PROCEEDINGS

POSTER PRESENTATIONS

ALLTOPICS

PAPERS:
COLLECTED AND ARRANGED BY JUDITH DOBMANN AND SIMONE HUNZIKER.
PLEASE NOTE THAT AUTHORS ARE RESPONSIBLE FOR CONSISTENCY IN SPELLING.

ESTIMATING EXTREME FLOODS USING VARIOUS LIKELIHOOD MEASURES WITHIN THE GLUE UNCERTAINTY FRAMEWORK

Sarka Blazkova[1], Keith Beven[2]

[1] T.G. Masaryk Water Research Institute, Podbabska 30, 160 62 Prague 6, Czech Republic,
sarka_blazkova@vuv.cz

[2] Institute of Environmental and Natural Sciences, Lancaster University, Lancaster LA1 4YQ, UK,
K.Beven@Lancaster.ac.uk

SUMMARY

The GLUE methodology (Generalized Likelihood Uncertainty Estimation) has been applied for the modelling of flood generation and the estimation of flood frequency on the basis of continuous simulation, using various likelihood measures and their combinations. Examples from the Czech Republic of large catchments Zelivka (1187 km^2) and Skalka (672 km^2) are given as well as of a small heavily instrumented catchment Uhlirska (2 km^2) and a small ungauged catchment Ryzmburk (3 km^2).

Keywords: floods, GLUE, continuous simulation, uncertainty, TOPMODEL, prediction bounds

1 INTRODUCTION

GLUE (Generalized Likelihood Uncertainty Estimation, e.g. Beven and Freer, 2001) is based on the equifinality of models or sets of model parameters. Parameters are sampled by Monte Carlo procedures from physically reasonable ranges and the model is run with realisations generated from each set of parameters. The resulting models are weighted by likelihoods computed as some goodness of fit criterion of the simulations using measured hydrographs, regional frequency curve, flow duration curve, frequency of snow water equivalents (e.g Blazkova et al., 2002), etc.

2 CONTINUOUS SIMULATION FOR ESTIMATING FLOOD FREQUENCY

Continuous simulation for flood frequency estimation using TOPMODEL is discussed in Beven (1987), Blazkova and Beven (1997), and Cameron et al. (1999, 2000). A simple stochastic rainfall model has been employed to provide an input into the rainfall runoff model TOPMODEL. The results have been compared to observed flood frequency curves. Cameron et al. (1999) used observed hydrographs for conditioning the frequency curves. In this contribution we have used the frequency TOPMODEL containing also snow accumulation and melt and the movement of precipitation event over the catchment.

3 EXAMPLE APPLICATIONS

The catchment of the Skalka reservoir on the Ohre River has been subdivided into 3 subcatchments. A larger part of the catchment is in Germany: Eger (300 km^2), Roslau (317 km^2). The third subcatchment in the Czech Republic has the area 55 km^2. As a first step 10 thousand simulations of 100 years have been computed. A ranking was done on the basis of combination of likelihoods on observed flood frequency up to 10 years return period at the outlet of the 3 catchments, frequency of maxima of snow water equivalents and of flow duration curve at the outlet of the whole catchment. The second step was to compute series of the length of 10 thousand years of the best parameter sets and evaluate prediction bounds.

The Zelivka catchment (1187 km^2) was subdivided into 7 subcatchments. A combined likelihood has been computed and transformed in various ways. The higher the power transform the more weight is given to the best simulations and the bounds get narrower (see Figure 3-1). In the case of Zelivka some simulations have been rejected on the basis of exceeding the probable maximum precipitation (PMP computed by the Institute of Atmospheric Physics of the Academy of Sciences of the Czech Republic).

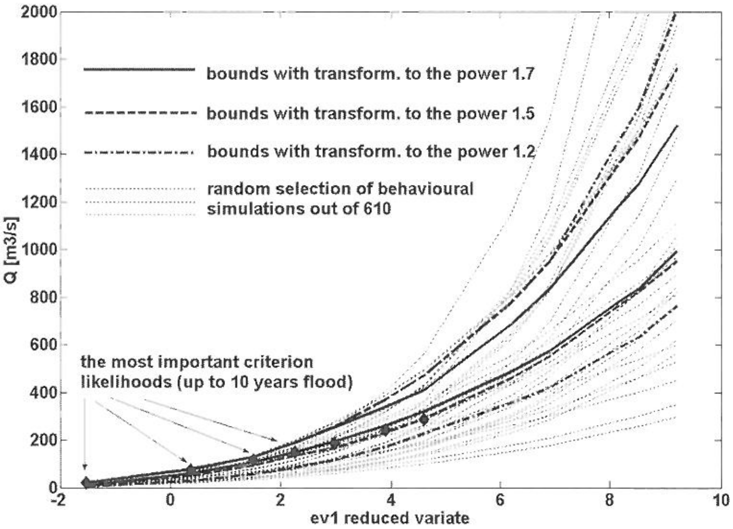


Figure 3-1: Prediction bounds on the Zelivka catchment.

4 CONCLUSION

The GLUE methodology provides a flexible way of taking account of all available conditioning information in the use of continuous simulation for flood frequency estimation. The methodology reflects the modelled effect of changing hydrological processes at different event magnitudes, and the realisation effect in matching the observed data series (themselves only a short realisation of all potential events). The resulting predicted frequencies are dependent on the evaluation measures used, but explicitly take account of uncertainty in the model parameterisations in assessing the risk of a possible event magnitude. Further examples of the use of this methodology can be found at www.vuv.cz.

ACKNOWLEDGEMENTS

The studies were supported by the Ministry of Environment of the Czech Republic under the grants VaV/510/3/96, VaV510/3/97 and VaV510/1/99 and by the Czech Ministry of Education under the grant OK373 which made it possible to participate in the EUROTAS project of EU. Data was provided by the Czech Hydrometeorological Institute (CHMI). An important part of the simulations has been carried out at the Lancaster University parallel system. Data from Eger and Roslau have been provided by Landesamt für Wasserwirtschaft Munchen through the Commission for transboundary streams. International cooperation goes on partly within the FRIEND project UNESCO.

REFERENCES

Beven, K.J. (1987): Towards the use of catchment geomorphology in flood frequency predictions, Earth Surf. Process. Landf., Wiley, Chichester.

Beven, K J and Freer, J. (2001): Equifinality, data assimilation, and uncertainty estimation in mechanistic modelling of complex environmental systems, J. Hydrol., Elsevier, Amsterdam.

Blazkova, S., Beven, K.J. (1997): Flood Frequency Prediction for data limited catchments in the Czech Republic using a stochastic rainfall model and TOPMODEL, J. Hydrol., Elsevier, Amsterdam.

Blazkova, S., Beven, K. J. (2002): Flood Frequency Estimation by Continuous Simulation for a Catchment treated as Ungauged (with Uncertainty), Water Resources Research, AGU, Washington, in press.

Cameron, D. et al. (1999): Flood frequency estimation by continuous simulation for a gauged upland catchment (with uncertainty), J. Hydrol., Elsevier, Amsterdam.

Cameron, D. et al. (2000): Flood frequency estimation by continuous simulation (with likelihood based uncertainty estimation), Hydrology and Earth System Sciences, EGS, Katlenburg-Lindau.

FLOOD MEASUREMENT TECHNIQUES IN PRESENT AND PAST

M. Deutsch[1], G. Spanknebel[2] & K.-H. Pörtge[3]

[1] Institute of Geography University of Erfurt, Group of Historical Floods and Historical Flood Defence, Nordhäuser Straße 63, D-99089 Erfurt, amdeutsch@arcor.de

[2] Thuringian Ministry of Agriculture, Nature Reserve and Environment, Department of Water Management, Beethovenplatz 3, D-99021 Erfurt, h.spanknebel@tmlnu.thueringen.de

[3] Institute of Geography University of Göttingen, Goldschmidtstraße 5, D-37077 Göttingen, kpoertg@gwdg.de

SUMMARY

The territory of the free state of Thuringia, covering a total area of about 16.259 km^2, counts as a flood-generating region. Together with the aim of gaining as much extensive and reliable information about water-levels and discharge reached during flooding as possible, this fact led to the appropriate measurements and calculations already being carried out in Thuringia towards the end of the 18th century. Over the next 200 years, the methods of taking measurements as well as the technical instruments needed for this purpose were constantly improved and developed further.
The aim of the poster is to introduce the development of measurements of water-level and discharge at chosen water-bodies in the present free state of Thuringia, using examples. An examination of the techniques employed in Thuringia at that time to measure water-level and discharge should be included, using historical measurements from the 18th and 19th centuries.

1 EARLY WATER-LEVEL AND DISCHARGE MEASUREMENTS IN THURINGIA IN THE 18TH AND 19TH CENTURIES

The oldest proof of calculations of flood discharges is available for the lower reaches of the Unstrut from 1796. The aim was to obtain details, which should be as accurate as possible, of the total amount of run-off for a ca. 20 km-long section of the Unstrut (between the districts of Schönewerda and Nebra) which was fashioned into a waterway between 1791 and 1795. Furthermore, the nature of the effect which the opening of 5 newly-constructed locks had on the shipping activity during flooding was also supposed to be investigated. In addition to this the profile of the river near the lock weirs had already previously been measured. Using the observed water-levels during flooding and velocity obtained for the 17th and 18th of May 1796, as well as cross-section data, the overall amounts of discharge were calculated (from 17th May [12 o'clock] until 18th May [12 o'clock]).
Although the calculations towards the end of the 18th century remained limited to a few points on the Unstrut, it was still possible for the Prussian water authorities (responsible for the area's management since 1816), to carry out highly extensive measurements and analyses of flood water-levels and discharge amounts between 1830 and 1860 on the lower reaches of the river. The necessary details for this were delivered to a form of water gauge which after approx. 1817/1820 was introduced to more than 10 sites and was then observed daily. On the other hand, the levelling of the river was already carried out in May 1796 at different points on the Unstrut. Taking the velocity of the flow into consideration, in this way it is possible to gain a huge amount of highly accurate and reliable data relating to the water depth or discharge. They constitute an essential arithmetical guide for the regulation measures in place since 1857 on the river. Finally it's worth mentioning that after the 1870s the current meter by Woltman was also used on the Unstrut.
Details of the discharge measurements from the 19th century are also available for the Elster. According to a report from Williams, the Construction Inspector for Royal Saxony, "*Investigations into the amount of flooding*" were carried out within the town jurisdiction of Gera (at Heinrich Bridge) during 1897 and 1898. The data were then urgently required for the intended alteration of the river. The technical instruments employed included water depth gauges as well as more up-to-date innovations. The latter included the so-called hydrometric drainage pipe invented by the engineer A. Frank from Munich. The 7-metre long instrument, which would be placed in the river, enabled a highly accurate measurement of the water velocity of the White Elster to be obtained for different depths. In addition, a so-called hydrometric rope was successfully used for the investigation of the mid-surface velocity, developed by the aforementioned Williams.

2 MEASUREMENTS OF WATER-LEVEL AND DISCHARGE IN THURINGIA IN THE 20TH CENTURY

The first water-level recording stations in Thuringia were installed between the middle and the end of the 19th century, firstly on the rivers Saale and Unstrut, then on the Werra. At first, the stations consisted solely of water-measuring rods associated at the official altitude network, which were mainly installed in areas with significant threat of flooding. Observation books and lists were completed already in this time.

The establishment of flood-warning gauges as the basis for the flood-warning service principally dates back to the 1920s and the years after WWII. The voluntary observers who read the water-level rod once daily were given the additional task of registering looming floods and to report them to the relevant officials via telegram. Flood telegrams were also sent off during the course of an event as soon as the fixed warning levels had been exceeded.

The installation of water-level recorders, following the float-counterbalance principle, reduced the amount of time required by the volunteers to complete their duties. The first gauge houses with gauge wells were then developed in which the measuring instruments could be accommodated and operated.

The first attempts to install a system of automated gauges on East German water-bodies date back to the 1960s. Then, they attempted to record water-level values on punched paper tape at the stations and then to feed the analysis to a central computer in Berlin. At the beginning of the 1980s, the East German Ministry for the Environment made the uniform control system of water-supply, to be based on data transmission via FM radio, more widespread. Digital remote water-level recorders formed the basis of the system.

Nowadays, a diverse range of technologies is employed. Alongside square-codings, which are still steered by floats, pressure receivers and other measuring devices are mainly used where the constructing of gauge houses would be impossible or prove ineffective. These days, flood-warning gauges signal automatically when the appropriate water-level for raising the alarm is exceeded. The limit reporters connected to the telephone network inform the emergency services through a previously-agreed announcement.

Since April 2000, the public can also benefit from accessing current water-levels, discharges and hydrographs via internet or videotext.

The method of discharge measurement has changed little in all these years. The term itself is actually imprecise as, in the majority of cases, discharge is determined through the velocity of flow. Today, computer programmes are also coming into use for discharge calculation. Nevertheless, their results are still used to establish a relationship between water-level and discharge. The direct measurement of discharge, using ultrasound for instance, has so far failed to catch on in Thuringia.

REFERENCIES AND SOURCES

Anordnung über den Hochwassermeldedienst vom 29. Juni 1961, Gesetzblatt II der DDR, Nr. 44, p. 291.

