionsplans erreicht. Es ist nunmehr der Nachweis zu erbringen, dass seit 1995 umgesetzte Maßnahmen (wie versprochen) Extremhochwasser in ihren Scheiteln um bis zu 30 cm verringern werden.

Im Vorfeld der Erstellung des Aktionsplans sind Untersuchungen durchgeführt worden zur Abschätzung der Wirkungen unterschiedlicher Rückhaltemaßnahmen im Rhein-Einzugsgebiet und an den darin verlaufenden Gewässern. Für diese Arbeiten konnten für den Rhein Rechenmodelle eingesetzt, in anderen Fällen von Dritten durchgeführte Untersuchungen genutzt und schließlich Überlegungen der Fachleute zur Abrundung herangezogen werden. Berücksichtigung fanden alle 1997 für denkbar erachteten Maßnahmen.

Schon damals zeigte sich, dass die ausgeprägte Heterogenität des Rheingebiets mit sehr unterschiedlichen Gebietsreaktionen und meteorologischen Bedingungen zu sehr deutlichen Unterschieden zwischen Wirkungen im Nah- und Fernbereich führt **(Abb. 1)**. Maßnahmen ergeben vor allem positive Wirkungen vor Ort. Dies gilt für kleine Hochwasser stärker als für große, da die verfügbaren Volumina sehr begrenzt sind und die zu beeinflussenden Wellenfüllen mit der Ereignisgröße überproportional zunehmen. Zudem sind die Maßnahmen in großen Gebieten nicht gleichmäßig verteilt und liegen oft so ungünstig, dass Wirkungen im Fernbereich kaum noch feststellbar sind. Steuerbare Retentionen in und an den Gewässern, vor allem den Hauptvorflutern, zeigen die offenkundigsten Wirkungen. Enorme Wirkungsunsicherheiten ergeben sich infolge von Überlagerungseffekten. Solche können in besonderen Fällen auch zu negativen Veränderungen an den Wellen führen. Dadurch, dass alle Rückhaltungen in ihrer Größe mehr oder weniger abflussabhängig sind, folgen aus der jeweiligen Hochwassergenese und den unterschiedlichen Wellengrößen bei der Bereitstellung gleicher Maßnahmen und bei gleichen Scheitelhöhen an entfernt liegenden Pegeln erhebliche Wirkungsunterschiede. Grundsätzlich können gewisse Kumulierungen der denkbaren Maßnahmen nur für extreme Hochwasser angenommen werden. Erst sehr außergewöhnliche Ereignisse (ca. $>HQ_{100} - HQ_{500}$) gewährleisten, dass auch nahezu alle Teilwellen die zur Aktivierung vieler Maßnahmen erforderliche Größe erreichen.

Für die derzeit begonnenen Wirkungsberechnungen im Auftrag der IKSR ist das Modellgerüst (Rückgratmodell) zum rechnerischen Nachweis auf die großen Nebenflüsse unterhalb von Basel erweitert (Neckar, Main, Lahn, Saar/Mosel) und bietet eine verläßlichere Basis als die 1997 gegebene. Berechnungen oder Abschätzungen von Maßnahmenwirkungen an kleineren Gewässern bzw. im Einzugsgebiet werden von den jeweils zuständigen Staaten/Ländern, bezogen auf festgelegte Knoten im Rückgratmodell, zugeliefert. Damit ist auch von intensiveren Kenntnissen und verbesserten Untersuchungsmethoden auszugehen.

Die hinsichtlich der Nachweise zu verwendenden Modellwellen werden auf Grundlage historischer Ereignisse mit festgelegten Scheitelabflüssen als Zielgrößen für fünf Pegel am Rhein (Maxau, Worms, Kaub, Köln, Lobith) erzeugt. Die Scheitel sind zu erreichen unter den Bedingungen des Jahres 1995 und liegen bei Jährlichkeiten um 200 bis über 1000 Jahre. In weiteren Rechenläufen werden die bis Ende 2005 als realisiert gemeldeten Maßnahmen eingesetzt. Dabei handelt es sich um solche, die

- ausschließlich anthropogen unbeeinflußbar (z. B. Entsiegelung, Änderung des Bewuchses)
- nur unter natürlichen Voraussetzungen (z. B. Mindestwasserstände in Gewässern, um Polder füllen zu können)
- beliebig steuerbar (z. B. Polder neben hoch eingestauten Gewässern)

wirken sowie um Maßnahmen, für die klare, abgestimmte Einsatzregelungen bestehen. In keinem Fall ist davon auszugehen, daß Sondersteuerungen realisierbar sind, die im Hinblick auf von Dritten gewünschte Fernziele entwickelt werden. Ganz im Gegenteil verfolgen alle Einzelsteuerungen Unterziele, die oftmals im Konflikt zu einem wünschenswerten Gesamtziel stehen. Es bleibt allerdings zu hoffen, daß sich für alle An- und Unterlieger in der Kumulierung der Maßnahmen letztlich positive Wirkungen ergeben.

Sämtliche Berechnungen werden über die Zielpegel hinaus bis zum Beginn des Deltarheins (Lobith) durchgeführt. Auf diese Weise ergeben sich in allen Abschnitten des Rheins Wirkungen für unterschiedliche Extremabflüsse. Die Verwendung der drei gewählten Modell-Basiswellen für die fünf Zielpegel und von zusätzlich zwei Wellen nur für den Oberrhein führt auf 17 unterschiedliche Wellenabläufe. Damit ist zu hoffen, dass verallgemeinerungsfähige Ergebnisse entstehen, die Scheitelreduktionen in Abhängigkeit von Wellengrößen zeigen und evtl. vorhandene optimale Wirkungsbereiche erkennen lassen.
Jedenfalls ist davon auszugehen, dass oberhalb bestimmter Scheitelabflüsse/-Jährlichkeiten, keine Scheitelreduktionen mehr erzielbar sind, weil sich die verfügbaren Wirkungen in den ansteigenden Ästen der Wellen verbraucht haben. Es wäre sinnvoll, die durchaus positiven Wirkungen – Verlangsamung des Wellenanstiegs, Verkürzung der Überschreitungsdauern bestimmter Schwellenwerte – als ein weiteres oder erweitertes Handlungsziel in den „Aktionsplan Hochwasser“ aufzunehmen.

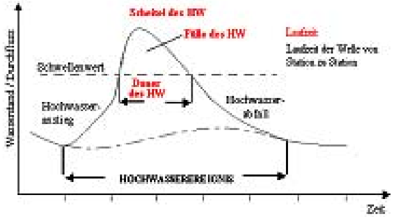


Abb.1: **Abschätzung der Wirkungen von HW- Schutzmaßnahmen**

Wirkung von	**Maßnahmen im Einzelnen**	**im Nahbereich**												**im Fernbereich**											
		auf kleine Hochwasser						auf große Hochwasser						auf kleine Hochwasser						auf große Hochwasser					
		Laufzeit	Dauer	Fülle	Scheitel	*	**	Laufzeit	Dauer	Fülle	Scheitel	*	**	Laufzeit	Dauer	Fülle	Scheitel	*	**	Laufzeit	Dauer	Fülle	Scheitel	*	**
▪ Bewuchs, Boden, Gelände	Brachland, Wiese, Aufforstung		-	-	-	▨																			
	ökologische Bewirtschaftung		-	-	-	▨			+	(-)	-	▨				(-)	(-)	▨							
	Entsiegelung, Versickerung		-	-	-	▨																			
▪ Gewässernetz	Renaturierung	+	+		-	▨		+	(+)		(-)	▨		(+)	(+)		(-)	▨							
	Deichrückverlegung von																								
	-Winterdeich (Banndeich)	+				▨		+				▨		+			(-)	▨		+			(-)	▨	
	-Sommerdeich	+			(-)	▨		(+)				▨		(+)			(-)			+					
	Sommerpolder							+		-	(-)	▨								(+)		(-)	(-)	▨	
	technische Rückhaltungen (gesteuert)																								
	- an Nebengewässern	(+)	(+)	(-)	(-)	▨		(+)	(+)	(-)	(-)	▨		(+)	(+)		(-)	▨		(+)	(+)		(-)	▨	
	- an Hauptgewässern	+	(+)	(-)	(-)	▨		(+)	(+)	(-)	(-)	▨		(+)	(+)	(-)	(-)	▨		(+)	(+)	(-)	(-)	▨	
	Erhöhung der Abflusskapazität																								
	- Vertiefung der Querschnitte, Bett				-	▨					-	▨		(-)			(+)		▨	(-)			(+)		▨
	- Vertiefung der Querschnitte, Vorland				-	▨					-	▨		(+)			(-)	▨		(+)			(-)	▨	
	- Verbreiterung der Querschnitte, Bett				-	▨					-	▨		(-)			(+)		▨	(-)			(+)		▨
	- Verbreiterung der Querschnitte, Vorland				-	▨					-	▨		(+)			(-)	▨		(+)			(-)	▨	
	- Engpassbeseitigung				-	▨					-	▨		(-)			(+)		▨	(-)			(+)		▨
	Örtlicher Hochwasserschutz																								
	Deiche, Mauern, Aufhöhung (Warft)	-			(+)!	▨		-			(+)!	▨		(-)			(+)		▨	(-)			(+)		▨
▪ Verhalten der Anlieger	- Angepaßtes Bauen					▨						▨						▨						▨	
	- Angepaßte Nutzung					▨						▨						▨						▨	
	- Erhöhung des Hochwasserbewußtseins					▨						▨						▨						▨	

+ verlängernd, erhöhend
( ) bedingt wirksam

- verkürzend, vermindernd
! Risiko für Oberlieger beachten

* **Schäden mindernd**

** **Schäden erhöhend**

Impact assessment of flood mitigation measures

Matthijs Kok
HKV Consultants, the Netherlands
P.O. Box 2120, NL 8203 AC Lelystad, the Netherlands
m.kok@hkv.nl

Assessing impacts of flood mitigation measures (such as dike strengtening, lowering flood plains, building watertight compartments, retention areas and spatial planning) can be done with traditional cost/benefit methods. These methods are in decision making for two reasons not sufficient. First, flooding does also influence “goods’ having not only a purely economical value, such as human lives, cultural goods and the value of keeping control of the situation. Second, measures do not have only economic costs, but may provide other non-economical costs and benefits. Examples are the impacts on landscape of dike strenthening (see for example Walker et al, 1994) or the increase of nature values by lowering the flood plains. However, in this presentation we concentrate ourselves on the economic approach. In this approach the expected yearly risk is calculated, where risk is defined as the product of the probability of flooding and the economic damage of a flood. Assessing these probabilities is not easy, because there are many failure mechanisms and many dike sections (and structures). For an adequate assessment these factors have to be taken into account. Assessing flood damage is often done by assuming a ‘flood scenario’, calculating flood depths. These depths are combined with damage functions, which give the relation between depth and damage. Next, the Present Value of the expected yearly risk is calculated to assess the total benefits, taking into account economic growth and sometimes also climate change is included. Incorporation of economic growth and climate change changes the problem into a dynamic investment problem, as already described by Van Dantzig (1956). Repeated investments in flood mitigation measures are necessary from an economical point of view.

In the presentation we will discuss three new methodological developments in the economical impact assessment of flood mitigation measures. First, the relation between the exceedance frequency of water levels (which is often used as the indicator of flood probability) and the flood probability will be discussed using some examples. In the examples we will not consider all failure mechanisms, but only the mechnism ‘overflow and wave overtopping’. In this example we consider the natural variability of water levels, but also knowledge uncertainties. Second, the approach of Van Dantzig is recently extended by Eijgenraam (2003), and we will present the consequences of his approach. In his approach, the ‘optimal’ protection level decreases in time (safety will increase), due to economic growth. And by climate change the flood probability increases, and additional investments are neceassary from an economical point of view. Thirdly, assessment of flood damages has a lot of uncertainties, and we present results of an uncertainty analysis of flood damage using, carried out by HKV Consultants and Delft University of Technology.

Literature

Dantzig, D. van., 1956. *Economic decision problems for Flood prevention*. **Econometrica**, 1956.