Council-Archive Sömmerda (Thuringia): Acta Judicialia die auf Veranlassung der Navigations Commission bey Anschwellung des hiesigen Geraflusses von den hiesigen Gebieten zu treffenden Vorkehrungen betreffend, Signature: Gebesee, A, No. 890

Deutsch, M. et al. (2000): The Development of Flood Warning and Messaging Service in Thuringia. Kassel Reports of Hydraulic Engeneering No. 9. Herkules Verlag Kassel

Spanknebel, G. et al. (1999): Modernisierung des Hochwasserwarn- und –meldedienstes im Freistaat Thüringen. Wasserwirtschaft – Wassertechnik (Heft 4), Berlin

Williams, R. (1902): Erläuterungsbericht zum Project für die Elsterberichtigung in Gera (Reuss). Ein Beispiel aus der Praxis der Flussberichtigungen von R. Williams, Königlich Sächsischer Bauinspector, Leipzig

ESTIMATION OF DESIGN FLOODS IN CHANGING CONDITIONS

Helen Lobanova, Vladimir Lobanov

State Hydrological Institute, 23, Second Line, St. Petersburg, Russia, lobanova@EL6309.spb.edu

SUMMARY

General problems of estimation of design floods in changing conditions are discussed. They are: non-homogeneity of flood time series, non-stationarity of parameters of flood time series and non-regularity of appearance of flood events. New methods have been developed for assessment of extraordinary outlying data, for assessment of design values for peak over threshold, for extraction of man's impact components and computations in changing conditions. Application is given in form of some examples.

Keywords: changing conditions, design flood, non-homogeneity, non-stationarity, non-regularity

1 INTRODUCTION

There are two main groups of factors impacting on flood events in changing conditions: modern climate change and anthropogenic influence on watersheds and in river channels. The existing approach for the assessment of flood frequency is based on the distribution function theory and it is suitable for homogeneous and stationary conditions. The application of this approach in changing conditions is limited by two main reasons:

- non-homogeneity of flood time series connected with extraordinary outlying observations, different factors of anthropogenic influence and climatic processes of different time scales, including long-term modern climate change;
- non-stationarity of parameters of flood time series connected with non-stationarity of anthropogenic factors and climate change.
- The third main peculiarity of flood time series, that is not taken into account usually, is their non-regularity of appearance, that varies from several flood events during a year (storm floods) to some events during century (as mud streams).

2 SUGGESTED APPROACH

New suggested approach allows to take into account all these peculiarities. The following main methods have been developed:

- statistical criteria for the assessment of extraordinary outlying observations which have been advanced for non-symmetric and autocorrelated flood time series;
- methods for extraction of maximum runoff components connected with anthropogenic impact and restoration of «natural» flood runoff time series for different input informational conditions;
- methods for extraction of homogeneous different time scale components in «natural» conditions including long-term component of modern climate change;
- methods for modelling of cyclic properties of stochastic components and regular long-term trends for deterministic-stochastic components;
- methods for the future assessment of climate change component on the basis of time series models and climate scenarios;
- new formula for calculation of empirical probability of non-regular extreme events;
- new approach for the assessment of design frequency of floods connected with period of exploitation of water projects in the future;
- methods for empirical estimation of random errors of design floods in conditions of climate change and man's impact.

3 METHODS AND EXAMPLES

3.1 Assessment of extraordinary outlying data

In flood time series could be included extraordinary values, which are outlying data (extraordinary maximums, as a rule) from the common empirical distribution. The statistical tests are used for an assessment of statistical significance of such outlying data. Main peculiarities of these criteria are normal distribution and random sample, which is used for the testing. From other side, the time series of floods have non-symmetric distribution and sometimes – a significant auto-correlation. Therefore the classical tests have been extended for the sample with auto-correlation and non-symmetric distribution by Monte-Carlo stochastic modelling. The results are given for example in: Lobanov & Lobanova (1983). Example of application of extended criteria in comparison with the classical ones is given for the longest records of annual maximum (AM) in UK (25 time series). As a result, statistically significant outliers have been obtained in 13 records when classical criteria are used and for 7 time series only when the extended tests have been applied. This way, the classical criteria give outliers more often than they can be for a non-symmetric distribution, which used practically always for floods.

3.2 Assessment of design values for peak over threshold (POT)

Well-known formula *i/(n+1)* is suitable for regular random events, where *i* – rank, *n* – common number of events. Flood events can be several times in a year and extremes of extremes – several times in century. For calculation of empirical probability (frequency) of distribution of such non-regular events a new formula has been developed:

$$P_i(X_i) = \frac{1}{n+1}[1+\frac{n-1}{n-T_m}(n-\sum_{j=1}^{m-i+1} T_j)] \tag{1}$$

when $X_1(T_1) > X_2(T_2) > \ldots > X_m(T_m)$ and where
$X_1, X_2, \ldots$ are the random events, $T_1, T_2, \ldots$ are the time interval between them (in years), m is a common number of random events in the time series, i is a rank number, n is a size of the sample. On the basis of this formula the hydrological computations for POT in chosen 15 time series in UK with the longest records have been fulfilled. For comparison the results of computations of annual maximums for the same sites are given too. Parameters of empirical distributions of AM and POT are differ and the relationships between parameters are represented by the following empirical equations:

$$POT(m)=0.796AM(m)-8.478, \quad R=0.991 \tag{2}$$

$$POT(Cs/Cv)=0.993AM(Cs/Cv)+3.907, \quad R=0.875 \tag{3}$$

where *m, Cs/Cv* – are mean and ratio of skewness and variation coefficients for empirical distributions of POT and AM, *R* is a correlation coefficient.

3.3 Extraction of man's impact components and computations in changing conditions

The main factor of man's influence on floods is seasonal re-distribution of runoff by reservoirs. It leads to a reduction of maximum flood discharges. Other man's influence factors, such as water intake and outtake, woodcutting, etc. are not significant for maximum discharges as usual. Dam regulation could be obtained as a difference between observed runoff in conditions of regulation and runoff restored for natural conditions. For the synthesis of natural runoff in dam site several methods could be suggested: water balance of reservoir, precipitation-runoff model, relationships with analogues in “natural” conditions, etc. As a result the design floods are computed for restored “natural” conditions and impact of operation is added to a computed value. Other scheme, when the observed record is restored, is used for stable operation conditions. Examples of computations of floods are given for some large reservoirs in Russia and for the Nile River – site Aswan in Egypt (Lobanova, 1999).

REFERENCES

Lobanova, H.V. (1997): Assessment of Sustainable Floods and Water Resources Management by reservoirs in Russia. Proc. Int. Conf. LACAR97, Argentina, 10 pp.

Lobanov, V.A. & Lobanova, H.V. (1983): Adaptation of Smirnov-Grubbs test for non-symmetric and auto-correlative consequences. Ref. Journal Geophysics, **8**, 14-28 (in Russian).

ODRAFLOOD – A FLOOD FORECASTING SYSTEM FOR THE ODRA DRAINAGE BASIN

Heinz-Theo Mengelkamp[1], Robert Backhaus[2], Ryszard Ewertowski[3], Markus Klein[1], Hilmar Messal[1] and Zenon Wozniak[4]

[1] GKSS Research Center Geesthacht, Max-Planck-Str., D-21502 Geesthacht, Germany, mengelkamp@gkss.de

[2] DLR German Aerospace Center, Porz-Wahnheide, D-51147 Köln, Germany, Robert.backhaus@dlr.de

[3] MRI Maritime Research Institute/Instytut Morski, ul. Monte Cassino 18A, PL 70-167 Szczecin, Poland, rewert@main.amu.edu.pl

[4] IMGW Institute of Meteorology and Water Management, ul. Parkowa 30, PL 51-616 Wrocław, Poland, zenon.wozniak@imgw.pl

SUMMARY

A flood forecasting simulation system has been developed which comprises a grid based rainfall-run-off model, two wave transformation models for different parts of the river system and two local scale models for the inundation of floodplains and urban areas. A brief description of all models and some results are described.

Keywords: Flood forecasting, rainfall-runoff model, wave transformation, floodplain inundation

1 INTRODUCTION

In July 1997 two episodes of heavy rainfall in the upper watershed of the Odra river caused severe flooding in the Czech Republic, Poland and some areas in Germany. Hundreds of cities and villages were inundated, more than 100 casualties occurred and vast areas of land were flooded for weeks. The critical situation had to be assessed by the disaster management authorities for taking adequate and effective measures. In case of such a critical flood situation the assessment needs

1. quantitative predictions of water levels and discharges which must be accurate and reliable for as long-term as needed for taking effective measures,
2. a set of rules for the intelligent control of weirs and polders and the resulting impact on the river flow,
3. a knowledge base of consequences of predicted levels and discharges on vulnerable urban and rural areas.

2 OBJECTIVES

The ODRAFLOOD project, "Simulation of flood events in the Odra basin with a coupled model system" develops a multi-scale system that meets various demands of a comprehensive flood forecasting and warning system. The goals of the project are:

- extension of the prediction period and effectiveness of flood forecasts,
- analysis of past flood events,
- scenarios for improving flood mitigation and flood management,
- generation of risk maps for vulnerable areas,
- strategies for refining rules for control and projecting of reservoirs, polders and other constructions,
- provision of basic components (models and scenarios) for the development and implementation of an operational flood forecasting system.

3 SYSTEM COMPONENTS AND FIRST RESULTS

The structure of the system refers to the chain of processes converting extreme rainfall and/or snow melt into runoff and river discharge, transforming the flood waves downstream, and inundating local areas. After first being applied and calibrated separately, the models will then be coupled, each model component of larger-scale processes and upper-stream areas delivering boundary conditions for the next component in the model chain.

The rainfall-runoff relationship is simulated with the GKSS model SEROS, which is a combination of the land surface scheme SEWAB (Mengelkamp et al., 1999, 2000) and the large-scale routing scheme (Lohmann et al.. 1996). It is applied to the whole Odra basin covering 120,000 km² with a horizontal grid size of 7x7 km^2. The routing network and sub-catchments of each gauging station are determined from a DEM (Figure 3-1). Forcing data from 50 synoptic stations and about 1250 precipitation stations are used to force the model. Daily discharges of 29 gauging stations and of 13 reservoirs in the mountainous region are used to calibrate and verify the model.

The wave transformation in the Odra river is simulated with the operational hydrodynamic models of IMGW (for upper and middle Odra) and MRI (for middle and lower Odra).

In the lower Odra, flow conditions are much more complex because various types of polders and weirs, tailbacks, wind effects and lateral flows in the channel network of the estuary. These effects are all covered by the MRI hydrodynamic model.

Like a magnifier to the MRI model, the two-dimensional model TRIM simulates transient heavy lateral flows and tailbacks on the main river (Casulli and Cattani, 1994). Figure 3-2 shows the reduction of the water level in the centered longitudinal section of the river 2.5 h after an embankment breach.

The complex and small-scale morphology of buildings and terrain determines the inundation of urban areas. High-resolution elevation models are generated for the cities of Wroclaw and Frankfurt/O./Slubice (Figure 3-3). DLR simulates inundation scenarios with the dynamical-statistical model ARCHE and investigates the effect of mobile flood protection walls and similar measures (Braun et al.,1997).

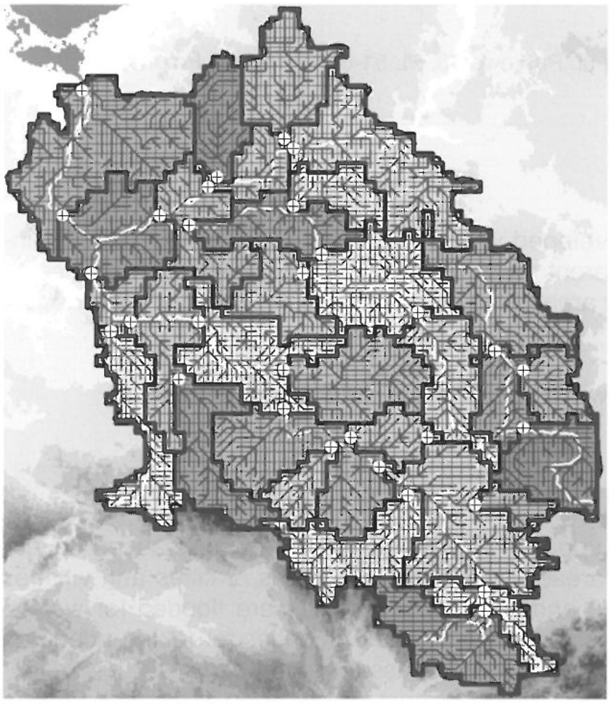


Figure 3-1: Routing network of the Odra basin on a 7 km grid, location of gauging stations and sub-catchments.

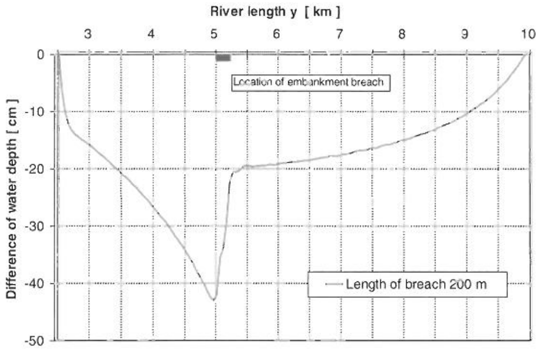


Figure 3-2: Reduction of water level by embankment breach.

Figure 3-3: High-resolution DEM of Frankfurt/O.

REFERENCES

Braun, G., S. Ernst, B. Hörsch, S. Weiers (1997): Hochwasserschutz und -prävention durch räumliche Modellierung. (Flood protection and prevention by spatial modeling) In: GIS, Nr. 5/97, Vol. 10, 10-15

Casulli, V., E. Cattani (1994): Stability, accuracy and efficiency of a semi-implicit method for three-dimensional shallow water flow. Computers Math. Appl. Vol. 27, No. 4, pp. 99-112.

Lohmann, D., R. Nolte-Holube, E. Raschke (1996): A large scale horizontal routing model to be coupled to land surface parameterization schemes. Tellus 48A, No. 5, 708-721.

Mengelkamp, H.-T., K. Warrach, C. Ruhe, E. Raschke (2000): Simulation of runoff and streamflow on local and regional scales, Meteor. Atmos. Phys., 76, 107-117

Mengelkamp, H.-T., K. Warrach, E. Raschke (1999): SEWAB – a parameterization of the surface energy and water balance for atmospsheric and hydrologic models, Adv. Water Res., 23, 165-175

A KNOWLEDGE-BASED EXPERT SYSTEM FOR SELECTING A PROBABILITY DISTRIBUTION FUNCTION FOR FREQUENCY ANALYSIS OF HYDROLOGICAL ANNUAL MAXIMA AT A SITE

Mauro Naghettini[1], Márcio de Oliveira Cândido[2]

[1] Federal University of Minas Gerais, Avenida Contorno 842 – 8 andar, 30110-060 Belo Horizonte, MG, Brazil, naghet@dedalus.lcc.ufmg.br

[2] Companhia de Pesquisas de Recursos Minerais, Avenida Brasil 1731, 30140-002 Belo Horizonte, MG, Brazil, marcio@cprmbh.gov.br

SUMMARY

The usually short samples of hydrological observations recorded at a site and the large uncertainties involved in parameter and quantile estimation make the task of selecting a probability distribution function for frequency analysis of annual maxima a subjective matter. Conventional goodness-of-fit tests are not powerful enough to provide the necessary objective backing to such a decision-making process and may lead a novice hydrologist to improper choices. In this paper, we describe our experience in employing the technology of artificial intelligence and fuzzy-logic theory to build a computer expert system that emulates the reasoning principles of a human expert in selecting a probability distribution for hydrologic frequency analysis. Such a system has been applied to 20 relatively large samples of daily rainfall and streamflow annual maxima, recorded at gauging stations located in the Brazilian southeast. In order to check the system performance, the same samples have been submitted to a panel of experts in frequency analysis. The comparison of the results provides evidence that the computer system performs at an expert level and may be utilized to help an inexpert to select an appropriate distribution for at-site hydrologic frequency

Keywords: frequency analysis, hydrologic extremes, expert system.

1 INTRODUCTION

In practice, experts in frequency analysis of hydrological variables employ their knowledge and past experience to construct a set of heuristic rules and rather *ad hoc* procedures, which provide the *rationale* for justifying the choice of a specific probability distribution function, among a number of candidate models. However, different experts may reach to different conclusions. In this paper, we describe a set of contemporary knowledge-based rules that have been implemented into a computer expert system in order to provide guidelines, which are reasonably similar to those employed by a human expert, for selecting a probability distribution for hydrologic frequency analysis. The computer system is constructed under FuzzyCLIPS, a version of NASA's CLIPS tool for building expert systems developed by the Canadian National Research Council. Briefly, the system first takes the numerical information abstracted from a data sample, then analyze it under the light of a built-in knowledge-based set of heuristic rules, and, finally, transform it into decision statements. L-moments and L-moment ratios are employed to summarize the data sample variability. Then, the monotonically inductive reasoning process first uses the sample L-moments to decide on plausible 2-parameter and 3-parameter candidate parametric forms, on the basis of L-moment diagrams and on Monte Carlo-derived properties of L-skewness and L-kurtosis. In the sequence, Filliben's goodness-of-fit test is employed to eventually increase, and never decrease, the previously assigned confidence level of each candidate distribution. Finally, a mathematical combination of these confidence levels and the number of estimated parameters provides the criterion of statistical parsimony to discriminate among distributions of the same family. The remaining distributions are then classified according to their respective mean overall confidence levels and the decision statements are formulated. An operational English version of the Windows-based expert system, the so-called SEAF, is available for download from the URL http://www.ehr.ufmg.br.

2 THE KNOWLEDGE-BASED REASONING SYSTEM

The proposed set of heuristic rules which will form the knowledge basis of the reasoning procedures of the expert system is composed by the following steps :

a) Check for homogeneity, serial independence, and presence of outliers in annual data series by conventional tests (Mann-Kendall, Kendall's τ, and Grubbs & Beck, respectively) and ask user whether or not to proceed and whether or not to remove outliers;
b) Calculate sample L-Moments and L-Moment ratios: $\ell_1\left(\hat{\lambda}_1\right)$, $\ell_2\left(\hat{\lambda}_2\right)$, t_2 (L-CV), t_3 (L-Skewness), and t_4 (L-Kurtosis), for the sample of size *n*, according to conventional formulation;
c) Estimate parameters for the following 2-parameter distributions: *dist* = Normal, Log-Normal, Exponential, and Gumbel, and their respective Monte Carlo-simulated finite-sample variances $Var^{dist}(\tau_3)$;
d) Do the same for the following 3-parameter distributions: *dist*=Pearson III, Log-Pearson III, Generalized Extreme Value (GEV), and Generalized Pareto (GPA);
e) If t_3 is a N[τ_3^{dist}, $Var^{dist}(\tau_3)$], define the confidence interval $\left[\tau_3^{0.025}, \tau_3^{0.975}\right]$ for each 2p distribution;
f) On the basis of the interval $\left[\tau_3^{0.025}, \tau_3^{0.975}\right]$ and on the sample L-skewness t_3, select all plausible 2p distributions and associate to each one a preliminary confidence level, which should be calculated according to a 'membership function' of the bell-shaped type with the 0.5-level threshold;
g) If t_4 is a N[τ_4^{dist}, $Var^{dist}(\tau_4)$], define the confidence interval $\left[\tau_4^{0.025}, \tau_4^{0.975}\right]$ for each 3p distribution;
h) On the basis of the interval $\left[\tau_4^{0.025}, \tau_4^{0.975}\right]$ and on the sample L-kurtosis t_4, select all plausible 3p distributions in a manner similar to that described in item f;
i) Apply Filliben's test for both 2p and 3p distributions and define the confidence interval $\left[\rho_{0.05}^{dist}, 1\right]$;
j) On the basis of the interval $\left[\rho_{0.05}^{dist}, 1\right]$ and on the test statistic r^{dist} select all plausible distributions and associate to each one a secondary confidence level, which should be calculated according to a 'membership function' of the cumulative type with the 0.5-level threshold;
k) If skewness $g_x<0$ (or $g_{\ln x}<0$), remove Pearson III (or Log-Pearson III) from the analysis;
l) Check for the sign of GPA (GEV) shape parameter κ; if $\kappa>0$ remove distribution from the analysis;
m) Apply the following parsimony criterion $CI_{adjusted} = 1-(1-CI_{average})(n-1)/(n-p)$, where *CI* denotes the confidence level and *p* the number of estimated parameters, in order to discriminate among distributions of the same family, such as Pareto versus Exponential, GEV vs. Gumbel, and so on;
n) Check whether the presence of low outliers significantly modify parameter and upper-tail estimation. Remove from the analysis those distributions for which the sample minimum is inferior to an arbitrarily chosen level of 0.9 of the respective estimates for the location parameters; and
o) Classify distributions according to their average confidence levels and provide general decision statements.

3 THE SYSTEM PERFORMANCE

In order to check the system performance, SEAF has been applied to 20 samples of discharge and daily precipitation annual maxima, recorded at gauging stations located in southeastern Brazil; the samples have been selected such that their sizes had to be larger than 35. Concurrently, the same samples have been submitted to a panel of human experts composed by two statisticians, one engineer, and one university professor. In average, 78% of the individual expert selections have been ranked by SEAF as plausible model candidates. As the panel consensual first choices are concerned, SEAF appropriately selected 75% of the cases; this number increases to 100% as both first and second choices made by SEAF are considered. As related to the panel most frequent choices, these numbers change respectively to 76% and 82%. From the set of individual expert results we have analyzed, there were no apparent evidences suggesting a systematic preference for a particular 2p or 3p distribution or a family of distributions.

4 CONCLUSION

Despite the complexities inherent to at-site frequency analysis of hydrological annual maxima, it is our conclusion that SEAF performs at an expert level and may provide a powerful tool to help an inexpert to make a reasonable choice among a number of possible probability distribution models. Obviously, the system is not perfect and is currently in development. We take this opportunity to advance our sincere thanks to eventual suggestions, corrections or comments addressed to any one of the authors of this paper.

EFFECT OF MEASUREMENT ERROR IN FLOOD ESTIMATION

Bhagabat P. Parida

University of Botswana, Private Bag 0022, Gaborone, Botswana, paridab@mopipi.ub.bw

SUMMARY

To illustrate the possible effects of measurement error on identification of the parent statistical model for a given flood series, relationships between the observed coefficient of variation and coefficient of skewness of flood sample with respective true values have been derived and presented. Using these relationships a table has been constructed, which can be used for identification of true statistical characteristics of the observed sample, hence the underlying parent distribution and also for reliable flood quantile estimation.

Keywords: Measurement Error, Modelling Error, Sampling Error

1 INTRODUCTION

Use of error free flood data, is one of the essential factors that contribute towards the reliability of design flood estimates at specified risks. In real life situations, even the use of some of the best measurement techniques such as the use of current meter is likely to induce measurement errors up to ± 5%, which can go up to as much as ±10 to 20% in case the stage-discharge curve or the slope-area method is used (Herschy, 1985). Since flood discharges in many large and perennial rivers are generally measured by using a stage discharge curve, it is obvious that the recorded discharges hence the annual peak flood values computed using such a method are likely to be infested with large amount of measurement error. But, most of the present day analysts apriori assume that the measured flood discharges to be perfectly correct ignoring the limitations of the hydrologic data and any peculiarities in the data are instead analysed by hypothesising an elaborate statistical model. Studies by Potter and Walker (1981), Parida (1993) and Kuznetsov (2001) have observed that the effect of modelling error in flood frequency analysis is far more damaging that the sampling error. Even another study by Hosking and Wallis (1986) has shown that measurement error can result in less accurate estimates of flood quantiles even with the use of method of Probability Weighted Moment for parameter estimation. In view of these, it may be important to know the effect of measurement error, particularly in identifying the underlying statistical model for the observed series.

2 STATISTICAL FORMULATION & RESULTS

Let z be the measured value of flood discharge at a given stage and if x represents the true flood discharge at that stage with ε as the associated random measurement error, then $z = x + \varepsilon$.
Since ε is independent of x, the conditional expectations of ε given x i.e.{ $E(\varepsilon|x)$ } is always zero. For estimating the various parameters of the observed series in terms of the parameters of the true series and the error component, it is assumed that the conditional standard deviation of ε i.e.{ $\sigma(\varepsilon|x)$ } will be equal to $\alpha.x$ (where α is a coefficient determined based on measured data) and the conditional probability density function of ε is normally distributed. Hence

$$\text{(1)} \qquad \mathrm{E}(z\,|\,x) = \bar{x} \;\; or, \;\; \bar{z} = \bar{x} \quad and$$

$$\text{(2)} \qquad \sigma\,(z\,|\,x) = \sigma\,(x\,|\,x) + \sigma\,(\varepsilon\,|\,x) = 0 + \alpha.x = \alpha.x$$

$$\text{(3)} \qquad \sigma_z^2 = \mathrm{E}\,(z-\bar{z})^2 = \mathrm{E}\left[(x_i - \varepsilon - \bar{x})^2\right] = \mathrm{E}\,[(x_i - \bar{x}) - \varepsilon]^2 = (1+\alpha^2)\sigma_x^2 + \alpha^2\bar{x}^2$$

Using the above equations, we can write the coefficients of variation (Cv_z) and the coefficient of skewness (g_z) of the observed flood discharges in terms of the coefficients of variation (Cv_x) and skewness (g_x) of the true flood discharges (x_i) as :

(4) $Cv_z = [(1 + \alpha^2) . Cv_x^2 + \alpha^2]^{0.5}$ and

(5) $g_z = \mu_{3z} / \sigma_z^3 = g_x . [1+ 3\alpha^2 + \{6 \alpha^2/ (g_x. Cv_x)\}] / [1+ \alpha^2 \{ 1+ (Cv_x)^2\}]^{1.5}$

To illustrate the effect of measurement error on the true flood values, three different values of true coefficients of variation (viz: 0.2, 0.3 and 0.5) were chosen which were then subjected to varying degrees of measurement error, α, (10 - 20%) and for each case the Cv_z values were computed using Eqn. (4). Also for these cases and with different chosen values of g_x, values of coefficient of skewness of the observed series (g_z) have been computed using Eqn. (5) and the results tabulated in Table 2-1.

Table 2-1: Effect of Measurement Error on Flood Statistics.

Error coefficient α (in %)	True Flood Statistics		Obs. Flood Statistics		True Flood Statistics		Obs. Flood Statistics		True Flood Statistics		Obs. Flood Statistics	
	Cv_x	g_x	Cv_z	g_z	Cv_x	g_x	Cv_z	g_z	Cv_x	g_x	Cv_z	g_z
10	0.2	0.83	0.22	1.14	0.3	0.93	0.32	1.14	0.5	1.01	0.51	1.14
		1.14		1.45		1.14		1.35		1.14		1.27
		1.68		2.00		1.78		2.00		1.86		2.00
		2.00		2.32		2.00		2.22		2.00		2.14
15	0.2	0.47	0.25	1.14	0.3	0.69	0.34	1.14	0.5	0.86	0.53	1.14
		1.14		1.83		1.14		1.61		1.14		1.43
		1.31		2.00		1.52		2.00		1.70		2.00
		2.00		2.71		2.00		2.49		2.00		2.31
20	0.2	0.01	0.29	1.14	0.3	0.37	0.37	1.14	0.5	0.67	0.55	1.14
		0.83		2.00		1.14		1.95		1.14		1.63
		1.14		2.33		1.19		2.00		1.49		2.00
		2.00		3.24		2.00		2.85		2.00		2.53

Consider a case, where a true series has $Cv_x = 0.2$ and $g_x = 0.83$. It can be observed that, a 10% induction of measurement error into the series would not only result in 10% increase in the Cv_z values, but also can give a feeling as if the observed series belonged to Extreme Value Type I (EV-I) distribution ($g_z = 1.14$). And when the error element is increased to 20 %, not only the Cv increased by a whooping 35% but also made the series look as if it belonged to Pearson Type III distribution ($g_z = 2.0$). As another instance for $Cv_x = 0.2$, the series which normally should have been modelled using a Normal Distribution ($g_x = 0.01$), would most likely be modelled using an EV-I distribution ($g_z =1.14$) due to induction of a 20% error. In general, measurement error not only distorts the Cv_z and g_z values but also the underlying distribution.