Eijgenraam, C.J.J. “KBA Ruimte voor de Rivier. Hoogte van dijken”, Centraal Plan Bureau, Memorandum, 6 september 2004.

Walker, W., M. Kok et al., 1994. *A Policy Analysis of Dutch River Dike Improvements: trading off Safety, Cost, and Environmental Impacts*. **Operations Research** 42, 5, 823-836, 1994.

Risikomanagement in der Kommune

Reinhard Vogt
Hochwasserschutzzentrale Köln
Willy-Brandt-Platz 2, D-50679 Köln, Deutschland
reinhard.vogt@steb-koeln.de

Bei den Hochwassern der letzten Jahre, z.B. an der Donau, der Elbe und der Oder, bei denen es neben Überfluten der Deiche auch Deichbrüche gab, war seitens der Bevölkerung der Hauptvorwurf gegen die jeweiligen Kommunen, dass die Verwaltung im Vorfeld der Katastrophe keine ausreichenden Informationen über die zu erwartenden Schäden herausgegeben hätte. Über mögliche Überflutungshöhen und vorsorgenden Objektschutz bzw. entsprechende Verhaltensvorsorge gab es nur unzureichende Informationen.

Daher ist es zwingend geboten, der Bevölkerung entsprechende Informationen in Form von Gefahrenkarten zur Verfügung zu stellen. Da hier große Möglichkeiten zur Verringerung des Schadenspotentials liegen und die Eigenvorsorge gestärkt werden muss, sind Gefahrenkarten für das gesamte Kölner Stadtgebiet in verschiedenen Ausfertigungen mit den Pegelständen 10,70m K.P (etwa 40 jährlich) bis zu dem Katastrophenwasserstand von 12,50m K.P. entwickelt worden.

Anhand dieser Karten kann jeder ersehen wie sein Haus oder Grundstück bei welchem Kölner Pegelstand betroffen ist und wie hoch das Wasser in seiner Strasse steht. Für hochwasser- und grundwassergefährdete Gebiete, auch für zukünftig geschützte Bereiche, für die es schließlich dennoch keinen absoluten Schutz vor Überschwemmungen gibt, ist die Bauvorsorge, die die Bausubstanz und die Nutzungen an mögliche Hochwasserüberflutungen anpasst, unerlässlich und besonders wichtig zur Schadensminimierung.

Die ständige Sensibilisierung der Bevölkerung und der entsprechenden Entscheidungsträger sowie die deutliche Verringerung der Schadenspotentiale sind elementare Bestandteile der Kölner Hochwasserschutzkonzeption.

Durch Aufklärung und umfangreiche Information über die Hochwasserproblematik und die daraus resultierende Bewusstseinsänderung in der Bevölkerung und der Politik werden die Umsetzung der Vielzahl von vorsorgenden Maßnahmen zur Verlangsamung und Vermeidung von Abflüssen und des baulichen Hochwasserschutzes erleichtert und teilweise erst ermöglicht. Die Akzeptanz für den Bau von Rückhalteräumen und den Erhalt von Überschwemmungsgebieten wird geschaffen, Schadenspotentiale werden nicht weiter aufgebaut bzw. die bestehenden reduziert und die Eigenvorsorge der Bevölkerung unterstützt. Die dauernde Einbindung der Bürger in den vorsorgenden Hochwasserschutz und in die Intensivierung der Bürgerberatung ist hier besonders wichtig.

Increasing flood losses indicate increasing flood risk - What are the responsible parameters?

Wolfgang Kron
Münchener Rück, München
Königinstrasse 107, D-80791 München, Germany
wkron@munichre.com

Increasing flood losses

Flood catastrophes and the resulting economic and insured losses have increased significantly in the past decades. About a third of the economic catastrophe losses incurred worldwide are due to the effects of floods; more than half of all the people that were killed in the natural catastrophes of recent decades were the victims of floods. In global terms, the great flood catastrophes of the 1990s alone accounted for losses exceeding US$200bn (Tab. 1). The comparison of decade figures clearly shows dramatic increases.

Table 1: Great flood catastrophes 1950–2004, decade comparison

	1950–1959	1960–1969	1970–1979	1980–1989	1990–1999	1995–2004	Factor: last 10 yrs. : 60s
Number	6	6	8	18	26	15	2.5
Economic losses	32	23	21	30	245	154	6.7
Insured losses	0.0	0.25	0.4	1.6	8.8	8.3	33

MRNatCat*SERVICE* - Losses in US$ bn, 2004 values © Munich Re, Geo Risks Research – January 2005

Central Europe has experienced large events almost every other year during the past decade. The 1993 and 1995 floods in the Rhine system were followed by the Odra flood in 1997 and the Whitsun flood in Southern Germany in 1999, and all these were dwarfed by the Elbe flood in August 2002. Then, Germany suffered losses of €11.6bn, Austria and the Czech Republic added another €3.1bn and €3.0bn, respectively.

What is risk?

When talking about "increase in losses", it is important to distinguish the terms *hazard* and *risk*. While *hazard* is the existence of a possibly dangerous natural phenomenon and the probability of an extreme manifestation of that phenomenon, *risk* also looks at what may happen in that case. In the scientific community it is widely agreed that risk is the product of a hazard and its consequences. Hence, three components determine the risk:

1. the **hazard** i.e. the threatening natural event including its probability of occurrence;
2. the **exposure**, i.e. the values/humans that are present at the location involved;
3. the **vulnerability**, i.e. the lack of resistance to damaging/destructive forces.

In its most simple form risk is computed by multiplying these three components.

From this definition follows that:

1. Where natural forces are gentle or where destructive events happen extremely seldom, the risk - in general - is low.
2. Where there are no people or values that can be affected by a natural phenomenon, there is no risk. In a similar way a *disaster* can only happen when people are harmed and/or their belongings damaged.
3. Where people are well prepared, the impacts of nature's forces may be kept at a low level; therefore, the risk is low.

An example shall illustrate this: a very strong earthquake in an uninhabited region without human property cannot cause disaster. Similarly, a strong earthquake in a well-prepared region will not be catastrophic. In a poorly prepared region, however, even a moderate tremor may cause a devastating catastrophe. The earthquake hazard is clearly highest in the first case, while the earthquake risk is highest in the third case.

Causes of flood losses

The increase in losses is a direct function of the number of people that live in exposed areas. Flood plains are usually cheap as building land, attractive and easy to develop. They offer good conditions for establishing the necessary infrastructure. Flood plains are particularly advantageous for commercial and industrial facilities that need a large amount of space and sometimes use river water as process or cooling water. Larger rivers offer the possibility of transporting freight by ship. Towns and cities are interested in further development. They have to make land available for development or for commerce and industry.

Land development and accumulation of *values* in hazard-prone areas is beyond any doubt the major driving factor for the increase in losses. In the 1950s and 1960s, at least in Central Europe, flood protection, one measure of reducing vulnerability, seemed to have kept pace with the development of values, and the resulting risk remained nearly constant. Nowadays, this is not true anymore. Unfortunately, many people still believe that flood events can be controlled as long as appropriate technological precautions are taken.

Flood control measures undoubtedly prevent frequent losses and discomfort. This effect is counterbalanced, however, by the fact that the feeling of security it creates leads people to expose more and more objects of increasing value to the risk of flooding. Never before have they had so many valuable but at the same time vulnerable possessions. The rooms in the basement where homeowners used to store coal and wood, have now made way for well-equipped party rooms with all kinds of electronic devices, wall-to-wall carpets etc. As a result, the *vulnerability* is quite low for high-frequency events, but it tends to be extremely high at the upper end of the frequency function.

Finally, the flood *hazard* is increasing as well. It is indisputable that a warmer climate will lead to the atmosphere having a higher water vapour content. One upshot will be extreme rain intensities in regional or local severe weather situations. The fact that losses occur is attributable to these very extremes and not to a change in the mean values.

In this context, it is important to realise that flooding may be due to quite different causes, ranging from storm surges and tsunamis to river floods, flash floods and debris flow events. River floods are hydrological extreme events that may have significant impact to an entire country. They are the result of copious rainfall usually continuing for a period of days over a large area. In contrast to this, flash floods, while being more destructive, normally occur as individual events of only local significance. They are expected to gain importance: even if mean precipitation is smaller. It will be more concentrated in time though, so that more flash floods will occur.

Strategies against flood risk

Risk and loss minimisation call for an integrated course of action. At the same time, the flood risk must be carried on several shoulders: the state, the people affected, and the insurance industry. Only when all three partners cooperate with each other in a fine-tuned relationship in the spirit of a risk partnership is disaster prevention really effective. Suitable prevention strategies must embrace all aspects from the origins of floods to the avoidance of the loss potentials involved. This is a challenge to all groups involved.

While prevention of extreme *floods* is very limited by retaining more water in the catchment this measure must still have top priority whenever possible. However: extreme floods in large catchments are not attributable to surfaces which have been made impervious by human activity; this has a relatively minor impact. Likewise, river restoration, and dyke relocations can only reduce extreme flood peaks to a limited degree.

Flooding can be influenced by technological measures such as retaining the water at specially designated places, or directing the flood waters by means of dykes within in a predetermined area.

Flood losses occur when people and their possessions are affected by flood waters. The precautions that can be taken are warding off the water or extricating oneself and one's valuables from its effects. Solutions include revising land use regulations, adopting permanent and temporary structural measures, modifying the management of values, and taking appropriate action in the event of an impending flood.

The *flood risk* can be minimised by suitable measures designed to prevent floods, flooding, and losses. Nevertheless, there will always be a residual risk; and that is where insurance comes in. Insurance makes the uncertainty of future financial strains calculable. In return for a premium, the policyholder can either buy complete freedom from that uncertainty or (by paying a lower premium) limit the loss to a certain deductible.

In the discussion of flood control measures, the different types of flood are usually all lumped together. No distinction is made between relatively common floods (e.g. with a return period of five to ten years), major floods (e.g. 100-year events), and catastrophic floods, which only occur on average every few centuries. This approach is a fundamentally wrong and results in conflicting stances and solutions. A distinction must be made between frequent and very rare floods and between small and large catchments, because the measures called for in each case are quite different. Table 2 lists the most important measures for each group of events roughly in the order of their significance and efficacy. Of course, all other measures have to be incorporated as well, but the fact is that they are not always equally effective.

Table 2: Measures designed for flood control and flood prevention, in the order of their effectiveness and importance

Frequent floods Return periods below approximately 20 years **"Natural" or "soft" measures**	- Improved infiltration, removal of impervious surfaces - Decentralised retention - River restoration - Dyke relocation, widening of river cross sections - Simple dykes
Rare floods Return periods between 20 and 100 years **Technological measures**	- Retaining basins, retention areas - Engineered dykes - Polders - Dyke relocation, widening of river cross sections
Very rare floods Return periods (far) exceeding 100 years **Organisational measures**	- Flood management - Flood response - Emergency relief - Financial provisions (insurance)

Catastrophes are not only products of chance but also the outcome of interaction between political, financial, social, technical, and natural circumstances. Risk can never be eliminated completely, it can only be reduced. The decisive point is the awareness that nature can always come up with events against which no human means can prevail

Author:
Dr.-Ing. Wolfgang Kron
Head of Hydrological Risks
Geo Risks Research/Environmental Management
Munich Reinsurance Company
Königinstrasse 107
80791 Munich
Tel.: (089) 3891 5260
Fax: (089) 3891 5696
e-mail: wkron@munichre.com

Transboundary effects of flooding and flood reducing measures along the Rhine in Northrhine-Westfalia (Germany) and Gelderland (the Netherlands)

Rita Lammersen
Institute of Inland water Management and waste water treatment (RWS-RIZA)
P.O. Box 9072, NL 6800 ED Arnhem, the Netherlands
r.lammersen@riza.rws.minvenw.nl

Bernd Mehlig
The Northrhine-Westfalia State Environment Agency (LUA)
Wallneyer strasse 6, D-45133 Essen, Germany
bernd.mehlig@lua.nrw.de

1. Introduction

After the big floods in 1993 and 1995, which took place in the river Rhine basin, the Province of Gelderland (The Netherlands), Rijkswaterstaat (The Netherlands) and the Ministry of Environment, Nature Conversation, Agriculture and Consumer Protection in Northrhine-Westfalia (Germany) signed a declaration for cooperation in flood control. As part of the cooperation, the project "Effects of extreme floods along the Niederrhein (Lower Rhine)" was carried out to investigate the effects of extreme floods along the Rhine in Northrhine-Westfalia (NRW) and in Gelderland. The aim of the project was to raise knowledge on the occurrence and behaviour of extreme floods in the Rhine catchment, to indicate areas vulnerable for flooding in NRW and Gelderland and to develop techniques and tools for the evaluation of flood reduction measures.