3 CONCLUSIONS

It is evident from the above that the measurement error can change the coefficient of variation and the coefficient of skewness of the flood series considerably, so far so that they prompt the designer to choose a different parent distribution for computation of flood quantiles. Besides these, the spurious Cv values are likely to misdirect a hydrologist in identification of a homogeneous region when a regional analysis is primarily based on such information. Thus, the above table conversely can be used to establish the extent of measurement error in the observed series knowing the values of Cv_z and g_z and hence in the identification of an appropriate statistical model for reliable estimation of flood quantiles.

REFERENCES

Herschy, R.W. (1985): Stream flow Measurements, Elsevier App. Sc. Pub., London, 553

Hosking, J.R.M. and Wallis, J.R. (1986): The Value of Historical Data in Flood Frequency Analysis, Jr, Water Resources Res., USA, 22(11), 1606 – 1612.

Kuznetsov, V.A. (2001): Errors or Uncerainties in Measurement? , Jr. Measurement Techniques, N.Y., 44(10), 1020 – 1023.

Parida, B. P. (1993): Statistical and Physically Based Flood Frequency Analysis, Unpublished Ph.D. Thesis submitted to Indian Institute of Technology, Delhi.

Potter, K.W. and Walker, J.F. (1981): A Model of Discontinuous Measurement Error and Its Effect on the Probability Distribution of Flood Discharge Measurement, Jr. Water Resources Res., 17(5), 1505 – 1509.

THE JOINT RETURN PERIOD OF PEAK DISCHARGE AND VOLUME: A NEW BASE FOR FLOOD ESTIMATION

Aldo I. Ramirez, Álvaro A. Aldama

Mexican Institute of Water Technology, Paseo Cuauhnahuac 8532, Col. Progreso, Jiutepec, Morelos, Mexico. C.P. 62550, aramirez@tlaloc.imta.mx, aaldama@tlaloc.imta.mx

SUMMARY

Design floods for dams and other structures are often estimated by using flood frequency analyses of maximum annual discharges. However, a design flood must be fully characterized by a hydrograph, in order to determine the dimensions of the structure. Due to flood frequency analyses rely upon the estimation of probability distributions associated with peak discharges only, the design hydrograph is fully determined by using arbitrary procedures. The description of a hydrograph must involve, at least, its most important parameters, namely peak discharge and runoff volume.

A new approach for estimating the design flood has been developed and is presented in this paper. The method is based on the use of the bivariate extreme-value probability distribution of peak discharge and volume. An expression for the joint return period of these two parameters is derived. It is shown that an infinite number of pairs of values of peak discharge and volume possess a given joint return period. Two examples involving the revision of the design flood of the "El Infiernillo" and "Huites" dams in Mexico are also presented.

Keywords: Design flood estimation, joint return period, storage reservoir design, multivariate distribution, peak flow rate, runoff volume.

1 INTRODUCTION

One of the most commonly employed methods for design flood estimation is flood frequency analysis (see, for example, Ponce, 1989). This method consists of fitting a theoretical extreme-value probability distribution to the maximum annual flow rate data, thus enabling the hydrologist to estimate, via extrapolation, the flow rate or peak discharge corresponding to a given design return period, T_r. For example, the flood-related design parameters for a dam are its flood control capacity and the design discharge of the spillways or any other flood discharge structure the dam may have. Those parameters are obtained by routing the *design hydrograph* through the reservoir. Therefore, they are determined by the form of such hydrograph, not only by its peak flow rate. In practice, the form of the design hydrograph is arbitrarily defined. Furthermore, experience demonstrates that the response of some reservoirs may be more sensitive to the flood runoff volume than to its peak discharge. Thus, it is highly desirable to address the problem of characterizing the whole design hydrograph in a probabilistic framework.

2 HYDROGRAPH PARAMETERIZATION

In order to simplify the description of a hydrograph, $Q=Q(t)$, where Q represents flow rate and t, time, it is highly convenient to parameterize it. The simplest parameterization of a hydrograph must contain its most important parameters, namely: peak discharge, Q_p, time to peak, t_p, and runoff volume, V. The authors of this paper have developed a simple parameterization of this kind in terms of a family of (odd degree) Hermitian polynomials (Aldama and Ramírez, 1998a). This parameterization or any other suitable can be used to describe the whole hydrograph.

3 MULTIVARIATE PROBABILISTIC CHARACTERIZATION OF DESIGN HYDROGRAPHS

If only peak discharge and volume are considered, a biparametric description of a design hydrograph, of the form: $Q = Q(t; Q_p, V)$, results. Thus, it is convenient to characterize a design hydrograph by means of a properly constructed *bivariate extreme value distribution*, defined as follows:

(1) $$F_{qv}(Q_p,V) = P(q \le Q_p \cap v \le V)$$

where q and v represent random variables in a two-dimensional random space.

The return period of a hydrograph whose probabilistic characterization is given by the bivariate distribution $F_{qv}(Q_p,V)$ may be defined as the reciprocal of the probability of simultaneous exceedance of Q_p and V, i. e., by the joint return period:

(2) $$T_{Q_p,V} = \frac{1}{P(q > Q_p \cap v > V)} = \frac{1}{1 - F_q(Q_p) - F_v(V) + F_{qv}(Q_p,V)}$$

It must be noted that the knowledge of $F_{qv}(Q_p,V)$ not only allows the determination of the joint return period, $T_{Q_p,V}$, but also of the return periods of the peak discharge, T_{Q_p}, and of the volume, T_V.

4 DESIGN FLOOD ESTIMATION

It is evident that there exist an infinite number of pairs of values of Q_p and V that possesses a given return period. Therefore, it is necessary to determine which one of these pairs produces the worst effects on the dam to be designed or revised.

Let $Z_m = Z_m(Q_p,V)$ represent the highest free surface elevation that is achieved in a reservoir once a hydrograph is routed through it. Thus, the determination of the design flood for a given $T_{Q_p,V}$, may be posed as the following nonlinear optimization problem:

(3) $$\max_{(Q_p,V)} Z_m = Z_m(Q_p,V)$$

subject to $$T_{Q_p,V} = \frac{1}{1 - F_q(Q_p) - F_v(V) + F_{qv}(Q_p,V)}$$

5 APPLICATION

In the study cases, the results show that with the joint return period approach, Huites dam, which had been designed for a conventional return period of 10,000 years, is hydrologically safe for the 7,000 year flood. On the other hand, El Infiernillo dam, which was also designed for the 10,000 year flood is barely safe for the 750 year event. In both cases, the design flood for a return period of 10,000 years shows a smaller peak discharge compared to the peak discharge obtained with the traditional univariate flood frequency analysis. However, the new approach assigns it a greater runoff volume.

6 CONCLUSIONS

The proposed method allows the association of a return period to the whole hydrograph and not just the peak flow rate. The design event is determined by computing the pair of values of peak discharge and runoff volume that produces the worst effects on the dam to be designed or revised. The application of the method to the "El Infiernillo" and "Huites" dams in Mexico, shows that the design hydrograph that is computed by employing the proposed method produces an elevation that overtops the dam, making it unsafe, while the traditional flood frequency analysis procedure would lead one to believe that the dam is safe.

REFERENCES

Aldama, A. and A. Ramírez (1998a): Hydrograph parameterization through Hermitian interpolants (in Spanish), *Ingeniería Hidráulica en México*, 13, 19-28.

Ponce, V. (1989) *Engineering Hydrology*, Prentice Hall, Englewood Cliffs, New Jersey.

MONITORING OF DESIGN FLOODS AS A BASIS OF SAFETY FOR HYDRAULIC ENGINEERING STRUCTURES

Anatoly Rozhdestvensky, Vladimir Lobanov

State Hydrological Institute, 23, Second Line, St. Petersburg, Russia, lobanov@EL6309.spb.edu

SUMMARY

Concept of monitoring of design flood is introduced. Possible changes in designed values connect with an increasing of record's size, development of new effective methods for computations, man's impact, influence of modern climate change, etc. Algorithm of re-computation of design floods is suggested. The particular examples show the increasing of re-computed design maximums during a long-term period of operation of hydraulic engineering structures.

Keywords: design flood, monitoring, re-computation, safety

1 INTRODUCTION

Now it is considered, that the safety of hydraulic engineering structures depends only on reliability of a material from which they are constructed and monitoring of which deterioration it is necessary to carry out with the purpose of the prevention of destruction. At the same time, the second and not less significant factor is a design flood discharge, for which all hydraulic engineering structures for water passing through the dam are computed. Till now a design flood discharge was defined once at designing of dams (SNIP-2.01.14-83, 1984). At the same time there are two basic reasons, on which it is necessary to carry out monitoring of this discharge and its recalculation if it is necessary. These reasons are as follows:

- as a rule, many dams were projected many years ago, when short-term period of observations took place, therefore parameters of distributions and the design flood discharges, determined on their basis, had the large errors;
- more effective methods of computations of the design floods now have appeared which allow to obtain more reliable results.

Besides that the basis for monitoring of design floods is modern changing conditions connected with man's impact in river channels and basins and possible impact of modern anthropogenic climate change.

2 APPROACH

Monitoring of design floods for working hydraulic engineering structures includes the following procedures:

- restoration of "natural" time series of floods for the period of work of hydraulic engineering structures till now;
- restoration of a long-term time series of floods in natural conditions at the site of a hydraulic engineering structure (dam) on a basis of the most long-term time series on the rivers - analogues which are taking place in natural conditions;
- estimation of homogeneity and stationarity of restored long-term time series in view of an estimation of possible man's impact and anthropogenic climate change;
- calculation of parameters of flood distributions and design flood discharges on the basis of a long-term time series in natural conditions;
- comparison of the computed results with the earlier computed design floods and making a decision about change of design values, rules of operation and reconstruction of a hydraulic engineering structure when this difference is significant.

The periodicity of such recalculation of the design floods depends on the probability (return period) of new observed maximum floods. For realization of the offered approach the new methods have been developed (Rozhdestvensky, 1990)

3 EXAMPLES

The application of the offered approach has been realized on an example of re-computation of design maximum floods for the cascade of the Dnieper hydropower stations, which has more than 50 years period of work. More precise parameters of distributions and design values have been obtained on a basis of the most long-term time series of observed and restored flood maximum discharges. It is established that the recomputed design floods were on 30-50% bigger than computed earlier for water projects, that causes a necessity of reconsideration of the operation rules of dams' regulation and in some cases - reconstruction of dams. Results of comparison are given in the Table 3-1.

Table 3-1: Comparison of design and re-computed maximum water discharges.

No.	Site of observations on the Dnieper River	Design (thou.m^3/s)	Re-computed (thou.m^3/s)	Difference (in %)
1	Vishgorod	21,3	29,3	38
2	Kiev	30,8	43,0	40
3	Kremenchug	34,0	44,4	31
4	Lotzmanskaya Kamenka	36,0	47,5	32

Increasing of design maximum discharges connects, in general, with an increasing of ratio of a skewness coefficient (*Cs*) to a coefficient of variation (*Cv*). In past, when short-term time series took place this ratio had been established as 2, in a case of re-computation it becomes Cs/Cv = 3.5.

The second example connects with a well-known catastrophic flood in Lensk city – the Lena River (Eastern Siberia) in 2001, when 18 thou. of inhabitants became homeless and were about 40 victims. Lensk city was flooded in whole and destroyed during this inundation and today's problem connects with a restoration of the city and a project of flood safety dam. Main discussion takes place about design maximum water level with a return period in 100 years. Former design maximum level was 170,07 m without flood 2001. If flood 2001 is included in observation record (with general period of observation in 70 years), the design maximum water level will be 173,15-173,57 m depending on the variant of computation, i.e. on 3.5 m higher than the existing one. Comparison is given in Figure 3-1.

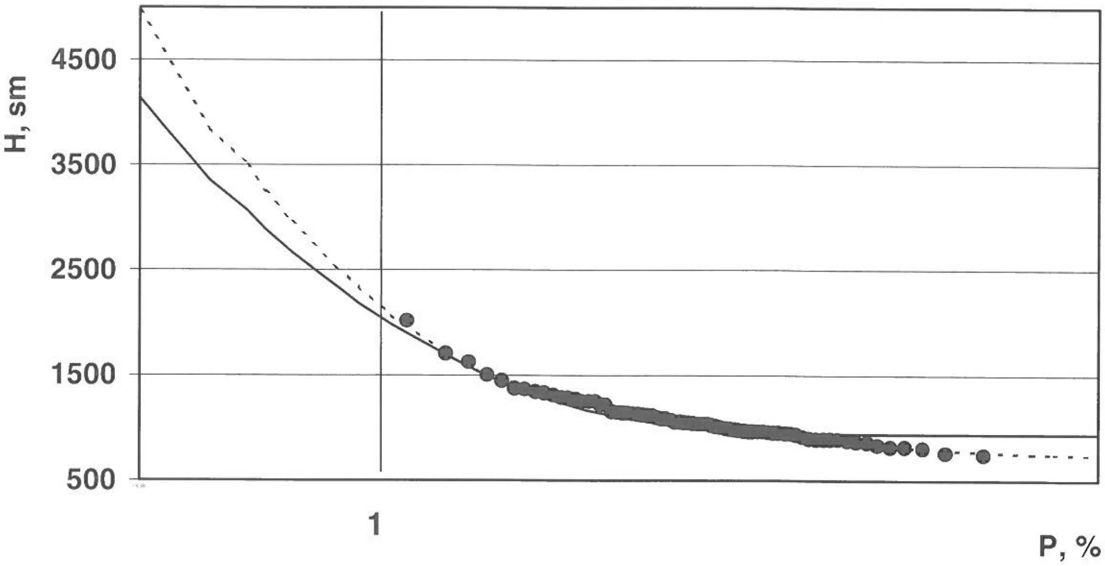


Figure 3-1: Empirical distribution of maximum water level (black points) and its analytic approximation for 2 cases: with flood 2001 (dotted line) and without it (continuous line).

REFERENCES

SNIP-2.01.14-83 (1984): Norm and Rules in Construction, State Standard, Moscow, Ministry of Construction of Russia, 1984, - 39 pp. (in Russian)

Rozhdestvensky A.V. et al. (1990): Assessment of efficiency of hydrological computations. Gidrometeoizdat, St.Petersburg (in Russian)

FLOOD RISK MAPPING BASED ON AIRBORNE LASER SCANNER DATA: CASE OF THE LLOBREGAT RIVER

Antonio Ruiz[1], Xavier González[2], Ignasi Herms[2], Leonardo Bastianelli[3]

[1] Cartographic Institute of Catalonia, Parc de Montjuïc, E-08038 Barcelona, Spain, toni@icc.es

[2] RSE Aplicaciones Territoriales, S.A., Alcalde Barnils 72 3r, Sant Cugat, E-08190 Barcelona. Spain.

[3] Aquater SpA Italy, Via Miralbello 53, 61047 San Lorenzo in Campo, Italy

SUMMARY

The application of LIDAR data to flood risk mapping has been tested in an area of Llobregat river, close to Barcelona, Spain. The accuracy and high density of the data allowed a detailed representation of the flooded areas. Model size limitations in standard software have been found.

Keywords: flood, laser scanning, LIDAR, mapping

1 INTRODUCTION

Extreme flood events are a major natural hazard in the Spanish Mediterranean basin. In the past decades many flood control structures, mainly dams, have been built. Many of these dams were originally designed for hydropower or irrigation purposes many years ago.

In the last decade efforts to perform better flood management comprise real time hydrological warning systems, remote control, weather forecast information systems, computer simulation of mathematical models, etc. Now these can take advantage of cutting-edge technologies like meteorological radar and satellite communications systems.

Light Detection And Ranging (LIDAR) has proved to be an accurate and practical alternative to conventional methods for the generation of Digital Surface Models (DSMs) for hydraulic modelling and flood mapping. A test area of 15 km along the Llobregat River has been chosen in which floodplain is invaded by urban development.

The scopes of the study are:

1) Check the accuracy of DSMs derived from LIDAR technology.
2) Check its usefulness for hydraulic computations and floodplain delineation computations.
3) To establish the guidelines for the forthcoming flood risk-mapping programs in Catalonia.

2 LIDAR DATA

Table 2-1: LIDAR survey parameters.

Plane	Partenavia P-68C Observer
Speed	120 knots
LIDAR system	ALTM 1210
Frequency	10,000 points/s
Flying height	800 m AVG
Scan angle	15°
Scan frequency	24 Hz
Points measured	8826860
Point density	0.64 points/ m^2
Scanned surface	1378 Ha

Initial terrain data was by an airborne laser-scanner operated by the company Aquater Spa Italy. The system parameters are shown in Table 2-1. The number of flying lines was 8 and it required 44 min of flying time.

With the last pulse points a DSM with one metre grid step was computed and vegetation and small buildings were removed automatically. Points on bridges were removed by hand editing. Large buildings and other obstacles to water flow like containing walls were preserved in this high-resolution model. Bridges were surveyed with the help of a total station. No other topographic data was used in addition to the LIDAR DEM. Bathimetric profiles were not surveyed because the river level was so low that it was considered negligible in front of the flow during a flooding event.

Five sport fields to be used as control fields were surveyed by RTK GPS. The heights in these flat areas were used to check the LIDAR DSM. In each field a minimum of 15 points were measured. The

LIDAR values in each of the areas were triangulated and an interpolated height was computed and compared to the LIDAR DSM. Triangles with height differences larger than 30 cm were neglected.

There was a systematic difference of 18 cm between surveyed points and LIDAR (Table 2-2). LIDAR values were always lower. This difference could be due to a systematic shift in the GPS/INS trajectory solution of the plane, to the geoid or a geodetic network error. As it was a constant we were able to remove it and it had no influence on the results.

Table 2-2: Checking of LIDAR data.

Zone	N	<z>	Std dev
1	12	0.14	0.07
2	14	0.22	0.04
3	14	0.20	0.03
4	13	0.23	0.05
5	18	0.14	0.06

3 PHOTOGRAMMETRIC DATA

Comparable photogrammetric data has been collected from aerial photographs at 1:5000 scale. A 1:1000 topographic map with 1 m contours has been drawn. We tried to capture a 3D model of the buildings and bridges but many mistakes in the data classification made very difficult to accomplish this purpose. Also, the restitution complexity moved us to simplify the classification of captured data.

At the moment of writing this report we still have not been able to repeat the hydraulic computations with the photogrammetric data.

4 HYDRAULIC MODELLING

Hydraulic simulation models like HEC RAS and MIKE can be linked to GIS systems thanks to preprocessing and post-processing modules. Computation of water levels and velocities and mapping show up details such as which particular streets are flooded, which areas remain safe, what is the water depth in flooded areas and how much time the flood lasts. These results are necessary to develop flood emergency plans.

The LIDAR DSM was used to extract the cross sections for the hydraulic modelling and also to perform automatic flood delineation. HEC RAS and Mike-11 modelling programs were used to determine floodplains corresponding to 100 and 500 years return period, encroachment areas and legal buffer zones. Simulations were conducted for models with and without bridges and for stationary and non-stationary flows.

Existing GIS post-processing modules HEC GeoRAS and MIKE 11 GIS for HEC RAS and MIKE 11 in PC systems seem to be limited by a maximum of 10.000.000 cells. If a 2 m cell grid is used then the area covered is 40 km^2 which is not too large.

5 CONCLUSIONS

The LIDAR technique has shown to be accurate for generating DSM for flood hazard mapping at 1:5000 map scale. The high data density of the LIDAR DSM results in an automatically delineated flooded area that covers some streets but not surrounding buildings. Also, the low standard deviation of height differences demonstrates the high accuracy of this technique.

At the moment of writing this report the comparison with photogrammetric data has not been performed yet but LIDAR data seems to be enough for flood modelling at this scale and only bridges require a topographic survey from the ground. No other topographic or photogrammetric data was required in this test area.

REFERENCES

Baltsavias, E.P. Airborne laser scanning: basic relations and formulas. ISPRS J. Photogr. Rem. Sensing 54 (2/3), 199-214.

Wehr, A., Lohr, U. (1999): Airbornelaser scanning – an introduction and overview. ISPRS J. Photogr. Rem. Sensing 54 (2/3), 68-82.

Mandlburger, G., Brockmann H. (2001) MOdelling a watercourse DTM based on airborne laser-scanner data using the example of the River Oder along the German/Polish Border. OEEPE-Workshop, "Airborne Laser-scanning and Interferometric SAR for Detailed Digital Elevation Models". Stockholm.

CONCEPT FOR THE IMPROVEMENT OF FLOOD WARNING BY DISTRIBUTED SOIL MOISTURE MEASUREMENTS

W. Schaedel, R. Becker

Institute of Water Resources Management, Hydrolic and Rural Engineering, University of Karlsruhe (TH),
wolfram.schaedel@iwk.uka.de, rolf.becker@iwk.uka.de

SUMMARY

Flood warning in small or middle size catchments can only be improved by a prolonged advanced warning time in combination with decent reliability. Precipitation forecasts in flood warning only lead to a temporal but not reliable betterment. A tremendous improvement in reliability can be reached by including the spatial distributed preconditions of the catchment. Distributed soil moisture measurements (TDR) identify this catchment's state. The so gathered point information of soil moisture can be regionalized by a spatial distribution extracted from Landsat-TM images. The moisture distribution serves as input data for a hydrological warning model (HBV).

Keywords: flood warning, hydrological precondition, soil moisture, TDR measurement, remote sensing

1 INTRODUCTION

The tremendous importance of rivers and their stream banks for the quality of life in densely populated areas is indisputable. The sustained protection of these valuable areas and their inhabitants in many cases require environmentally sound flood protection measures. Nevertheless a residual risk of extreme floods always remains, which threatens peoples' safety as well as the catchment's diverse recreational and economic uses. Especially in catchments typical for Baden-Württemberg up to a few hundred square kilometres severe damage often occurs, when high floods are recognized too late. In areas of that size critical flood discharge is formed rapidly, if the ground will be saturated. These floods, when observed with conventional runoff gauges, are often recognized so late, that the remaining advance warning time does not allow effective protection to lower damage (e.g., Baden-Baden, Ettlingen, Schömberg, parts of Kocher and Jagst catchments).

2 GOAL

Because of the fast runoff generation in small or middle size catchments a genuine need exists for a new flood warning system to be developed. If it were possible to prolong the advance warning time in combination with decent reliability, the flood situation in these catchments could often be relieved.
Depending on prediction time, precipitation forecasts allow a prolongation of the advance warning time, but the high non-linearity of precipitation-runoff processes attenuate the reliability of any system. Precipitation-runoff processes are correlated with the catchment's hydrological preconditions that are taken into account in some hydrological models, e.g. by preprecipitation index. This statistically generated variable is unsuitable in case of extreme flood events. Thus improved estimation of the catchment's preconditions is of tremendous importance.
The non-statistical estimation of preconditions by persistent operational observation of the catchment's soil moisture condition improves the reliability of flood warning. The soil moisture acts as a state variable controlling the risk of surface runoff, which is assumed to provoke critical floods. Critical soil moisture conditions can be identified by measurements in certain areas representative for the catchment. The operationally yielded point information of soil moisture can be regionalized by a spatial distribution extracted from Landsat-TM images. In this fashion the catchment status can be determined and combined with precipitation forecasts, thus allowing for the comprehensive risk calculation of critical floods.

3 METHODOLOGY

Spatial distribution of soil moisture and representative measurement areas are found by processing Landsat-TM images. Usually the medium infrared channels 5 and 7 of the Landsat-TM-5 („Thematic Mapper") are used to assess moisture of vegetation and soil. These two channels only perform a part of the moisture information of a Landsat scene: An increase of water content makes the reflectivity decrease in the visible and infrared ranges of wavelength. Better results are earned by a multi analysis of variance of all TM-channels (Vogt, Lenco, 1995). This is achieved by a standard principal component analysis, which is directly operated on each TM-data set (comparable with Crist, Cicone, 1984). Thus 6 channels are reduced to 4 principal components (Kalman-Loéve-Transformation). In general the first three components explain approx. 95-98% of the total variance of an image. Based on principal component structure an attachment to the information „brightness", „greenness" and „wetness" is possible. The principal component „wetness" shows a positive correlation to the medium infrared channels (5, 7) and mostly a negative to the others. By comparison of wet and dry TM-image different soil moisture zones can be identified. The application of this procedure with other TM-images indicates the distributed soil moisture dynamic. Superposing topographic index, land use, soils, and geology, the dynamic structure of soil moisture can be explained and reconstructed for any other catchment with the same boundary conditions. From this dynamic classification, measurement areas representative for catchment's soil moisture conditions can be extracted with different purposes: a.) Identification of ground states b.) Identification of extreme states. The regionalisation of these measurements can be done by the derived dynamic soil moisture distribution.

To estimate the overall condition in the catchment, persistent soil moisture measurement facilities will be installed. The core of each will be a time domain reflectrometer (TDR), Tektronix 1502. Up to 47 twin rod probes of different lengths can be connected to the TDR via a multiplexer. A programmable single board computer (SBC), equipped with a GSM modem to enable remote access will control the system.

4 CONCLUSION

This satellite based technology enables the detection of soil moisture dynamics in a catchment. The coupling of soil moisture measurements and satellite based regionalisation will lead to a non-statistical soil moisture state and thus to the catchments preconditions. An increase in reliability for flood warning and flood forecast in small sized catchments will result.

REFERENCES

Vogt, T., Lenco, M. (1995): Wetland Mapping and monitoring on the Rhine Alluvial Plain (Alsace, France) with Landsat TM. Sistema Terra, Vol. 4 (3): 75-78

Crist, E.P., Cicone, R.C. (1984): Application of the Tasseled Cap Concept to Simulated Thematic Mapper Data. Photogrammetric Engineering and Remote Sensing, Vol. 50 (3):343-352

FLOOD ESTIMATION USING THE «HYDROLOGICAL ATLAS OF SWITZERLAND»

Rolf Weingartner, Felix Hauser

Institute of Geography, University of Berne, Hallerstr. 12, CH-3012 Berne, Switzerland,
wein@giub.unibe.ch, hauser@giub.unibe.ch

The «Hydrological Atlas of Switzerland» combines and represents current knowledge on the resource Water in general surveys of the whole country. The hydrological knowledge acquired in Switzerland over many decades of measuring activity, analysis and research is thus made available not only to specialists and research scientists but also to a wider public. The sequence of maps follows the topics of the water cycle and covers the chapters Fundamental Maps, Precipitation, Snow and Glaciers, Evaporation, Rivers and Lakes, Water Balance, Material Balance, Soil- and Groundwater. In 2002 the Atlas comprises six publication sets and contains a total of 44 plates. Additional plates are scheduled. Switzerland has frequently been affected by flood events. This topic therefore receives great concern and is top on the agenda of Swiss hydrology. Important regional aspects of hydrology are represented by means of maps and tables and embrace different viewpoints. Immediate digital access to the information is available. The host and variety of flood information can – according to Figure 1 – be subdivided into «Basic disposition», «Variable disposition», «Initial event» and «Flood event». The occurrence and magnitude of floods (Figure 2) are therefore determined by both the basic and variable disposition on the one hand and the initial event on the other.

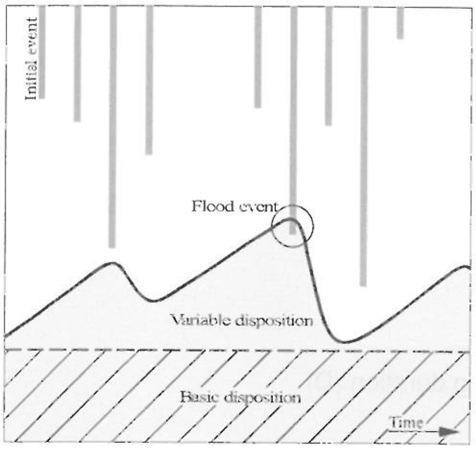


Figure 1: Scheme of basic disposition, variable disposition and initial event in a catchment (acc. Gamma, 2000).