2. Research Methods

In order to reach the aim of the project "Effects of extreme floods along the Niederrhein (Lower Rhine)" research was carried out for the whole catchment area of the river Rhine followed by a more detailed investigation of the area of the Lower Rhine in Germany and the Dutch Rhine branches.

A stochastic weather generator, developed by the Dutch Meteorological Institute (KNMI), was used to produce an artificial time series of 1000 year of precipitation and temperature (Buishand and Brandsma, 2001). The input consisted of 30 years of measured meteorological data of 34 different weather stations inside the Rhine catchment area. The generated time series, with the same statistics as the historical data, was then put into a rainfall-runoff model of the complete Rhine basin (HBV) and was transformed to discharge. A selection was made of the 16 most extreme events, based on the HBV results at Andernach and Lobith. These 16 extreme events were then put into a 1-dimensional flood routing model to compute the 16 highest discharge waves at Andernach in a more accurate way, taking into account flooding and retention measures along the Rhine upstream of Andernach (for more information see Eberle et al., 2004 and Lammersen, 2004).

With the two most extreme discharge waves at Andernach flood simulations have been performed using the 2-dimensional model Delft-FLS. A Delft-FLS model was made of the Rhine downstream Rhine-km 642 (which is downstream of Andernach) using a 100 m X 100 m grid on top of a digital terrain model. In this model dikes and flood walls are modeled as grid cells. When the water level reaches the dike level a dike collapse occurs. In case of a flood wall, or a natural levee, the floodwall or levee simply overflows and no collapse is simulated. Two situations have been considered: the year 2002 and 2020, with the dike levels of 2002 and 2020 respectively. The input of the 2D-model consisted of the discharge at Andernach and the tributaries of the Rhine. The output consisted of information about locations of a dike collapse or an overflow, inflow to the protected area, flood patterns inside the protected area, effect on the discharge wave and finally the discharge capacity of the Rhine (for more information see Gudden, 2004, and Lammersen, 2004).

The results of the 2D flood simulations were then transferred to a 1-dimensional SOBEK-model. Each dike collapse or overflow was modeled as a retention basin. Parameters like surface area, capacity, inflow and outflow were based on information from the Delft-FLS model (for more information see van der Veen et al., 2004a and Lammersen, 2004).

Using the SOBEK-model the effect of flood reduction measures in Northrhine-Westfalia was studied in combination with the effects of dike overflows. These investigations were made with the eight most extreme discharge waves, which had been calculated for Andernach. Two situations have been considered: the year 2002 and 2020, with the flood reduction measures and dike levels being realized in 2002 and 2020 respectively (for more information see Van der Veen et al., 2004a, Van der Veen et al., 2004b, Mehlig, 2004 and Lammersen, 2004).

3. Results

Based on the 1000 year rainfall the hydrographs with the 8 highest peak discharges were chosen. All hydrographs are different in shape and their peak discharges are cover the full range of being higher than the 1995 flood, via the magnitude of discharge where the water reducing measures are working up to being higher than the design flood level. In all cases, dike overflow takes place along the Oberrhein, causing a more or less apparent damping of the floodwave at Andernach. Nevertheless they do exceed the flood levels where the dikes along the Lower Rhine are designed for. This causes inundation along the Lower Rhine, first in the southern part, later in the middle part (figure1). This is due to the growing design-flood-level along the Lower Rhine as well as to the damping of the floodwave, which is caused by the flooding upstream. The inundation of the southern and middle part of the Lower Rhine reduces the peak discharge in the northern part of the Lower Rhine and in The Netherlands. Nevertheless in present time (situation 2002) transboundary inundations can occur. By building a flood wall in Emmerich, this will be prevented in future (situation 2020).

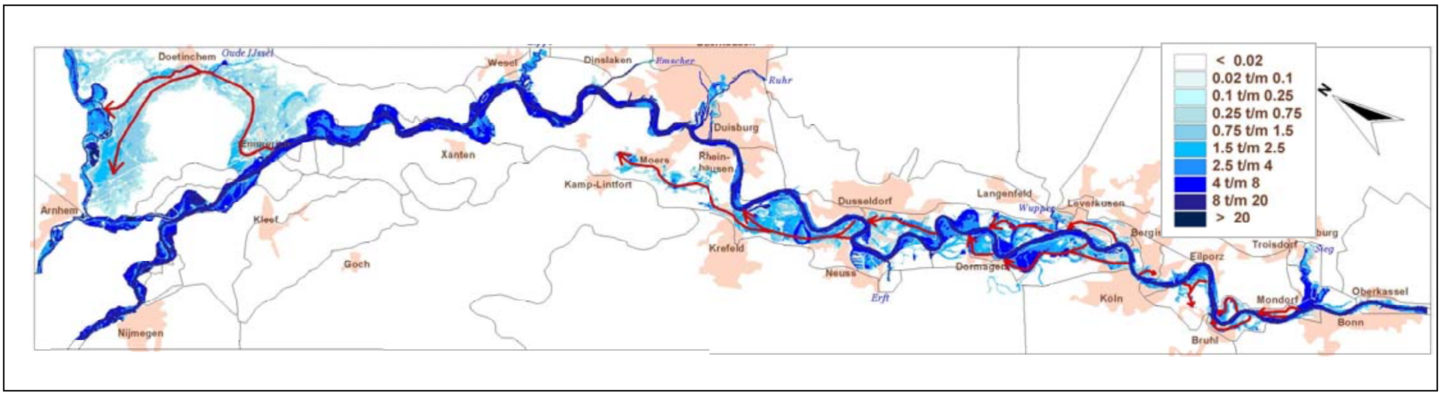


Figure 1. Flooding along the lower Rhine (situation 2002): maximum water depths [m] and main streams behind the dikes.

Figure 2 shows the development of peak discharges along the Lower Rhine for two scenarios. In the first scenario calculations were done without taking into account dike overflow along the Lower Rhine. In this situation the peak discharge increases along the Rhine due to additional inflow of tributaries. Taking dike overflow into account (second scenario) the peak discharges may also decrease rapidly at certain points along the river as a result of dike overflow. In this scenario peak discharges also may rise dramatically at points where water, which is flowing parallel to the River Rhine behind the dikes, returns to the main stream.

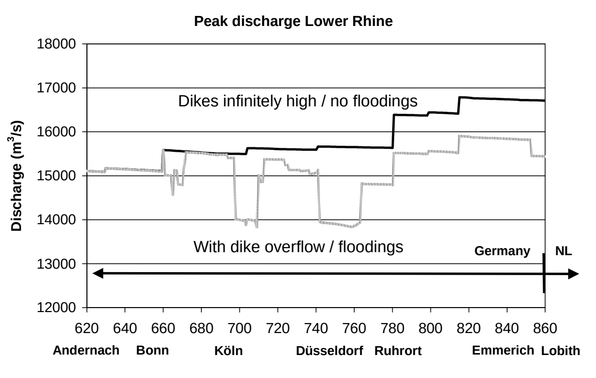


Figure 2. Maximum discharge with and without dike overflow (situation 2002, situation with dike overflow at the Upper Rhine, flood wave HW8).

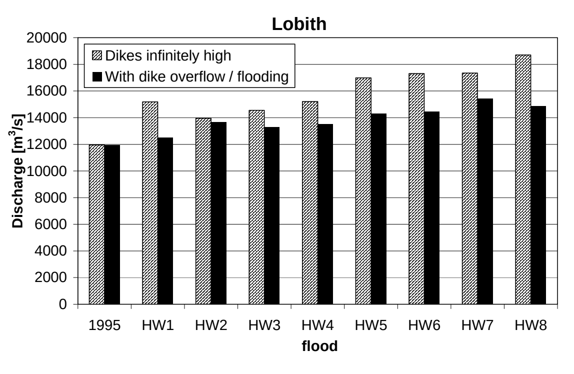


Figure 3. Peak flow at Lobith with and without dike overflow for the 1995 flood and the eight most extreme discharge waves.

For the measurement point Lobith, which is situated downstream of the Lower Rhine, the resulting peak discharges for all hydrographs can be seen in figure 3. Also here all flood waves are damped due to the dike overflow along the Upper Rhine and the Lower Rhine.

In NRW and Gelderland several flood reduction measures are planned. Some of them such as lowering of groynes, lowering of the floodplains, removal of hydraulic obstacles from the riverbed or setting back of dikes will cause an enlargement of the discharge capacity between the dikes. As the study showed, these measures cause a lowering of the water level at the location of the measure and further upstream. By building retention basins water will be extracted from the river and temporarily stored. As result of this reduction of the discharge, the water level in the river at the location of the retention basin and downstream of the retention basin decreases.
The investigations showed, that the planned flood reduction measures in NRW are most effective at floods equal to the flood of 1995, but have little effect under more extreme conditions. It could be shown, that these effects can be enlarged by optimizing the control levels of the planned retention basins and by improving the combination of measures (figure 4).
Measures in Germany affect the water levels in the Netherlands and the other way around (figure 5).

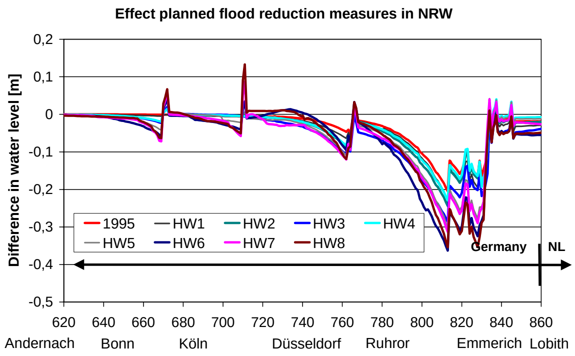


Figure 4. Effect of flood reduction measures planned in NRW, improved version.

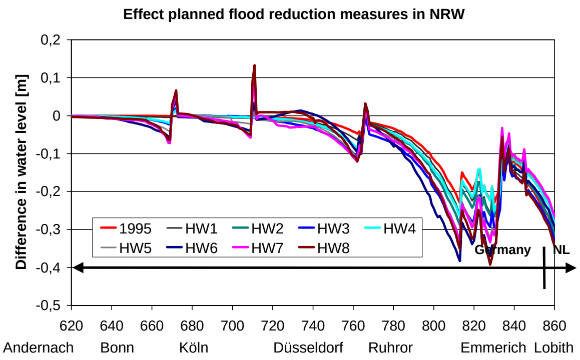


Figure 5. Combined effect flood reduction measures planned in NRW (improved version) and The Netherlands.

4. Conclusions and outlook

In the project "Effects of extreme floods along the Niederrhein (Lower Rhine)" the effects of flooding and flood reducing measures were investigated in order to get insight in the occurrence and behaviour of extreme floods along the Rhine. It was focused on the flooding pattern along the Lower Rhine and the Dutch Rhine branches, as well as the development of the discharge and the effect of the flood reduction measures in this river reach.
It could be shown, that floods at the Lower Rhine can exceed the flood levels were dikes are designed for. This causes inundations along the Lower Rhine, first in the southern part, later also in the middle part. Inundation of the southern and middle part of the Lower Rhine reduces the peak discharge in the northern part of the Lower Rhine and in The Netherlands. Nevertheless in present time (situation 2002) transboundary inundations can occur. By building a flood wall, this will be prevented in future (situation 2020). The planned flood reduction measures in NRW and in the Netherlands can reduce water levels in the river. These effects can be enlarged by optimizing the control levels of the planned retention basins and by improving the combination of measures on both sides of the border.
The flood design levels along the Rhine change along his course from Switzerland through Germany to The Netherlands. The study made clear, that under such circumstances the effects of flood reduction measures must be seen in combination with the effects of dike overflow upon the discharge and water level in the river. It also became evident, that the impact of dike overflow, flooding and flood reduction measures upon extreme floods is very large and should be taken into account in flood statistics. The techniques and tools, which are developed in this project will make this possible.