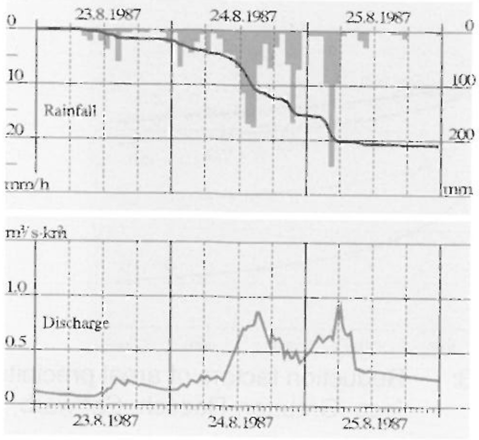
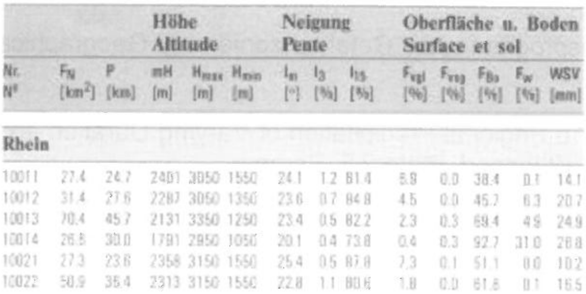


Figure 2: Hydrograph of a flood event in a catchment (acc. Naef et al., 1999).

The **basic disposition** of a catchment is established by catchment characteristics influencing the runoff generation, e.g. soil parameters and topographic aspects. Plate 1.2 «Characteristics of Small Basins» provides relevant information on the subject of small catchments covering a mean area of 30 square kilometres (Table 1). Switzerland is divided into 1080 small basins. By means of aggregation the information from small catchments can be derived for larger basins equally. Based on these properties numerous methods of flood estimation were developed, and further developed respectively. Barben (2001) incorporated some of these methods, which are used frequently in daily practice, into a programme package which allows for a direct flood estimation in ungauged catchments by way of 10 different methods.

Table 1: Basin characteristics of small Swiss catchments (Breinlinger, Gamma, Weingartner, 1992).



			Höhe Altitude			Neigung Pente			Oberfläche u. Boden Surface et sol				
Nr. N°	F_N [km²]	P [km]	mH [m]	H_{max} [m]	H_{min} [m]	I_m [°]	I_3 [%]	I_{15} [%]	F_{vgl} [%]	F_{vsg} [%]	F_{Bo} [%]	F_W [%]	WSV [mm]
Rhein													
10011	27.4	24.7	2401	3050	1550	24.1	1.2	81.4	5.8	0.0	38.4	0.1	14.1
10012	31.4	27.6	2287	3050	1350	23.6	0.7	84.8	4.5	0.0	45.7	6.3	20.7
10013	70.4	45.7	2131	3350	1250	23.4	0.5	82.2	2.3	0.3	69.4	4.9	24.9
10014	26.8	30.0	1791	2950	1050	20.1	0.4	73.8	0.4	0.3	92.7	31.0	28.8
10021	27.3	23.6	2358	3150	1550	25.4	0.5	87.8	7.3	0.1	51.1	0.0	10.2
10022	50.9	35.4	2313	3150	1550	22.8	1.1	80.6	1.8	0.0	61.6	0.1	16.5

Nr.	Basin number	F_{vgl}	Glacier cover
F_N	Basin area	F_{vsg}	Impervious area
P	Perimeter	F_{Bo}	Area covered with soil
mH	Mean altitude	F_W	Forested area
H_{max}	Maximum altitude	WSV	Mean water retention capacity of soil
H_{min}	Minimum altitude		
I_m	Mean slope		
I_3	Surface with slope less than 3°		
I_{15}	Surface with slope greater than 15°		

Plate 5.7 «Major Floods – Differing Reactions of Catchments to Intense Rainfall» permits further informative insights into the process of runoff generation, showing the complexity of this phenomenon.
The **variable disposition** is mostly influenced by the past history of an event. Factors influencing the runoff generation are subject to daily, seasonal and annual change. Experience gained in regional analysis reveals that mean annual and seasonal precipitation totals represent a meaningful indicator for the variable disposition of a catchment. The «Hydrological Atlas of Switzerland» covers this topic over four plates (2.2, 2.3, 2.6, 2.7). Additional information on the snow conditions displayed by chapter 3 should nevertheless be taken into account.
The **initial event** of a flood normally occurs, apart from some special incidents, along with extreme precipitation of varying duration. Plates 2.4 und 2.4^2 «Extreme Point Rainfall of Varying Duration and Return Period 1901–1970» indicate the relevant rainfall data for each grid point (resolution 1km • 1km) of Switzerland. For regional analysis these point values have to be depleted in relation to the surface of the observed basin. Plate 2.5 «Extreme Regional Precipitation of Varying Duration and Return Period 1981–1993» provides essential data and information on this subject (Figure 3). Relative depletion curves give an areal reduction factor (AF) for each zone, duration period and area size, which represents the ratio of the areal precipitation to the point value at the centre of the precipitation field (Grebner, Roesch, Schwarb, 1999).

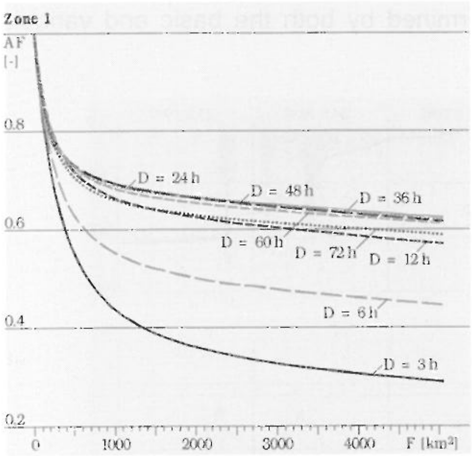


Figure 3: Reduction factors of areal precipitation with varying duration (D) (acc. Grebner, Roesch, Schwarb, 1999).

Last but not least, the most essential **flood characteristics** (eg. mean annual flood, 50-year peak flood, highest flood observed) of approximately 300 discharge stations availing of long-standing measuring series are represented in plate 5.6 «Flood Discharge – Analysis of Long-Standing Measurement Series». Floods of any return period can be estimated using the mean annual flood and the standard deviation of annual floods. The data also permit interesting areal comparison and help to classify current events.

REFERENCES

Barben, M. (2001): Beurteilung von Verfahren zur Abschätzung seltener Hochwasserabflüsse in mesoskaligen Einzugsgebieten. Institute of Geography, University of Berne, Berne.

Breinlinger, R., Gamma, P., Weingartner, R. (1992): Characteristics of Small Basins. In: Hydrological Atlas of Switzerland, Plate 1.2, Berne.

Gamma, P. (2000): dfwalk – Ein Murgang-Simulationsprogramm zur Gefahrenzonierung. Geographica Bernensia G66, Berne.

Grebner, D., Roesch, T., Schwarb, M. (1999): Extreme Regional Precipitation of Varying Duration and Return Period 1981–1993. In: Hydrological Atlas of Switzerland, Plate 2.5, Berne.

Naef, F. et al. (1999): Major Floods – Differing Reactions of Catchments to Intense Rainfall. In: Hydrological Atlas of Switzerland, Plate 5.7, Berne.

FLOOD INUNDATION MODELLING: A COMPARISON OF APPROACHES THROUGH PREDICTIVE UNCERTAINTIES AND THE VALUE OF SPATIAL DATA

Micha Werner

Delft University of Technology / Delft Hydraulics, P.O. Box 5048, 2600 GA Delft, The Netherlands,
Micha.Werner@wldelft.nl

SUMMARY

Flood extent mapping for spatially estimating flood hazards is increasingly being applied in both research and practice with the integration of hydrodynamic models and GIS a natural step to attain the spatial dimension. A variety of approaches are available, varying in model complexity and level of integration. Depending on availability of geographical data and data on flood events, the most suitable approach may differ from case to case. In the project presented in this poster, different approaches are investigated. The impact of availability, resolution and accuracy of geographical data is taken into account, together with the problem of model parameter identification. In a case briefly presented, two approaches are compared. The first applies a 1D hydrodynamic model and derives a flood inundation map through geographical interpolation. The second applies a raster based 2D hydrodynamic model.

Keywords: Flood Inundation mapping, uncertainty, parameter estimation, GIS

1 INTRODUCTION

Inundation through river flooding is a hazard affecting flood prone areas across the world. Modelling floodplain inundation is an important step in the understanding of the processes involved and also provides the link between estimation of flood discharges and flood risk and damage assessment (Paquier and Farissier, 1997). The spatial nature of floodplain inundation allows for a natural integration of Geographic Information Systems (GIS) in this modelling, and the increasing availability of highly detailed floodplain elevation maps and floodplain land use maps has furthered the potential of this integration. Models that can deal with native GIS data formats are integrated most naturally, with 2D model approaches being readily integrated (Bates and de Roo, 2000). Widely applied 1D hydrodynamic modelling approaches can also be integrated with GIS through application of interpolation techniques (Werner, 2001), although scope of application is not as wide as for the 2D approach. Although representation of hydraulic characteristics in complex 3D models is superior to that in 2D models, which is in turn superior to that in 1D models, problems with parameter identification and accuracy and resolution of data may cause this gain in hydraulic accuracy to be obscured. Availability of high-resolution spatial data for floodplains is increasing (Bates and de Roo, 2000), but using this high-resolution data does increase the computational burden, without necessarily adding to accuracy. This holds both for elevation data as for floodplain land use (roughness) data.

2 APPROACH

In the research project introduced here, different methods for modelling floodplain inundation through a combination of GIS and models are investigated. The methods range from a simple interpolation approach using results from a 1D model, through a simple 2D raster based inundation model to a more complex hydrodynamic 2D model. Each of these approaches has its merits, and examples in literature and practice of each approach fitting observed data are easily found, with optimisation typically being the parameter estimation philosophy applied. To compare models, an alternative methodology in parameter estimation is taken, where the existence of multiple "equivalent" parameter sets is accepted. Referred to as Generalised Likelihood Uncertainty Estimation, or GLUE (Romanowicz et al., 1996), this has been applied to both hydrological modelling as well as flood inundation modelling and uses Monte Carlo Simulation for exploring parameter distributions. To reduce an excessive number of model runs for computationally expensive models, Latin Hypercube sampling techniques are used here (McKay et al., 1979). Assessment of predictive uncertainties in estimated flood extent maps using the different modelling approaches, and the impact of availability, resolution and accuracy of spatial data are used in the comparison.

3 CASE: SCHWEMLINGER WIESEN, SAAR, GERMANY

As an illustration in this short paper, some results for the Schwemlinger Wiesen floodplain on the Saar River in Germany are presented. Two approaches are taken, the first using a 1D hydrodynamic model (SOBEK, abbreviated to sbk), the second using a 2D raster based hydrodynamic model (Delft-FLS, abbreviated to FLS, see Stelling et al., 1996). The resolution of the elevation model used is varied between 10x10m (dem10) and 20x20m (dem20), with the second elevation model derived from the first through aggregation by averaging. To account for the hydraulic barrier formed by a motorway running through the floodplain (Fig. 3-1a), a third elevation model is created, where cells on this motorway are maximised rather than averaged in the aggregation. (dem20r).

4 DISCUSSION AND CONCLUSIONS

Results show that predictive uncertainties for maximum levels at the gauging station used in calibration for the 1D and 2D model are similar (Fig. 3-1b, *sbk dem20 (no)*, *sbk dem10, sbk dem20r, sbk dem10*). Constraining models on flooding behind the motorway reveals that usage of the simple aggregated elevation data is unsuitable (*sbk dem20 (yes)).* The case shows that using only comparison of computed levels to those observed at gauging stations does not allow for a clear distinction in results achieved with models of differing complexity, but may result in erroneous estimation of flood extent and thus hazard (Fig. 3-1a, *sbk dem20 (no)*). Addition of information on geographical extent of the flood does not distinguish between the models but does indicate if the resolution of spatial data is suitable. The extent of areas inundated with a certainty of 95% in fig. 3-1a show that for models using suitable spatial data, these areas are insensitive to model complexity.

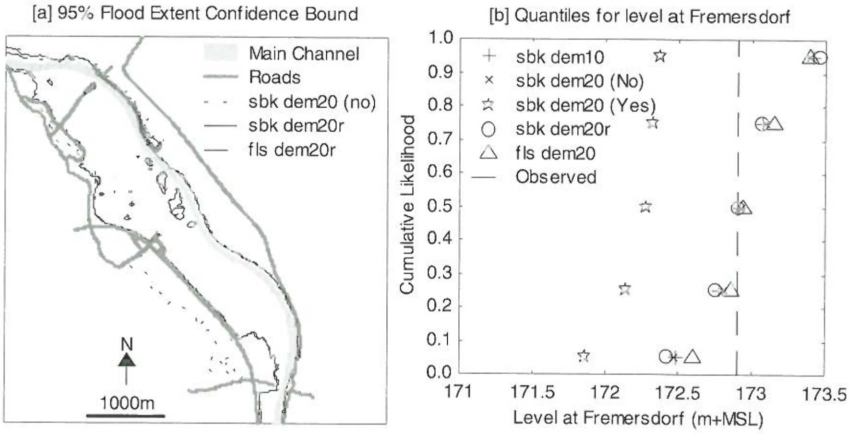


Figure 3-1: Flood extent maps and predictive uncertainties for levels at Fremersdorf.