5. References

Buishand, T.A. and Brandsma, T. (2001): Multi-site simulation of daily precipitation and temperature in the Rhine basin by nearest-neighbour resampling. Water Resources Research, 37, 2761-2776.

Eberle, M.; Hammer, M.; Busch, N.; Engel, H.; Krahe, P. and Wilke, K. (2004): Effects of extreme floods along the Niederrhein (Lower Rhine), section Extreme floods from the River Rhine basin; (in German: ISBN 9036956501, in Dutch: ISBN 9036956684).

Gudden, J.J. (2004): Effects of extreme floods along the Niederrhein (Lower Rhine), section Inundation in NRW and Gelderland; (in German: ISBN 9036956641, in Dutch: ISBN 9036956692).

Lammersen, R (2004): Effects of extreme floods along the Niederrhein (Lower Rhine), main report; (in German: ISBN 9036956382, in Dutch: ISBN 9036956390).

Mehlig, B. (2004): Effects of extreme floods along the Niederrhein (Lower Rhine), section Retention measures in NRW and in the Netherlands; (in German: ISBN 903695665, in Dutch: ISBN 9036956706).

Veen, R. van der; Lammersen, R.; Kroekenstoel, D.F. and Brinkmann, M. (2004a): Effects of extreme floods along the Niederrhein (Lower Rhine), section Input data for the DSS Lower Rhine and Rhine branches; (in German: ISBN 9036956668, in Dutch: ISBN 9036956714).

Veen, R. van der; Kroekenstoel, D.F. and Brinkmann, M. (2004b): Effects of extreme floods along the Niederrhein (Lower Rhine); section Results DSS Lower Rhine and Rhine branches; (in German: ISBN 9036956676, in Dutch: ISBN 9036956722).

Large scale simulation of land use change effects on floods in the Rhine (results from the LAHOR-project)

Axel Bronstert
Chair for Hydrology and Climatology, University of Potsdam
Postfach 601533, D-14415 Potsdam, Germany
axelbron@rz.uni-potsdam.de

From 1997 until 2001 an EU-funded project was conducted aiming to quantify flood risk for the Rhine basin under altered environmental conditions. The project was accomplished by Potsdam-Institute for Climate Impact Research and Univ. of Potsdam, University of Stuttgart, Bundesanstalt für Gewässerkunde and RIZA and supported by the CHR

The main focus of the project was on two important questions:

- To what degree do changes of land-cover and river training influence the flood situation in the Rhine basin, and
- To what degree can flooding be mitigated by water retention measures both in the landscape and along the river courses?

Therefore the project on the one hand aimed at quantifying the impact of landscape hydrology and river network hydraulics on flooding conditions in the Rhine basin. In this context the retention capacity of the landscape with its geophysical properties and the river training conditions were of importance. On the other hand, the mitigation potential of specific measures like infiltration ponds, altered agricultural management practices, restoration measures in small tributaries and polders or flooding areas in larger rivers were investigated. The aim was to provide results which could serve as sound scientific figures about a possible increase in flood risk caused by land-use changes or a possible decrease in flood risk induced by specific measures like decentralised water retention or the flooding of polders.

The project required an interdisciplinary and multi-scale approach. This was achieved by combining models for different purposes at different spatial scales, allowing the comparison of the impacts of land-cover conditions and the effects of river training activities (including the retention capacity in rivers and flood plains) on the discharge conditions in the river Rhine. The models had either to be adjusted or expanded in order to fulfil the project requirements.

Special attention had to be paid to the coupling of catchment hydrology and flood wave propagation as well as to the linkage between the land-use scenarios and the structure and parameterisation of hydrological modelling. The simulations were carried out by process-oriented rainfall-runoff modelling at three different spatial scales covering the Rhine basin from Maxau (Southwest Germany) to Lobith (Dutch/German border), which is a total area of more than 110 000 km². The mentioned modifications were necessary at the following spatial scales and will be explained hereafter:

1. To include process knowledge at the lower meso-scale (3 small catchments covering an area of about 100 - 500 km²), which was considered to be relevant for land-use change modelling but was not represented in the original version of the chosen model. This refers in particular to the representation of macropore-effects on infiltration conditions and therefore on the possible generation of infiltration excess overland flow and to the representation of urban storm water processes, such as runoff on impervious areas, retention in sewage systems and possible transfer to sewage treatment facilities
2. To transfer process knowledge ("up-scaling") simulated at the lower meso-scale to the upper meso-scale (101 larger sub-catchments of the Rhine, ranging between 400 and 2,100 km², covering a total area of 110,000 km²) where, as a consequence of data scarcity and data management constraints, a rather conceptual modelling approach had to be chosen, see below.

To route the runoff from all the different sub-catchments of the Rhine catchment in the main river system. This includes possible retention effects within the river corridor and/or in flood polders along the channel system of the Rhine and its main tributaries. This is primarily a matter of hydrodynamic modelling.

The following paragraph presents the results achieved at the macro scale, which are based on a regionalisation for the lower and upper meso-scale. However, the small scale results are not presented her, but are given in the corresponding final report published by the CHR.

The LAHOR-study is an example of a multi-scale, process oriented coupling of different models in order to assess the impacts of land-use and river training measures on the runoff of a large catchment. For the first time it was possible to give quantitative estimates for the impacts of land-use change and river training measures on the flood conditions for the river Rhine.

Three different land-use scenarios in the catchment, focussing on urbanisation and/or urban storm water treatment, have been taken into consideration:

1. Scenario D1 is based on a rather realistic scenario of a further ca. 10% expansion of urban areas;
2. Scenario D2 includes the increase of urban area of scenario D1 and, additionally, a planned project for controlled infiltration of urban storm runoff in 2500 km² urban areas, as recommended in the flood action plan of the International Rhine Commission in 1998, and
3. Scenario D3 representing an "extreme scenario" of a 50% increase of urban areas.

All scenarios D1, D2, and D3 also consider the effects of the planned or already constructed flood defence works along the Rhine between Maxau and Lobith. These modelled river training measures include flood polders along the Upper Rhine below Maxau (total volume 79.2 10^6 m³) and along the Lower Rhine (total volume 65.4 10^6 m³). However, the planned flood polders along the Upper Rhine upstream of Maxau (207.6 10^6 m³) have not been assessed in this study.

These three scenarios of land use and/or river training (river retention) measures were simulated driven by three different scenarios of meteorological forcing, one observed extreme and large-scale precipitation situation and two designed "extreme meteorological scenarios" in order to test the model system for even more severe meteorological conditions.

1. Scenario M95: Meteorological forcing (in its observed spatial and temporal distribution) of Jan/Feb 1995 which caused a flood in the Rhine with a return period > 100 years,
2. Scenario M95+: Meteorological forcing of Jan/Feb 95 plus an increase of precipitation of 20%,
3. Scenario M95++: Meteorological forcing of Jan/Feb 1995 plus a linear increase of precipitation of 20% plus an additional pre-event snow water equivalent of 20mm over the whole catchment

Table 1: Modelled changes in water level [cm] at five main gauging stations of the Rhine, due to scenarios of land-use change and river training (river retention) measures, for three different meteorological scenarios. Explanations for land-use and climate scenarios are given in the text

Rhine gauging station (km down Lake Constance)	Meteorological Scenario		
	M95	M95+	M95++
Worms (km 444)			
D1	0 (0/0)	10 (0/10)	16 (0/16)
D2	0 (1/0)	9 (0/10)	16 (-1/17)
D3	0 (-1/1)	-10 (-1/-9)	15 (-1/16)
Kaub (km 546)			
D1	1 (-1/2)	8 (-1/9)	9 (-2/11)
D2	1 /-1/2)	8 (-1/9)	9 (-1/11)
D3	-5 (-7/3)	3 (-6/8)	3 (-9/11)
Andernach (km 614)			
D1	0 (-1/1)	5 (-1/6)	6 (-1/8)
D2	1 (0/1)	6 (-1/6)	7 (-1/8)
D3	-5 (-7/2)	1 (-5/6)	2 (-6/8)
Köln (km 688)			
D1	0 (-2/1)	5 (-1/6)	4 (-2/6)
D2	1 (0/1)	5 (-1/6)	5 (-1/6)
D3	-8 (-9/2)	-1 (-7/6)	-3 (-9/7)
Lobith (km 857)			
D1	2 (-1/3)	2 (-1/3)	2 (-1/3)
D2	2 (-1/3)	3 (-1/3)	2 (-1/3)
D3	-1 (-5/3)	-2 (-6/3)	-5 (-8/3)

In Tab 1 a summary of the model results is presented by listing the combined effects of land-use and meteorological scenarios. The modelled differences in water levels (in cm) at five main gauging stations of the Rhine are given. The non-parenthetic values are due to the combined effects of land-use change (increase of urban areas) and river training (increase of flood-discharge retention in river polders). The values in parenthesis are due to land use change only (1st value) and due to river training only (2nd value). Positive numbers imply a decrease in water level, negative ones imply an increase.

From the differences in water levels listed in Table 1 one can draw several conclusions:

- The increase of flood peak level due to a further moderate (realistic) increase of urbanised areas (D1) is very small (water level increase 2cm of less) and therefore almost negligible.
- The influence of the proposed management of urban storm water results in a very limited mitigation of flood peaks (water level decrease 2cm or less) and therefore is almost negligible, too.
- The effects of water retention in flood polders (between Maxau and Lobith) have a stronger but still small effect (water level decrease of 3cm of less for the M95 scenario, up to 10cm for the M95+, and up to 17

cm for M95++). It is important to understand that consideration of the possible retention polders upstream of Maxau would yield an additional reduction in the range of 10 cm, in particular for the Upper Rhine area.

- The unrealistic, extreme land-use scenario (50% increase of urban areas) would result in a water level increase not much more than 10cm.
- The M95+ and even more the M95++ scenario results in higher reduction of flood levels in the case where the flood polders are active. This is due to the fact that according to the operation rules, the flood polders are to be filled only if flood discharge exceeds the 200-year value. In January/February 1995 (M95) the flood discharge along most stretches of the Rhine was above the 100-year value, but below 200 years. That is why the polders were used only at a few stretches resulting in small water level reduction only.

Some more general results from the whole study are summarised in the following:

(1) At the lower meso-scale level the influence of land-use on storm-runoff generation is stronger for convective storm events with high precipitation intensities than for long advective storm events with low precipitation intensities, because only storm events associated with high rainfall intensities are at least partially controlled by the conditions of the land-cover and/or the soil-surface. Convective storm events, however, are of minor relevance for the formation of floods in the large river basins of Central Europe because the extent of convective storms is usually local.

(2) An estimated, rather dramatic, further increase of urban areas of about 50% may result in an increase of medium-size flood peak discharge (e.g. return intervals between 2 and 8 years) in catchments of the lower meso-scale (up to ca. 1000 km^2):

— Between 0% and 4% for advective rainfall events, and

— up to 30% for convective rain storms.

(3) The flood impacts due to a more realistic representation of urbanisation increase are in the order of 1 to 5 cm in the main channel, while the effects are even less for extreme rainfall amounts.

(4) The decentralised storage, detention, and infiltration of urban storm water yields reduction of flood peaks in catchments of the lower meso-scale which are about the same size as the increase due to urbanisation.

(5) The superposition of flood waves originating in different sub-basins shows that the maximum effect of water retention in the landscape generally occurs in the rising limb of the flood wave in the main channel. The flood mitigation effect at the peak is considerably smaller.

(6) Water retention measures in polders along the Upper and Lower Rhine, under the given boundary conditions, yield flood peak attenuation along the Rhine all the way down to Lobith of between 1 cm and 15cm. The optimised and co-ordinated control of the polders can result in a considerable stronger decrease of the peaks.

Final report:

Bronstert, A., Bárdossy, A:, Bismuth, C., Buiteveld, H., Busch, N., Disse, M., Engel, H., Fritsch, U., Hundecha, Y., Lammersen, R., Niehoff, D., Ritter, N., (2003): Quantifizierung des Einflusses der Landoberfläche und der Ausbaumaßnahmen am Gewässer auf die Hochwasserbedingungen im Rheingebiet. Reports of the CHR, Series II, No. 18, 78pp.

Hydra-Models, a way to assess the influence of climate change and river programs on future dike heights and the probability of dike failure.

Robert Slomp
Institute for Inland Water Management and Waste Water Treatment (RIZA)
P.O. Box 17, NL 8200 AA Lelystad, the Netherlands
r.slomp@riza.rws.minvenw.nl

The use of Hydra-models is mandatory in the Netherlands for verifying the minimum safety levels of primary flood defences in the deltas of the Rhine and Meuse and in the IJssel lake area. Hydra-models can also be used in policy studies, the outcome of large river projects can be evaluated in combination with climate change. This paper will cover the possibility to assess the combined influence of climate change and river programs on future dike heights and the chance of dike failure. In this way a robust strategy can be determined. Realistic examples of climate change and project proposals can be combined.

Flood defences have been built to accommodate for the two major threats, high discharges and storm. Storms generate storm surges and waves but also impede drainage, so combinations of high water levels and waves threaten dikes. The largest estuaries have been closed off with storm surge barriers. However the locally built up storm surges to the land side of the storm surge barriers in combination with the impeded drainage remain a threat. In the IJssel lake area, at the mouth of the IJssel these storm surges amount up to 2 m and in the lower reaches of the Rhine and Meuse up to 50 cm. Impeded drainage to the sea, because of storm surges, adds between 1 m to 2,5 m to the water levels at design conditions, especially in the closed off estuaries Haringvliet and Hollandsch Diep. At the moment two large river projects are being prepared Room for the River (Ruimte voor de Rivier) and the Meuse works, (de Maaswerken), these projects will be finished in 2015. A number of studies on the impact of climate change on design water levels have been published. But up till now no studies combine both issues, the influence these large projects and climate change, on necessary dike heights in a detailed and precise manner for all stretches of the Rhine and Meuse rivers.

The main purpose of the Room for the River project is to accommodate for the difference in official design water levels caused by the high river discharges of 1993 and 1995. The Room for the River project mainly lowers design water levels on the Rhine Branches and lower Meuse (from Meuse km 201 to km 250) where the design water levels are primarily caused by high discharges. The project consists of increasing the discharge capacity of the river by enlarging the cross section. In the short term dikes will be laid back, side channels dug, river groins lowered. In some areas dike reinforcement will be inevitable, especially where the river is no longer the predominant threat but combinations of storm and river discharges are. On account of climate change large scale measures are being considered as measures for the long term e.g. flood retention reservoirs and bypasses through existing polders.

The Meuse works mainly improve the safety for people living in the Meuse flood plain, by lowering the design water levels, by raising the existing levees and by the construction of a number of flood retention reservoirs. The return period for the levees, built in 1995-2000, will be raised from 50 years to 250 years. In fact the river cross section has been diminished for most discharges, except for the design discharge of the Meuse, which has a return period of 1250 years. The Meuse Works have to compensate for these negative effects, no rise in design water levels downstream of the project area is permitted, from km 150 to 250.

The Hydra-models calculate

- The exceedence frequency of a fixed level of the hydraulic load. This fixed level can be the design water level or the dike height of a dike section or enclosed combination of dike sections, called a dike ring.
- The design water level or design height of a dike can also be determined for an exceedence frequency or return period.
- The wave overtopping rate for a given dike height and return period.

The Hydra-models make it possible to evaluate a certain project proposal in detail in a situation with and without climate change. Up till now the possibility to assess the combined influence of climate change and river programs on future dike heights and the chance of dike failure is only possible on the Rhine branches and the

Meuse. The areas where these calculations are currently possible are also more than 90% of the actual project area of Room for the River and all of the project area for the Meuse Works. In the delta's it is only possible to evaluate the influence of climate change on dike heights in the 2001 situation and to evaluate the influence of climate change and the project proposal on design water levels in the situation in 2015. New water level data for the situation after completion of the project proposal for the Room for the River project have to be generated first. There is no technical problem, to carry this out.

Examples of climate change are shown individually: sea level rise, a change in the design discharge and changes in wind speeds at design conditions. For the Rhine Branches and Meuse, the situation of design water levels and the probability of dike failure for a number of dike rings in 2001 will be shown as a reference. Then for the Rhine Branches the influence of a slight change in the design discharge, wind speeds at design conditions is illustrated together with the effects of the Room for Rivers program. Differences of design water levels and the probability of dike failure are shown for a number of scenario's.

The 2001 situation will be compared to the situation in 2015 after completion of the Room for the River project, with and without climate change on the Rhine Branches. On the Meuse the 2001 situation will be compared to the situation in 2015 after completion of the Meuse Works and Room for the River project, with and without climate change. In the Meuse Works two retention reservoir areas are part of the project proposal. The effect of the retention area, Lob van Gennep will also be evaluated separately.

There are more than 25 dike rings in the project area for the Room for the River project and 40 for the Meuse Works project. Information to evaluate dike sections has been generated every 100 meters, so in total there are more than 10 000 dike sections. For the situation in 2001 and the situation in 2015 all dike sections will evaluated. To demonstrate the influence of climate change a selection shall be made, to illustrate that the Hydra-models really work. So elaborate results for only two dike rings shall be shown per project.

Conclusions, which can be drawn at the moment on the basis of current calculations:

After completion of the Room for the River project in 2015 10 % of dikes still have to be reinforced to meet the minimum safety levels. If climate change is taken into account a lot more has to be done in the near future especially if no flooding occurs along the Rhine in Germany.

For the Meuse one can conclude that on the basis of the current project proposal, one of the project objectives, no rise in design water levels in the downstream areas will not be met. Additional measures in the Meuse Works project will have to be taken.

Posters presented at the workshop

Die mögliche Verschärfung des Hochwasser-Regimes des Rheins unter globaler Erwärmung

Gerd Bürger
Freie Universität Berlin, Institut für Meteorologie
Carl-Heinrich-Becker-Weg 6-10, D 12 165 Berlin, Germany
gerd.buerger@mail.met.fu-berlin.de

Axel Bronstert
Universität Potsdam, Lehrstuhl für Hydrologie und Klimatologie
Postfach 601533, D-14415 Potsdam, Germany
axelbron@rz-uni-potsdam.de

Das Einzugsgebiet des Rheins ist geprägt von alpinen Verhältnissen im Oberlauf, über Mittelgebirgsformationen im französischen und oberen deutschen Teil bis hin zu Flachlandformationen im niederländischen und unteren deutschen Teil. Die Charakteristika der Genese der großen Hochwasser am Rhein sind bestimmt durch Schneeakkumulation im Winter bzw. Schmelzwasserbildung im Frühsommer aus dem alpinen Raum und kombinierten Schneeschmelz- und Regenabfluss aus dem Mittelgebirgsraum im Winter und Frühjahr sowie durch Abfluss infolge von Regenfällen aus diesen und den übrigen Gebieten.

Ein solch komplexes hydrologisches Regime macht eine Beurteilung möglicher Klimafolgen für den Rhein, insbesondere für die Abschätzung von Hochwasserrisiken, besonders anspruchsvoll, denn sie verlangt die saisonal und räumlich adäquate Darstellung der Wirkungen von Temperatur- und Niederschlagsänderungen auf die Bildung von Schnee, Schmelzwasser und Abfluss. „Adäquat“ bezieht sich hierbei auf die klimatisch variierende Statistik der zeitlichen und räumlichen Verläufe dieser Größen, einschließlich ihrer charakteristischen Verzögerungen durch Schneeakkumulation und -schmelze sowie ihres Extremverhaltens. Insbesondere ist die Frage dringlich, ob es sich erhärten lässt, dass die bisher getrennten Phänomene der Frühjahrshochwasser (aus den tieferen Lagen der Alpen und aus den Mittelgebirgen) einerseits und der frühsommerlichen alpinen Taufluten andererseits sich vereinen und überlagern bzw. verstärken können. Die erhöhte Gefährdung durch Überschwemmungen am Ober-, Mittel- und Niederrhein von bisher nicht gekanntem Ausmaß wäre eine mögliche oder sogar wahrscheinliche Folge. In der Tat lässt sich ein entsprechender Effekt bereits heute an historischen Zeitreihen nachweisen: Relativ zu einer Klimatologie 1927-1956 weist die heutige (1967-1996) Ganglinie am Pegel Maxau (welcher noch als repräsentativ für den alpinen Bereich gelten kann) eine Verfrühung des frühsommerlichen Maximums von etwa einem Monat auf; für extreme Abläufe (95%-Quantil) liegt diese Verschiebung schon bei fast 2 Monaten! Zudem projizieren praktisch alle Szenarien der Klimaänderung für das Rheingebiet eine Intensivierung der Frühjahrshochwasser (aus den Mittelgebirgen) durch erhöhte Niederschläge.

Dieser Beitrag zeigt Ergebnisse aus Vorarbeiten zu dieser Problematik. Mithilfe ausgefeilter klimatologischer und hydrologischer Modelle soll die gesamte Wirkungskette, ausgehend von transienten globalen Klimaverläufen, deren Übersetzung in realistische lokale Wetterprozesse, über die hydrologische Wirkung als Zufluss zum Rhein und seinen Nebenflüssen bis hin zum Wellenablauf im Rhein abgebildet werden. Die naturgemäß große Unsicherheit möglicher Schlussfolgerungen solcher Simulationen soll durch die Durchführung zahlreicher, klimatisch ähnlich oder auch verschieden angetriebener Experimente aufgefangen und durch eine fundierte Signifikanzanalyse quantifiziert werden. Dies ergibt eine belastbare Abschätzung für die Möglichkeit eines Aufeinandertreffens der beiden oben genannten hydrologischen Regime des Rheins.

Die Identifikation von hochwasserrelevanten Flächen als Grundlage für die Beurteilung von extremen Abflüssen

Norbert Demuth
Landesamt für Umwelt Wasserwirtschaft und Gewerbeaufsicht Rheinland-Pfalz,
Amtsgerichtsplatz 1, D- 55276 Oppenheim, Deutschland
norbert.demuth@luwg.rlp.de

Simon Scherrer
Scherrer AG, Hydrologie und Hochwasserschutz
Stockackerstrasse 25, CH-4153 Reinach, Schweiz
scherrer@scherrer-hydrol.ch

Nach extremen Hochwasserereignissen kommt oft die Diskussion auf, wie diese Hochwasser entstanden sind und von welchen Flächen im Einzugsgebiet besonders viel Abfluss stammte. Diese Frage stellt sich in einer etwas anderen Form auch bei der hydrologischen Modellierung und bei der Ermittlung von Hochwasserabflüssen für die Bemessung von Schutzmaßnahmen. Die scheinbar einfachen Fragen, wie viel Wasser infiltriert, wie viel Wasser hält der Boden zurück und wie viel Wasser fließt sofort ab, sind dabei entscheidend. Nach wie vor ist die Voraussage, wie viel Abfluss auf Einzugsgebietsflächen im Starkregenfall entsteht, schwierig. Der im Auftrag der Wasserwirtschaftsverwaltung Rheinland-Pfalz entwickelte „Bestimmungsschlüssel zur Identifikation von hochwasserrelevanten Flächen“ soll mithelfen, Flächen unterschiedlicher Abflussbereitschaft mit geeigneten Geländeuntersuchungen zu erkennen. Der Schlüssel legt bei der Beurteilung großes Gewicht auf den Aufbau und die Beschaffenheit der Böden im Einzugsgebiet. Dieser Bestimmungsschlüssel soll einen Beitrag zur Versachlichung der Diskussion über Hochwasserentstehung leisten und die Grundlagen für die hydrologische Modellierung und damit auch für die Bemessung von Hochwasserschutzmaßnahmen verbessern.