REFERENCES

Bates, P., de Roo, A. (2000): A simple raster-based model for flood inundation simulation, Journal of Hydrology, Vol. 236: 54-57. The Netherlands

McKay et al. (1979): A comparison of three methods for selecting values of input variables in the analysis of output from a computer code, Technometrics, Vol. 21, No. 2: 239-245. Washington, USA

Paquier, A., Farissier, P. (1997): Assessment of risks of flooding by use of a 2-D model, Destructive Water: Water Caused Natural Disasters, their Abatement and Control, IAHS Publ. No. 239. Oxford, UK

Romanowicz et al. (1996): Bayesian Calibration of Flood Inundation Models, in Floodplain Processes, D.E. Walling and P.D. Bates (eds.), John Wiley & Sons Ltd. Chichester, UK

Stelling et al. (1996): Delft Flooding System, a powerful tool for inundation assessment based upon a positive flow simulation, Proceedings 3rd Hydroinformatics Conference, Copenhagen, Denmark

Werner, M. (2001): Impact of Grid Size in GIS based flood extent mapping using a 1D flow model, Phys. Chem. Earth (B), Vol. 26: 517-522. Oxford, UK

FLOOD MAPPING WITH SATELLITE SYNTHETIC APERTURE RADAR

Andreas Wiesmann[1], Urs Wegmüller[1], Marc Honikel[2], Tazio Strozzi[1], Charles Werner[1]

[1] Gamma Remote Sensing, Thunstr. 130, 3074 Muri, Switzerland, wiesmann@gamma-rs.ch

[2] Institute of Geodesy and Photogrammetry, Swiss Federal Institute of Technology Zürich, Switzerland, mhonikel@geod.baug.ethz.ch

SUMMARY

This contribution is an assessment of possible roles of satellite based Synthetic Aperture Radar (SAR) for flood estimation. It turns out that SAR data are a powerful source for flood mapping due to their all weather capability and their potential for change detection. Furthermore, systems with beam-steering capabilities (Radarsat, Envisat ASAR) permit a timely acquisition of data after a flood occurred.

Keywords: SAR, flood mapping, synthetic aperture radar, change detection

1 INTRODUCTION

Flooding is a dynamic event that can last from days to weeks. The extent of the flooded area changes with the time. Therefore, the monitored extent is related to the observation time. To be able to monitor the flood and furthermore the dynamic of the flood we need frequent observations. Spaceborne SAR data are well suited for this application due to their "all weather", and day/night capabilities and the sensitivity for change in the target geometry. Furthermore, SAR data provide information on the terrain height and the landuse, parameters that are also of interest in this context. In this paper we will show the potential of SAR for flood mapping will be discussed with a special emphasise on the improvements with the planned new sensors.

2 METHODOLOGY

In order to identify SAR related parameters well suited for flood mapping, it is necessary to assess the effect of the disaster on the scattering properties (Table 1). We have mainly two situations, a) the area is mostly covered with water and b) the water surface is mainly hidden by objects, e.g. in a dense forest. In case a) the dramatic change in the surface characteristics modifies the scattering mechanisms for the frequency range of the operating satellite based SAR systems (1 - 5 GHz) from volume scattering to specular scattering. That means that for smooth water surfaces the backscattering coefficient σ^0 is very low because the energy transmitted by the sensor is reflected on the water surface and only a small amount is scattered back to the sensor. This backscattering increases if the water surface is rough due to wind. The interferometric coherence γ, a measure for the stability of the scatterers, is very low. Figure 3-1 shows the σ^0 and γ values for some typical land classes.
In case b) the signature depends on the density of the forest. If the forest is dense, the water cannot be seen below the trees and is invisible for the sensors. The values of σ^0 and γ remain unchanged.
Depending on the amount of available data different approaches can be considered combining σ^0 and γ and the change of these parameters comparing the situation before or after the flood with the situation during the flood.

Table 2-1: process model and corresponding change in the SAR parameters.

Before hazard	During/After hazard	Change
farmland	shallow water surface	σ^0 decrease, γ decrease
forest	trees in water	σ^0 increase
urban area	buildings, obstacles in water	σ^0 increase

3 RESULTS

Three flood events at different locations and of different size have been investigated, two minor events in Belp, Switzerland and NE Hungary and a major event in the Mekong Delta. For all places the results are in good agreement with ground observations. Figure 3-2 shows the flood map of Bern airport towards the end of the flood on 26 May 1999. While the flooded fields are accurately mapped, the flooded forest between the river Aare and Gürbe is not detected. In Figure 3-3 a small-scale flood in NE Hungary is shown. The base map is a geocoded SAR image. The dynamic behaviour of the large-scale flood in the Mekong Delta in 1996 is shown in Figure 3-4. The water from the river Mekong floods from the north into the rice fields, lowering the backscattering behaviour. Some of the irrigation channels show a higher backscattering coefficient due to the trees standing in the water and causing high double bounce trunk-ground scattering.

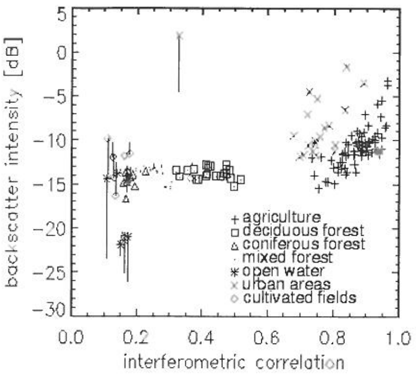


Figure 3-1: Backscatter intensity versus degree of coherence for a variety of surface classes for ERS data. If the backscatter change between the first and second data acquisition exceeds 0.5 dB the change is indicated by a vertical line.

Figure 3-2: Flood layer for 26-May-1999 (dark) obtained from multi-temporal ERS SAR data combined with the geographic map of the area. Grid size is 1 km.

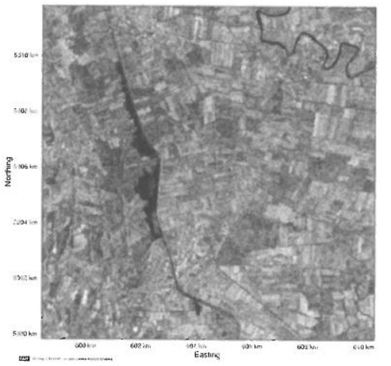
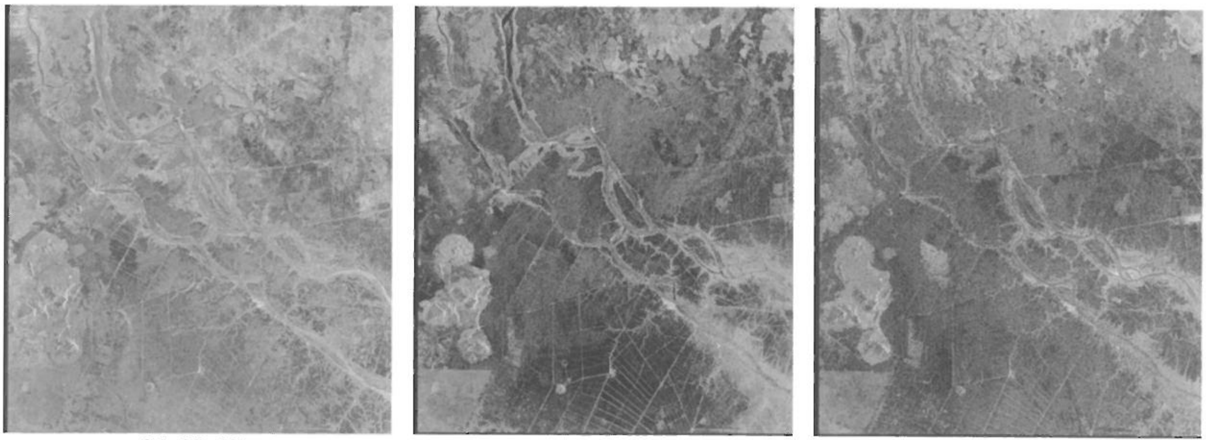


Figure 3-3: Multi-temporal SAR and change detection methods were used to map the flood extend on 11-Jan-1999 (UTM Zone 34, WGS-84, 20m pixel spacing). The dark polygon is indicating the flooded area.



96-08-02 96-09-06 96-12-20

Figure 3-4: ERS SAR images of the Mekong Delta showing different flood situations. The dark areas (low backscattering) indicate flooded fields.

4 CONCLUSIONS AND OUTLOOK

The results confirm the potential of satellite SAR for flood mapping. However, due to the 35-day repeat cycle of ERS it was not possible to map the max flood extent in the examples above. Future satellites like ENVISAT, Radarsat II and ALOS with beam-steering capabilities will reduce the reaction time to a few days at most. This will improve the capability to monitor flood and flood dynamics greatly.

PUBLICATIONS OF CHR

PUBLICATIONS OF CHR
KHR-VERÖFFENTLICHUNGEN
PUBLICATIONS DE LA CHR

CHR/KHR (1978): Das Rheingebiet, Hydrologische Monographie. Staatsuitgeverij, Den Haag/Le bassin du Rhin. Monographie Hydrologique. Staatsuitgeverij, La Haye. ISBN 90-12017-75-0
Nicht mehr lieferbar

CHR REPORTS
BERICHTE DER KHR
RAPPORTS DE LA CHR

I-20 KRAHE, P; HERPERTZ, D. (2001): Generation of Hydrometeorological Reference Conditions for the Assessment of Flood Hazard in large River Basins – Papers presented at the International Workshop held on March 6 and 7 2001 in Koblenz ISBN90-36954-18-5

I-19 BARBEN, M.; HODEL, H. P.; KLEEBERG, H. B.; SPREAFICO, M.; WEINGARTNER, R. (2001): Übersicht über Verfahren zur Abschätzung von Hochwasserabflüssen – Erfahrungen aus den Rheinanliegerstaaten. ISBN 90-36954-11-8

I-18 KOS, Th.J.M.; SCHEMMER, H.; JAKOB, A. (2000): Feststoffmessungen zum Vergleich von Messgeräte und Messmethoden im Rhein, 10-12 März 1998. ISBN 90-36953-54-5

I-17 ENGEL, H. (1999): Eine Hochwasserperiode im Rheingebiet. Extremereignisse zwischen Dez. 1993 und Febr. 1995. ISBN 90-70980-28-2

I-16 GRABS, W. (ed.) (1997): Impact of climate change on hydrological regimes and water resources management in the Rhine basin. ISBN 90-70980-26-6

I-15 ENGEL, H. (1997): Fortschreibung der Monographie des Rheingebietes für die Zeit 1971-1990/Actualisation de la Monographie du Bassin du rhin pour le période 1971- 1990. ISBN 90-70980-25-8

I-14 EMMENEGGER, CH. et al. (1997): 25 Jahre KHR. Kolloquium aus Anlaß des 25jährigen Bestehens der KHR / 25 ans de la CHR. Colloque à l'occasion du 25e anniversaire de la CHR. 1SBN 90-70980-24-x 1-15 ENGEL, H. (1997): Fortschreibung der Monographie des Rheingebietes für die Zeit 1971-1990 / Actualisation de la Monographie du Bassin du Rhin pour la période 1971-1990. ISBN 90-7098025-8

I-13 SPREAFICO, M., MAZIJK, A. VAN (réd.) (1997): Modèle d'alerte pour le Rhin. Un modèle pour la prévision opérationnelle de le propagation de produits nocifs dans le Rhin. ISBN 9070980-23-1

I-12 SPREAFICO, M.; MAZIJK, A. VAN (Red.) (1993): Alarmmodell Rhein. Ein Modell für die operationelle Vorhersage des Transportes von Schadstoffen im Rhein. ISBN 90-70980-18-5

I-11 BUCK, W.; FELKEL, K.; GERHARD, H., KALWEIT, H.; MALDE, J. VAN; NIPPES, K.-R., PLOEGER, B., SCHMITZ, W. (1993): Der Rhein unter der Einwirkung des Menschen - Ausbau, Schiffahrt, Wasserwirtschaft / Le Rhin sous l'influence de l'homme - Aménagement, navigation, gestion des eaux. ISBN 90-70980-17-7

I-10 NIPPES, K.-R. (1991): Bibliographie des Rheingebietes / Bibliographie du bassin du Rhin. ISBN 90-70980-13-4

I-9 CHR/KHR (1990): Das Hochwasser 1988 im Rheingebiet / La crue de 1988 dans le bassin du Rhin. ISBN 90-70980-11-8

I-8 ENGEL, H., SCHREIBER, H.; SPREAFICO, M., TEUBER, W.; ZUMSTEIN, J.F. (1990): Abflußermittlung im Rheingebiet im Bereich der Landesgrenzen / Détermination des débits dans les régions frontalières du bassin du Rhin. ISBN 90-70980-10-x

I-7 MENDEL, H.-G. (1988): Beschreibung hydrologischer Vorhersagemodelle im Rheineinzugsgebiet / Description de modèles de prévision hydrologiques dans le bassin du Rhin. ISBN 90-7098006-1

I-6 TEUBER, W. (1987): Einfluß der Kalibrierung hydrometrischer Meßflügel auf die Unsicherheit der Abflußermittlung. Ergebnisse eines Ringversuchs / Influence de l'étalonnage des moulinets hydrométriques sur l'incertitude des déterminations de débits. Résultats d'une étude comparative. ISBN 90-70980-05-3

I-5 TEUBER, W.; VERAART, A.J. (1986): Abflußermittlung am Rhein im deutsch-niederländischen Grenzbereich / La détermination des débits du Rhin dans la région frontalière germano-hollandaise. ISBN 90-70980-04-5

I-4 BUCK, W.; KIPGEN, R.; MADE, J.W. VAN DER; MONTMOLLIN, F. DE; ZETTL, H.; ZUMSTEIN, J.F. (1986): Berechnung von Hoch- und Niedrigwasserwahrscheinlichkeit im Rheingebiet / Estimation des probabilités de crues et d'étiages dans le bassin du Rhin. ISBN 90-7098003-7

I-3 HOFIUS, K. (1985): Hydrologische Untersuchungsgebiete im Rheingebiet / Bassins de recherches hydrologiques dans le bassin du Rhin. ISBN 90-70980-02-9