Floods in Europe - Loss experience of the last 25 years

Tobias Ellenrieder
Munich Reinsurance Company
Königinstrasse 107, D-80791 München, Germany
tellenrieder@munichre.com

Munich Re´s Geo Risks Research has been collecting information on losses from natural disasters since the early seventies and built up the world's largest data base of the kind: MRNatCatService. Statistical analyses drawn form these data show that economic and insured losses resulting from natural catastrophes have increased dramatically in Central Europe as well as worldwide during the last decades. At the same time, a significant increase in extreme hydrological events has been observed.

The poster presents an analysis of the temporal development of flood events and flood losses on (a) a global and (b) a regional scale (Central Europe) for the last 25 years. In this context, a flood event is defined as an inundation (by river flood and flash flood) affecting either economic values or human lives. With respect to the lower quality of loss information in the past, only flood events with a loss amount higher than 1 Mill. US$ were consulted.

There is an increase in both the number of flood events and annual economic losses in Central Europe. The same can be observed on a global scale. However, the European statistics are clearly dominated by the August 2002 event in Germany, Austria and the Czech Republic.

Losses resulting from flood events are caused by various factors. Fast flowing water can damage buildings and other structures (such as infrastructure), often in combination with the impact of transported sediments. Standing water deteriorates goods by soaking furniture, electrical appliances and buildings, often coming along with mould formation.

Compared to other natural perils like windstorm, earthquake etc., about one third of the economic losses in Central Europe are caused by floods. However, the insured damages make up only 20% of the total insured losses which is due to the smaller insurance penetration in the countries investigated.

Figure 1: Flood losses and flood events in Europe and globally

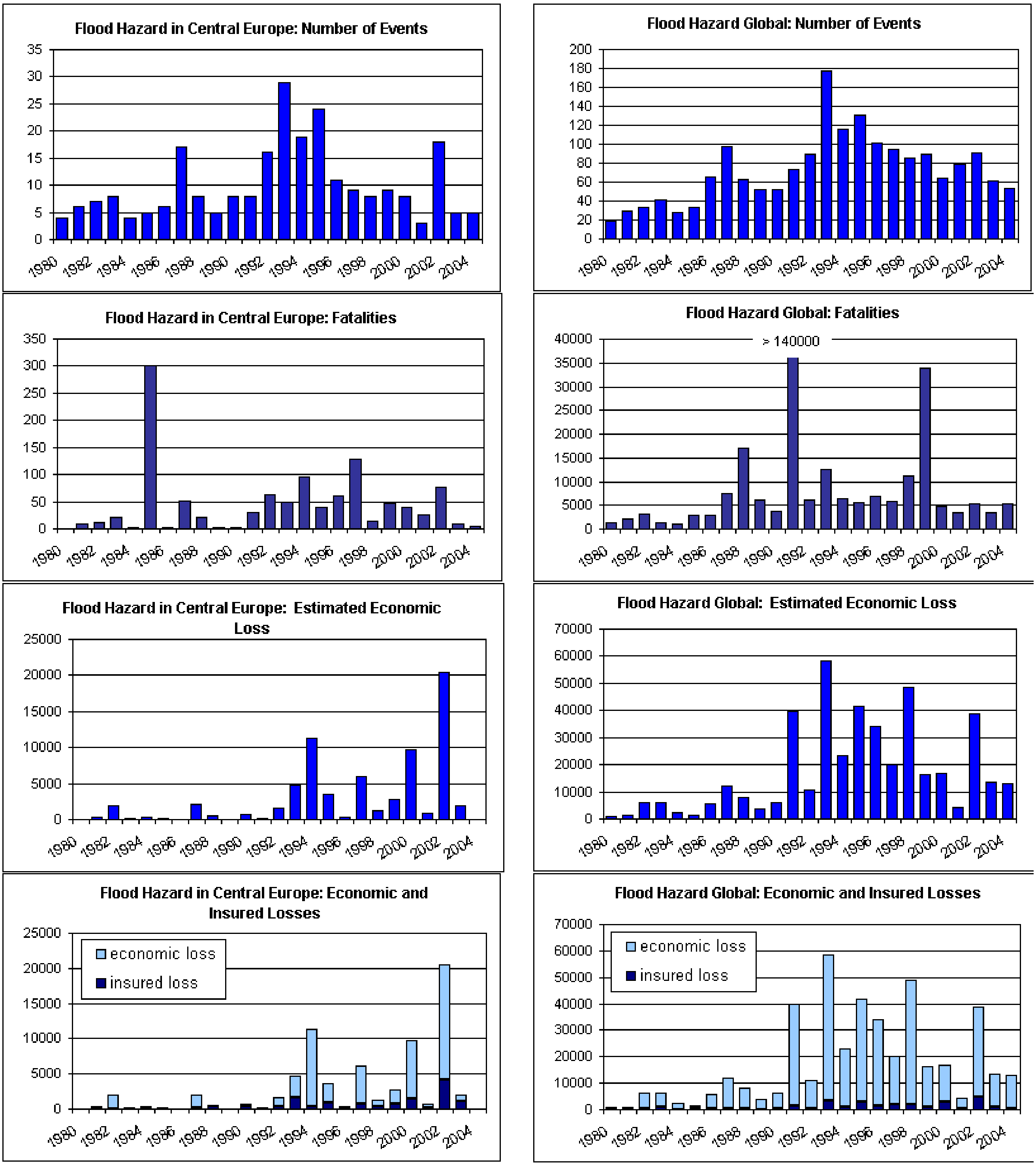
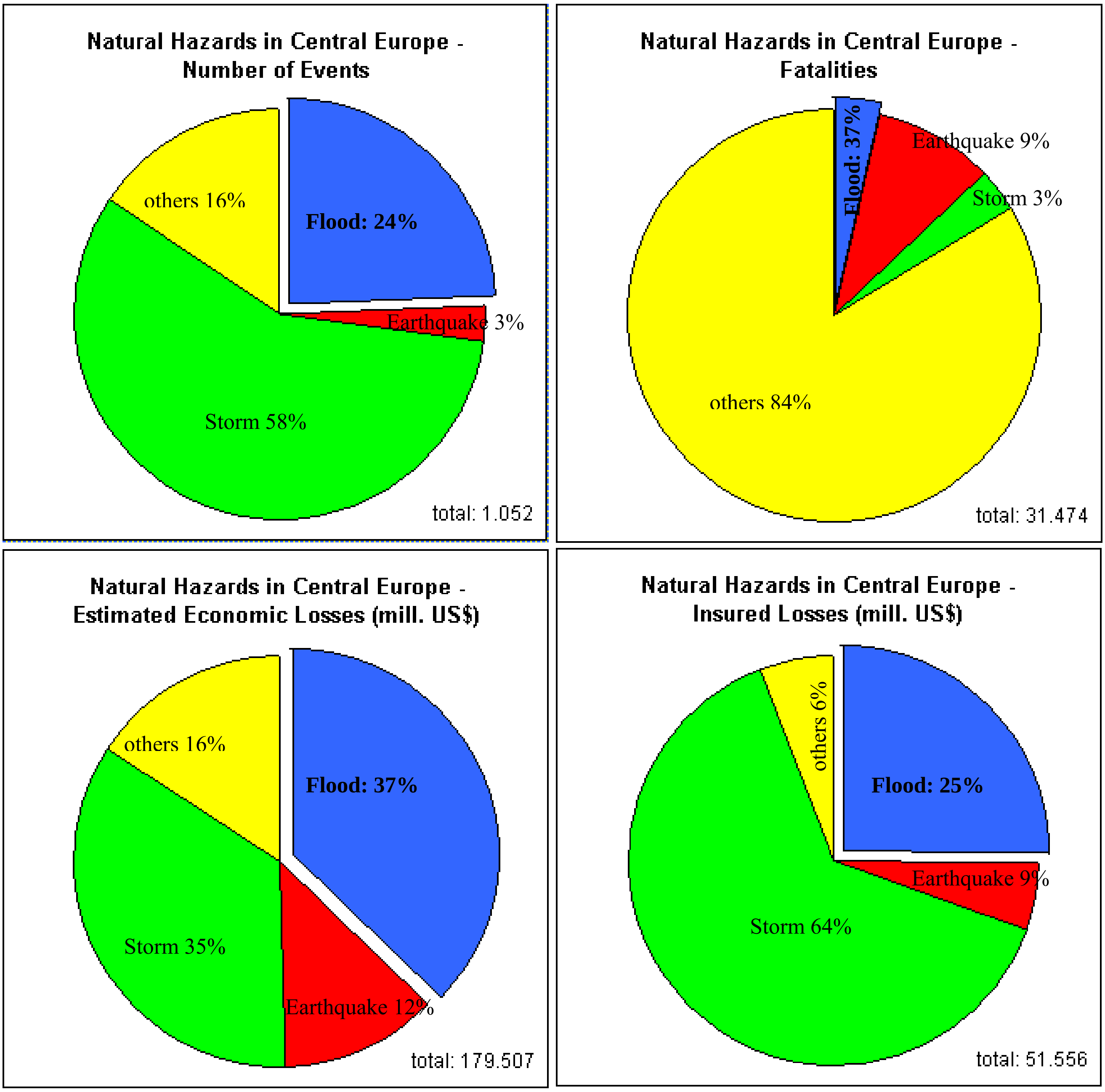


Figure 2: Proportions of numbers and impacts of different natural perils for Central Europe 1980-2004



Probabilistische Abflussvorhersage für das Einzugsgebiet des Rheins bis Rheinfelden

M. Verbunt[1], J. Gurtz[1], A. Walser[2] and C. Schär[1]

[1] Institute for Atmospheric and Climate Science, Swiss Federal Institute of Technology (ETH) Zurich
Winterthurerstr.190, CH-8057 Zürich, Switzerland
[2] MeteoSwiss, Zurich, Switzerland
Krähbülstrasse 58, CH-8044 Zürich, Switzerland
joachim.gurtz@env.ethz.ch

Ein hoch aufgelöstes Ensemble-Wetttervorhersagesystem, basierend auf 51 Läufe des Lokal Models (LM) ist für eine probabilistische Abflussvorhersage im Rhein-Einzugsgebiet bis Rheinfelden (34'500 km^2) benutzt worden. Dies, um die Unsicherheiten in Vorhersagedaten zu berücksichtigen. Das LM hat eine räumliche Auflösung von 10 km x 10 km und liefert stündliche Vorhersagen. Die Ergebnisse dieses Models werden benutzt, um das räumlich differenzierte hydrologische Einzugsgebietsmodel PREVAH (Precipitation-Runoff-Evapotranspiration Hydrotope based Model) in einer Auflösung von 500 m x 500 m anzutreiben.

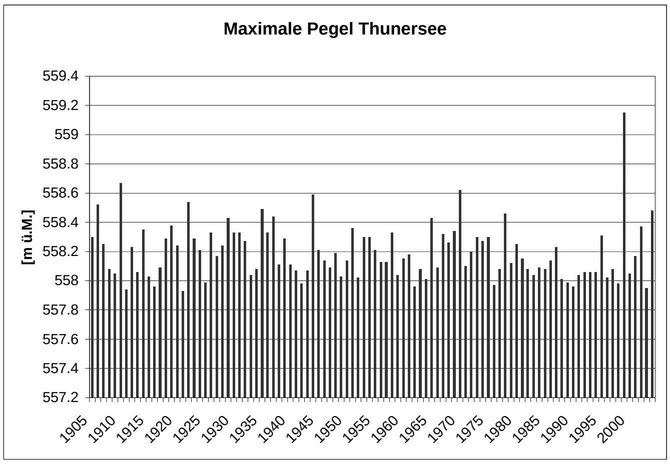
Für die Kalibrierung wurde das Einzugsgebiet in 23 Teileinzugsgebiete unterteilt. Der Kalibrierungszeitraum enthält die Jahre 1997 und 1998, während das Modell im Zeitraum von 1999 bis 2002 validiert wurde. Einige der Modellparameter wurden für jedes dieser Gebiete mit Hilfe eines halbautomatischen Kalibrierungsverfahrens bestimmt. Dabei wurden vor allem die Wasserbilanz und das Bestimmtheitsmass R^2 berücksichtigt. Die Resultate zeigen, dass das Modell recht gut in der Lage ist, die hydrologischen Prozesse in diesen Gebieten zu simulieren. Die lineare Güte beträgt beim Ausflusspegel Rheinfelden bezogen auf R^2 während des Kalibrierungszeitraums 0.95 und für die Validierungsperiode 0.91. Damit steht das Einzugsgebietsmodellsystem PREVAH für eine kontinuierliche Abfluss- und Wasserhaushaltsberechnung (einschliesslich Hoch- und Niedrigwasser) für das Rhein-Einzugsgebiet bis Rheinfelden und seine 23 Teileinzugsgebiete räumlich und zeitlich (1 Stunde) hochaufgelöst zur Verfügung.

Die untersuchten Fallbeispiele sind das Mai-Hochwasser 1999 im gesamten Rheingebiet und das November-Hochwasser 2002 im Gebiet des Alpenrheins. Diese Studie fokussiert auf die Nutzbarkeit von Ensemble-Vorhersagen als Grundlage für die Abflussvorhersage und behandelt die Vorhersagbarkeit von diesen Hochwasserereignissen. Unsicherheiten in den Vorhersagen wurden untersucht und Abflussprognosen von deterministischen Vorhersagen verglichen mit denen von probabilistischen Vorhersagen. Die Ergebnisse zeigen, dass in beiden Fällen die deterministischen Vorhersagen erhebliche Fehler beinhalten, dass aber das gekoppelte hydrologische LEPS-System Vorhersagen mit angemessenen Unsicherheitsintervallen und realistischen Andeutungen von extremen Hochwassern liefert. Eine Wahrscheinlichkeitsangabe zu den vorhergesagten Hochwasserscheitelwerten mit Hilfe von Ensembles wäre dann auch eine nützliche Alternative für die deterministische Abflussvorhersage. Bei der operationellen Hochwasservorhersage ist die Anwendung mit 51 Läufen kaum möglich wegen den hohen Rechenzeiten. Deshalb wurde die Möglichkeit untersucht, anstatt alle 51 Mitglieder nur 5 oder 10 repräsentative Mitglieder (RM) zu verwenden. Die Resultate zeigen, dass die Spannweite der Vorhersage nicht kleiner wird, wenn nur 5 oder 10 Mitglieder benutzt werden im Vergleich zu dem ganzen Ensemble. Die 5 oder 10 RMs-Ensembles liefern auch eine grössere Spannweite als 5 oder 10 willkürlich ausgewählte Mitglieder.

Einordnung von Extremhochwassern

Peter Schmoker
Berner Fachhochschule, bhc Projektplanung
Mühlematteweg 7, CH-3752 Wimmis, Switzerland
peter.schmoker@bhc.projektplanung.ch

Im Mai 1999 hat der Thuner See einen historischen Höchststand von 559.17 m ü.M. erreicht. Dies hat einerseits zu erheblichen Überflutungsschäden rund um den See geführt, andrerseits hat die Aare als Abfluss aus dem Thuner See ein Hochwasser verzeichnet, das zu bedeutenden Überschwemmungen zwischen Thun und Bern geführt hat (HQ Aare Bern Schönau: 620 m^3/s).

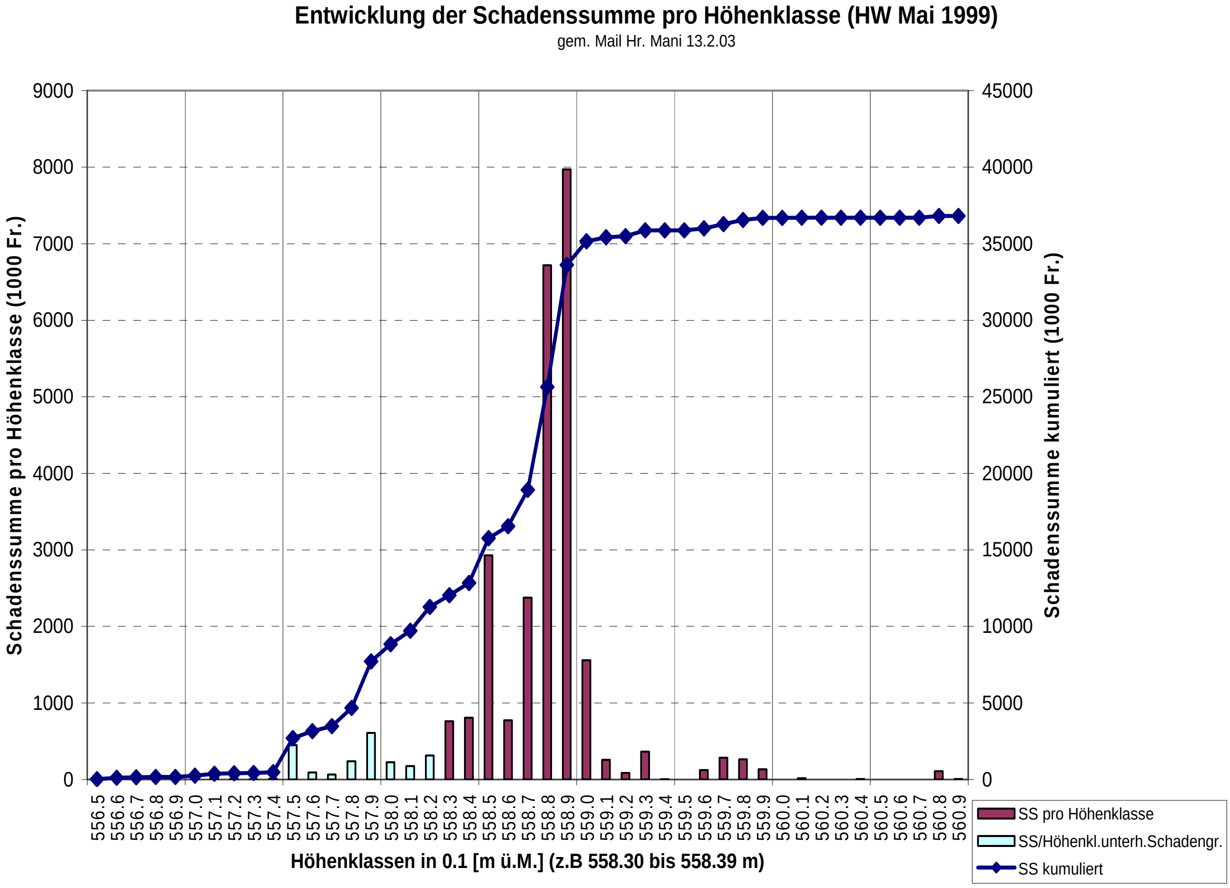


Eine statistische Einordnung des Ereignisses ist schwierig. Streng genommen sind die Voraussetzungen für die Anwendung der Extremwertstatistik nicht erfüllt. Durch die Seeregulierung sind sowohl der Wasserstand des Sees als auch die Abflüsse der Aare in Thun und Bern beeinflusst. Die verschiedenen Verfahren zur Berechnung der Auftretenswahrscheinlichkeit liefern für die Aare in Bern jedoch ein erstaunlich einheitliches Bild. Das Ereignis in Bern ist aufgrund dieser Auswertung als rund 500-jährliches Ereignis zu bezeichnen. Das Vertrauensintervall (90%-Signifikanzniveau) ist aber gross: es beträgt rund 200-1000 Jahre. Die Auswertung des Thuner Sees zum Vergleich liefert ein ähnliches Bild: Das Ereignis von 1999 (559.17 m ü. M.) weist eine Jährlichkeit von etwa 450 Jahren auf. Das 90%-Konfidenzintervall beträgt in diesem Fall 100-1000 Jahre und ist somit noch grösser als jenes von Bern.

Die prozessbezogene Betrachtung zeigt, dass im Frühling 1999 die mittelfristige und die kurzfristige Disposition zwar hoch, aber nicht ausserordentlich waren. Wasseräquivalentswerte wie Mitte April 1999 gemessen, wurden in den letzten gut 30 Jahren fünf Mal erreicht. Die Niederschlagssummen im April lagen ebenfalls im normalen Bereich. Die starke und ununterbrochene Schneeschmelze in der zweiten Aprilhälfte und anfangs Mai liessen den See vom langjährigen Tiefststand (557.53 m ü.M.) bis auf eine Kote von 558.1 m ü.M. ansteigen. Ähnlich intensive Schneeschmelzperioden gab es aber auch 1982 und 1970. Niederschläge und Schneeschmelze liessen den Seespiegel zwischen dem 11. und 15. Mai um 105 cm ansteigen. Dies ist der höchste bisher registrierte Seespiegelanstieg in 4 Tagen. In der Aare und der Kander wurden die höchsten Abflüsse seit Messbeginn registriert, dies obwohl die Wiederkehrperiode des 5-Tages-Gebietsniederschlags mit 5 Jahren niedrig war. Diese Diskrepanz ist auf die hohe Abflussbereitschaft der Einzugsgebiete infolge der intensiven Schneeschmelze und der Niederschläge im April zurückzuführen. Entscheidend für das Ausmass des Ereignisses war demnach die "optimale" Abfolge der verschiedenen Prozesse.

Aus der Erkenntnis heraus, dass ein vollständiger Schutz gegenüber Hochwasser nicht möglich ist, hat sich die Philosophie der Differenzierung der Schutzziele entwickelt. Je nach dem zu erwartenden Schadenpotential werden für die zu schützenden Gebiete unterschiedliche Annahmen bezüglich Eintretenswahrscheinlichkeit eines Ereignisses getroffen. Dieses Vorgehen ist auch in Thun bei der Planung von Hochwasserschutzmassnahmen wegweisend gewesen. Allerdings bedarf dieses Vorgehen einer statistischen Aussage bezüglich Eintretenswahrscheinlichkeit eines Ereignisses. Wegen der grossen Unsicherheit bei der statistischen Einordnung ist zur Bestimmung des Schutzzieles ein anderer Ansatz verwendet worden. Während dem Hochwasser sind beim Kanton und bei den Krisenstäben der Gemeinden laufend Schadenmeldungen eingetroffen. Der Zeitpunkt des Eintreffens dieser Schadenmeldungen ist protokollarisch festgehalten worden. Zudem ist natürlich der Seepegel weiterhin laufend gemessen worden. Damit lässt sich der Schadensverlauf in Abhängigkeit des Seespiegels aufzeichnen.

Es ist unschwer zu erkennen, dass ab einem einem Pegelstand von 558.80 m ü.M. die Schäden sprunghaft zugenommen haben.



Unter Einbezug aller involvierten Eigentümer, Interessensverbände und Fachstellen ist das Schutzziel auf 558.80 m ü.M. festgelegt worden.
Dieses Schutzziel ist im weiteren Verlauf der Planung auch mittels eines 1200m langen Entlastungsstollens in Thun erreicht worden.

30.3.05 / Peter Mani (Geo7) / Peter Schmocker (BFH/bhc)

Some comments on the estimation of extreme floods

Annegret Thieken

Bruno Merz

Heiko Apel
Engineering Hydrology, GeoForschungsZentrum Potsdam
Telegrafenberg, D-14473 Potsdam, Germany
thieken@gfz-potsdam.de

The estimation of flood hazard is often based on an extreme value analysis of discharge data. Such estimations are, however, rather uncertain (e.g. Merz & Thieken, 2005). Fig. 1 shows that large uncertainty bounds result if various distribution functions are adapted to a series of annual maximum floods (from 1880 to 1999) at the Cologne gauge on the river Rhine. Therefore, the question arises how this uncertainty can be reduced. Two different approaches are followed up for the gauges Cologne and Rees on the river Rhine.

At the Cologne gauge historic flood events listed in Krahe (1997) were considered. Flood events of 1497, 1342 and 1374 with water levels (according to the current gauge level) of 11.50 m, 11.53 m, and 13.30 m, respectively, clearly exceed the largest observed flood events in the time period 1880 to 1999. Discharges were obtained using the current rating curve. Owing to the morphological and hydraulic changes in the river bed the calculated discharges are very uncertain.