I-2 GERHARD, H.; MADE, J.W. VAN DER; REIFF, J.; VREES, L.P.M. DE (1983): Die Trocken- und Niedrigwasserperiode 1976. (2. Auflage 1985) / La sécheresse et les basses eaux de 1976 (2ème édition, 1985). ISBN 90-70980-0 1 -0

I-1 GREBNER, D. (1982): Objektive quantitative Niederschlagsvorhersagen im Rheingebiet. Stand 1982 (nicht mehr lieferbar) / Prévisions objectives et quantitatives des précipitations dans le bassin du Rhin. Etat de la question en 1982 (édition épuissée)

Katalog/Catalogue 1 SPROKKEREEF, E. (1989): Verzeichnis der für internationale Organisationen wichtigen Meßstellen im Rheingebiet / Tableau de stations de mesure importantes pour les organismes internationaux dans le bassin du Rhin. ISBN 90-70980-08-8

REPORTS SPONSORED BY CHR
BERICHTE UNTER DER SCHIRMHERRSCHAFT DER KHR
RAPPORTS SOUS L'ÈGIDE DE LA CHR

II-16 MAZIJK, A. VAN; GILS, J.A.G. VAN; WEITBRECHT, V.; VOLLSTEDT, S. (2000): ANALYSE und EVALUIERUNG der 2D-MODULE zur Berechnung des Stofftransportes in der Windows-Version des RHEINALARMMODELLS in Theorie und Praxis. ISBN 90-36953-55-3

II-15 KWADIJK, J.; DEURSEN, W. VAN (1999): Development and testing of a GIS based water balance model for the Rhine drainage basin. ISBN 90-70980-31-2

II-14 MAZIJK, A. VAN; LEIBUNDGUT, CH.; NEFF, H.-P. (1999): Rhein-Alarm-Modell Version 2. 1. Erweiterung um die Kalibrierung von Aare und Mosel. Kalibrierungsergebnisse von Aare und Mosel aufgrund der Markierversuche 05/92, 11/92 und 03/94. ISBN 90-70980-30-4

II-13 DRÖGE, B., HENOCH, H.; KELBER, W.; MAHR, U.; SWANENBERG, T.; THIELEMANN, T., THURM, U. (1999): Entwicklung eines Längsprofils des Rheins. Bericht für die Musterstrecke von Rhein-km 800 - 845. Arbeitsgruppe 'Sedimenttransport im Rhein' Projekt 3. ISBN 90-70980-29-0

II-12 SCHÄDLER, B. (Red.) (1997): Bestandsaufnahme der Meldesysteme und Vorschläge zur Verbesserung der Hochwasservorhersage im Rheingebiet. Schlußbericht der IKSR-Arbeitseinheit 'Meldesysteme / Hochwasservorhersage' - Projektgruppe 'Aktionsplan Hochwasser' / Annonce et prévision des crues dans le bassin du Rhin. Etat actuel et propositions d'amélioration. Rapport final de l'unité de travail 'Systèmes d'annonce / prévision des crues' - Groupe de projet 'Plan d'action contre les inondations'. ISBN 90-70980-27-4

II-11 SPREAFICO, M., LEHMANN, C., SCHEMMER, H.; BURGDORFFER, M.; KOS, T.L. (1996): Feststoffbeobachtung im Rhein, Beschreibung der Meßgeräte und Meßmethoden. ISBN 90-70980-22-3

II-10 WILDENHAHN, E.; KLAHOLZ, U. (1996): Grobe Speicherseen im Einzugsgebiet des Rheins. ISBN 90-70980-21-5

II-9 WITTE, W., KRAHE, P.; LIEBSCHER, H.-J. (1995): Rekonstruktion der Witterungsverhältnisse im Mittelrheingebiet von 1000 n. Chr. bis heute anhand historischer hydrologischer Ereignisse. ISBN 90-70980-20-7

II-8 MENDEL, H.-G. (1993): Verteilungsfunktionen in der Hydrologie. ISBN 90-70980-19-3

II-7 NEMEC, J. (1993): Comparison and selection of existing hydrological models for the simulation of the dynamic water balance processes in basins of different sizes and on different scales. ISBN 90-70980-16-9

II-6 CHR/KHR (1992): Contributions to the European workshop Ecological Rehabilitation of Floodplains, Arnhem, The Netherlands, 22-24 September 1992. ISBN 90-70980-15-0

II-5 MADE, J.W. VAN DER (1991): Kosten-Nutzen-Analyse für den Entwurf hydrometrischer Meßnetze / Analyse des coûts et des bénéfices pour le projet d'un réseau hydrométrique. ISBN 9070980-14-2

II-4 MAZIJK, A. VAN; VERWOERDT, P., MIERLO, J. VAN, BREMICKER, M.; WIESNER, H. (1991): Rheinalarmmodell Version 2.0 - Kalibrierung und Verifikation / Modèle d'alerte pour le Rhin version 2.0 -Calibration et vérification. ISBN 90-70980-12-6

II-3 SCHRÖDER, U. (1990): Die Hochwasser an Rhein und Mosel im April und Mai 1983 / Les crues sur les bassins du Rhin et de la Moselle en avril et mai 1983. ISBN 90-70980-09-6

II-2 GRIFFIOEN, P.S. (I 989): Alarmmodell für den Rhein / Modèle d'alerte pour le Rhin. ISBN 9070980-07-x

II-1 MADE, J.W. VAN DER (1982): Quantitative Analyse der Abflüsse (nicht mehr lieferbar) / Analyse quantitative des débits (édition épuisée)

INFORMATION ABOUT CHR

INTERNATIONAL COMMISSION FOR THE HYDROLOGY OF THE RHINE BASIN (CHR)

The **CHR** is an organisation in which the scientific institutes of the Rhine riparian states develop joint hydrological measures for sustainable development of the Rhine basin.

CHR's mission and tasks:

Acquiring knowledge of the hydrology of the Rhine basin through:

- joint research
- exchange of data, methods and information
- development of standardised procedures
- publications in the CHR series

Making a contribution to the solution of cross-border problems through the formulation, management and provision of:

- information systems (CHR Rhine GIS)
- models, e.g. models for water management and the Rhine Alarm model

Co-operating countries:

Switzerland, Austria, Germany, France, Luxembourg and the Netherlands.

Relationship with UNESCO and WMO:

The CHR was founded in 1970 following advice by UNESCO to promote closer co-operation between international river basins. Since 1975, the work has been continued within the framework of the International Hydrological Programme (IHP) of the UNESCO and the Operational Hydrological Programme (OHP) of the WMO.

Selection of CHR activities in 2002:

Changes in the discharge regime

Climatic changes and intervention by man in the Rhine catchment area may bring about a change in the discharge regime. A new CHR study will concentrate on investigating long series of discharges. It will attempt to explain differences in series of measurements, e.g. as a result of changes in soil use and/or other human intervention.

Sediment

Sedimentation and erosion can lead to problems in the navigable depth for shipping, to dehydration, to undermining of foundations, as well as to damage to nature and the landscape. CHR research in 2002 concentrated on the study of morphological models used in the Rhine catchment area.

Rhine GIS

The Geographical Information System is a database for the Rhine catchment area, holding digitised geographical and hydrological parameters. The database also covers meteorological time series.
The CHR Rhine GIS is used in increasingly more studies, to which the CHR is a partner.
In 2002, the system was expanded with new climatic data.

The Rhine Alarm model forecasts the progress of pollution following the discharge of harmful substances. In co-operation with its users, the model's user friendliness and sturdiness was considerably improved.

For more information on the CHR, refer to the web site: www.chr-khr.org

DIE INTERNATIONALE KOMMISSION FÜR DIE HYDROLOGIE DES RHEINGEBIETES (KHR):

Die **KHR** ist eine Organisation, in der wissenschaftliche Institutionen der Rheinanliegerstaaten gemeinsam hydrologische Grundlagen für die nachhaltige Entwicklung im Rheingebiet erarbeiten.

Mission und Aufgaben der KHR sind:

Erweiterung der Kenntnisse über die Hydrologie des Rheingebietes durch:
- gemeinsame Untersuchungen
- Austausch von Daten, Methoden und Informationen
- Entwicklung standardisierter Verfahren
- Veröffentlichungen in einer eigenen Schriftenreihe

Beiträge zur Lösung von grenzüberschreitenden Problemen durch die Entwicklung, Verwaltung und Bereitstellung von:
- Informationssystemen (KHR-Rhein-GIS)
- Modellen, wie z. B. Wasserhaushaltsmodelle und das Rhein-Alarmmodel

Die Länder, die sich daran beteiligen, sind:

die Schweiz, Österreich, Deutschland, Frankreich, Luxemburg und die Niederlande.

Beziehung zur UNESCO und WMO:

Die KHR wurde 1970 anlässlich der UNESCO-Empfehlung zur Förderung einer engeren Zusammenarbeit in internationalen Flussgebieten gegründet. Seit 1975 erfolgt die Fortsetzung der Arbeiten im Rahmen des Internationalen Hydrologischen Programms (IHP) der UNESCO und des Operationellen Hydrologischen Programms (OHP) der WMO.

Auszug aus den KHR-Aktivitäten für das Jahr 2002:

Änderungen im Abflussregime

Klimaänderungen und menschliche Eingriffe im Rheineinzugsgebiet können zu einer Veränderung des Abflussregimes führen. Eine neue KHR-Studie wird sich auf die Untersuchung langer Abflussreihen konzentrieren. Versucht werden soll, Unterschiede in den Messreihen zu erklären, z. B. durch Änderungen der Bodennutzung und/oder andere menschliche Eingriffe.

Sediment

Sedimentation und Erosion können zu Problemen hinsichtlich der Fahrwassertiefe für die Schifffahrt, zu Austrocknung sowie zu einer Unterhöhlung von Fundamenten, Schädigung der Natur und Beeinträchtigung der Landschaftswerte führen. Die KHR-Untersuchungen richten sich im Jahr 2002 auf die Untersuchung von morphologischen Modellen, die im Rheineinzugsgebiet eingesetzt werden.

Rhein-GIS

Das geographische Informationssystem ist eine Datenbank des Rheineinzugsgebietes mit digitalisierten geographischen und hydrologischen Kenngrößen. Diese Datenbank umfasst auch meteorologische Zeitreihen.
Das Rhein-GIS der KHR wird bei stets mehr Untersuchungen, bei denen die KHR als Partner fungiert, eingesetzt.
Das System wird 2002 um neue Klimadaten erweitert.

Das Rhein-Alarmmodell sagt bei Schadstoffeinleitungen den Verlauf der Verunreinigung vorher. Die Anwenderfreundlichkeit und Zuverlässigkeit des Modells wurde neulich in Zusammenarbeit mit den niederländischen Anwendern des Modells erheblich verbessert.

Nähere Informationen über die KHR können Sie auf der Website www.chr-khr.org finden.

LA COMMISSION INTERNATIONALE POUR L'HYDROLOGIE DU BASSIN DE RHIN (CHR)

La **CHR** est une organisation regroupant les instituts scientifiques des Etats riverains du Rhin dans le but d'établir des bases hydrologiques pour un développement durable dans le bassin du Rhin.

Mission et tâches de la CHR:

Elargir les connaissances sur l'hydrologie du bassin versant du Rhin par le biais:

- de la recherche commune
- de l'échange de données, méthodes et information
- du développement de procédures normalisées
- de publications dans les séries CHR

Contribuer à la résolution de problèmes transfrontaliers par la réalisation, la gestion et la mise à disposition de:

- systèmes d'information (SIG Rhin CHR)
- modèles, par exemple des modèles de gestion des eaux et le Modèle d'Alarme pour le Rhin

Les pays suivants apportent leur collaboration:

la Suisse, l'Autriche, l'Allemagne, la France, le Luxembourg et les Pays-Bas.

Relation avec l'UNESCO et l'OMM:

La CHR a été fondée en 1970 sur la recommandation de l'UNESCO en vue de favoriser une collaboration plus étroite entre les bassins versants internationaux. Depuis 1975, les activités se poursuivent dans le cadre du Programme Hydrologique International (PHI) de l'UNESCO et du Programme Hydrologique Opérationnel (PHO) de l'OMM.

Sélection des activités de la CHR en 2002:

Changements dans le régime d'écoulement

Les changements de climat et les interventions humaines dans le bassin versant du Rhin peuvent modifier le régime d'écoulement. Une nouvelle étude de la CHR se concentrera sur l'analyse de longues séries d'écoulement. L'objectif est d'expliquer les différences dans les séries de mesure par les changements de l'occupation des sols et/ou d'autres interventions d'origine humaine.

Sédiments

La sédimentation et l'érosion peuvent provoquer des problèmes de profondeur du chenal pour la navigation, de tarissement, d'affaiblissement de fondations, de dommages à la nature et de nuisance aux intérêts paysagers. En 2002, l'étude de la CHR a concentré ses efforts sur les modèles morphologiques qui sont utilisés dans le bassin versant du Rhin.

SIG Rhin

Le Système d'Information Géographique est une base de données pour le bassin versant du Rhin et contient des données de base géographiques et hydrologiques numérisées. Cette base de données comprend aussi des séries temporelles météorologiques.
Le SIG Rhin de la CHR est de plus en plus utilisé lors d'études auxquelles participe la CHR.
Le système a été enrichi par de nouvelles données.

Le Modèle d'Alarme pour le Rhin prévoit la propagation de la contamination lors de rejets de substances toxiques. Une bonne collaboration avec les utilisateurs du modèle a permis d'améliorer considérablement sa convivialité ainsi que sa fiabilité.

Pour de plus amples informations sur la CHR, consultez le site Internet: www.chr-khr.org

KOLOPHON

PUBLIKATION DER CHR/KHR
Sekretariat , Postfach17
8200 AA Lelystad
Niederlande
Email: info@chr-kh.org
Website: www.chr-khr.org

Übersetzungen: Password Translations, Heino

Drucker: Veenman drukkers, Ede

ISBN: 90-36954-60-6