The return periods of these events were estimated following the guidelines of DVWK (1999). The results are given in Table 1. Thus, the largest flood of 1374 can be classified as a 1000-year flood. Its magnitude is well estimated by the Generalised Logistic, the Gumbel or the Log-normal distribution in Fig. 1.

Furthermore, an upper bound was assessed using different methods: the classification of maximum floods of Francou & Rodier (1967), the estimation of floods with large return periods after Kleeberg & Schumann (2001) and an envelop curve of maximum observed floods using data of Stanescu (2002) and other sources. In addition, Lammersen (2004) assessed a maximum flood at the Cologne gauge by means of modelling techniques. The resulting values are summarised in Table 1. On the basis of these data some distribution functions shown in Fig. 1 can be ruled out, e.g. the Weibull distribution.

At the Rees gauge that is situated downstream of the Cologne gauge the probabilistic model of Apel et al. (2004, 2005) was applied. The model consists of a flood frequency analysis at the Cologne gauge, a generation of typical flood waves and discharges from the tributaries Ruhr and Lippe, a routing module as well as an estimation and simulation of possible levee breaches between the gauges Cologne and Rees.

In Fig. 2 the flood frequency analysis for the Rees gauge is contrasted to the results of the probabilistic model of Apel et al. (2004, 2005). Since levee breaches are included in the probabilistic model, it is capable of calculating an upper bound of the flood discharge. The upper bound of the probabilistic model is consistent with the results of Lammersen (2002). However, the data and modelling requirements of the probabilistic model are lower.

It is suggested that the results of flood frequency analyses should be complemented with simple estimation methods in order to reduce uncertainty. If more time and data are available a simple probabilistic model gives a good assessment of an upper bound of flood discharge.

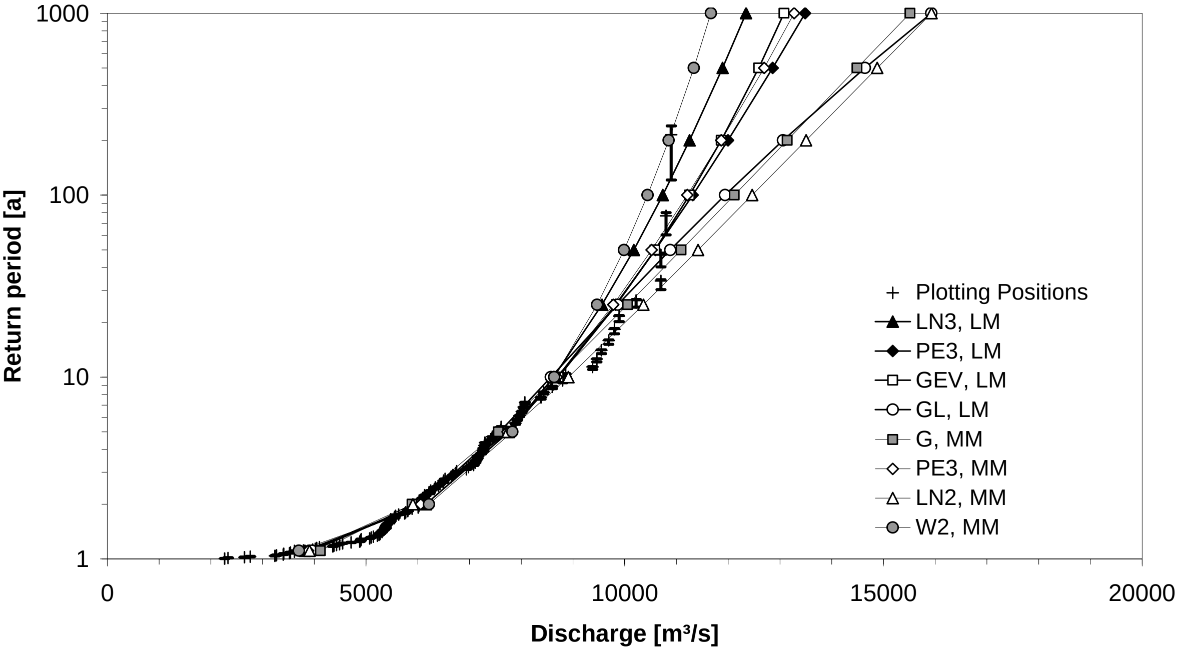


Fig. 1: Flood frequency analysis for the Cologne gauge with the annual maximum series from 1880 to 1999 and the following distribution functions: Lognormal with L-moments (LN3, LM), Pearson type III with L- moments (PE3, LM), General Extreme Value with L-moments (GEV, LM), Generalised Logistic with L-moments (GL, LM), Gumbel with method of moments (G, MM), Pearson type III with method of moments (PE3, MM), Log-normal with method of moments (LN2, MM), Weibull with method of moments (W2, MM) and six different plotting-position formulas (Weibull, Gringorden, Cunnane, Median, Blom and Hazen) given in Stedinger et al. (1992).

Table 1: Estimation of extreme floods at the Cologne gauge on the river Rhine.

Return period [a]	Discharge [m³/s]	Data/Method
226 – 270	12380	Historic flood of 1497; DVWK (1999)
339 – 451	12440	Historic flood of 1342; DVWK (1999)
677 – 1352	15680	Historic flood of 1374; DVWK (1999)
1000	15670	Guideline of Kleeberg & Schumann (2001)
2500	18100	Guideline of Kleeberg & Schumann (2001)
5000	19850	Guideline of Kleeberg & Schumann (2001)
10000	20380	Guideline of Kleeberg & Schumann (2001)
---	14240	Francou & Rodier (1967) with K = 3.5
---	17000	Envelope curve of data from Stanescu (2002)
---	15500	Modelling study of Lammersen et al. (2004)

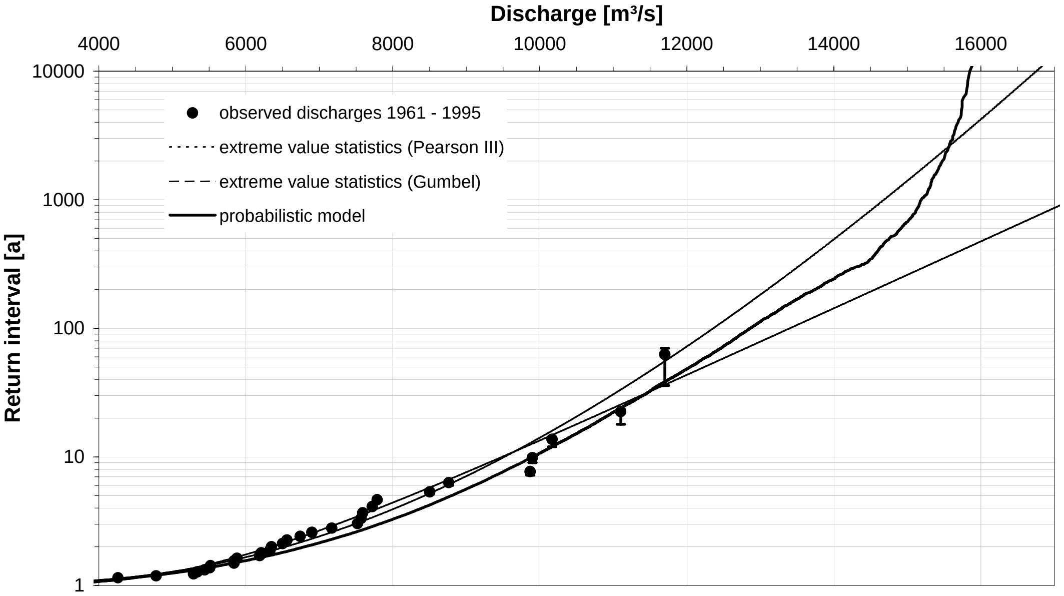


Fig. 2: Comparison of a flood frequency analysis for the Rees gauge and results of a probabilistic model of Apel et al. (2004, 2005).

References:

Apel, H., A.H. Thieken, B. Merz & G. Blöschl (2005): A probabilistic modelling system for assessing flood risks. - Natural Hazards (in press).

DVWK (1999): Statistische Analyse von Hochwasserabflüssen. Wirtschafts- und Verlags-Ges. Gas und Wasser, Bonn. 42 pp.

Francou, J. & J.A. Rodier (1967): Essai de classification des crues maximales. In: UNESCO (Ed.): Proceedings of the Leningrad Symposium on floods and their computation. 518 - 527 (in French).

Krahe, P. (1997): Hochwasser und Klimafluktuationen am Rhein seit dem Mittelalter. In: Immendorf, R. (Ed.): Hochwasser - Natur im Überfluß? Müller, Heidelberg, S. 57-82 (in German).

Kleeberg, H.-B. & A.H. Schumann. (2001): Derivation of design floods of low exceedance probabilities. - Wasserwirtschaft (in German)

Lammersen R. (2004): Grenzüberschreitende Auswirkungen von extremem Hochwasser am Niederrhein. Abschlussbericht 159 pp.

Merz, B. & A.H. Thieken (2005): Separating Aleatory and Epistemic Uncertainty in Flood Frequency Analysis. - Journal of Hydrology (doi:10.1016/j.jhydrol.2004.11.015, in press).

Stanescu, V.A. (2002): Outstanding floods in Europe: A regionalization and comparison. In: International Conference on Flood Estimation, Berne, Switzerland CHR-Report II-17,

Stedinger, J.R., R.M. Vogel & E. Foufoula-Georgiou, E. (1992): Frequency analysis of extreme events. In: Maidment, D.R., Handbook of Hydrology, McGraw-Hill, Inc., New York, pp. 18.1-18.66.

Mutlivariate statistical analysis of flood generation in the Meuse catchment

Paul Torfs
Wageningen University, Water Resources Department
Nieuwe Kanaal 11, NL 6709 PA Wageningen, the Netherlands
paul.torfs@wur.nl

Within the framework of a larger program, a hydrological model of the whole Meuse catchment was made by RIZA, the ministry responsible for the flood prediction and management in the Netherlands. This model is based build on the well known HSB model, and is semi-distributied. The KNMI, the meteorlogical institute of the Netherlands, has made by statistitical long artificial series of rainfall series as input for this model. A combination of both generates artificial but unusual long statitistical stationary series of discharges.

The research focused on the spatial analysis of these series for extremes.

Entropy was used as a method to analyse uniformity. Large extremes proved to be consistently uniform distributed, both in space and time.

Next a multivariate statisitical analysis of extremes was tried. Classical univariate analysis results in discharges and return periods for each of the subcatchments seperately. Bivariate analysis is more complicated, but results in insight in the statistical dependency of these extremes. Nearby catchments proved to be significantly stronger dependend than combinations of catchents further seperated.

Risk management of extreme flood events -a national research program funded by the German Federal Ministry of Education and Research-

Bruno Merz

Birgit Zillgens
GeoForschungsZentrum Potsdam, Section Engineering Hydrology
Telegrafenberg, D-14473 Potsdam, Germany
bmerz@gfz-potsdam.de
zillgens@gfz-potsdam.de

In January 2005 the national research program ‘Risk management of extreme flood events’, funded by the German Federal Ministry of Education and Research, has started. The program was initiated as consequence of the floods in August 2002 when intensive and lasting rainfall hit Germany, Austria, the Czech Republic and Slovakia in the catchments of the river Elbe and the river Danube. In Germany, 21 people were killed and substantial parts of the infrastructure were destroyed. The total loss in Germany is estimated to be 11.9 billion €.

The damage due to the August 2002 flood by far exceeds the damage caused by other natural disasters in Germany during the last decades. These floods have dramatically called attention to limits and deficits of flood risk management in Germany. The aim of the research program is to develop and implement improved instruments of flood risk management by the integration of different disciplines and stakeholders. It focuses on flood events with a return period greater than 100 years and with high damage potential. The program consists of three major subjects: (1) integrated concepts of flood risk management, (2) technical flood defense and (3) cross-sectional tasks. The cross-sectional tasks should warrant the knowledge transfer in practice and education as well as the national and Europe-wide networking of research activities. The research program stresses on implementation, which means, that the funded projects have to collaborate with responsible organizations at different political levels. The poster presents the concept of the research program.