Hydrological Risk

Recent advances in peak river flow modelling, prediction and real-time forecasting. Assessment of the impacts of land-use and climate changes

National Research Council of Italy
National Group for the Prevention of Hydro-Geological Disasters

Bologna, Italy, Faculty of Engineering
Via del Risorgimento 2, I-40136 Bologna
24-25 October 2003

(Co-sponsored by the National Research Council of Italy,
National Group for the Prevention of Hydrological Hazards)

Convened by

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Scientific Report

1. Summary

The workshop took place on October 24 and 25, 2003, at the Faculty of Engineering of the University of Bologna and was attended by a total of 56 registered participants, plus about 35 not registered university students who were invited to assist to selected lectures. 27 speakers were allowed to give a 15 minutes talk, followed by 5 minutes of discussion.

The workshop was opened by a short presentation given by Lucien Hoffmann, the European Science Foundation representative, and by a talk given by Armando Brath, Chair of the Organising Committee. Presentations were divided into 4 sessions: the first was entitled “Advanced techniques for hydrological processes modelling” and chaired by Armando Brath. Six talks were given within this topic that focused on process understanding and modelling in real world applications. The second session was devoted to “Meteorological and hydrological modelling for flood risk mitigation”, that is, a relevant issue in the field of flood hazards mitigation and forecasting. The session was chaired by Ezio Todini and was composed by six talks. The third session, “Real-time flood forecasting systems and flood modelling” was chaired by Renzo Rosso. Seven talks were given addressing this topic. The last session, titled “Design storm and flood estimation in gauged and ungauged catchments” was chaired by Elena Toth, was made up by six talks and addressed the problem of flood prevention via severe storms and peak discharge estimation in ungauged catchments. This is a relevant research topic that recently gained a lot of attention within the hydrologic community. Such interest is witnessed also by the recent launch of the International Association of Hydrological Sciences Decade for Prediction in Ungauged Basins (PUB).

The presentations raised some interesting discussions. They were allowed at the end of each presentations and addressed to issues raised by the audience and related to each talk.

Speakers were asked to provide a paper related to their presentations and most of them reacted positively. Therefore 23 contributions were collected, which will be published in a proceeding book, under the funding if the National Research Council of Italy.

The next Section of the present Scientific Report shows the workshop programme, updated after the meeting (some changes were made at the Agenda during the symposium). The third section is devoted to a scientific resume of the workshop outcomes. The list of the participants is reported in the fourth Section. In the appendix of the Report the abstracts of the contributions are collected.

2. Workshop programme

Friday, 24 October, 2003

14,30: **Presentation of the European Science Foundation**
Lucien Hoffmann, European Science Foundation Representative

14,40: **Introduction to the Conference**
Armando Brath, University of Bologna, Italy

14.55: **First session: Advanced techniques for hydrological processes modelling.**
Chairman: Armando Brath

Manfred Ostrowski, Darmstadt University of Technology, Germany
Linearity of hydrological models and related uncertainty

Stefan Uhlenbrook, University of Freiburg, Germany
The value of process data in flood modelling

J. Philip O’Kane, University College Cork, Ireland
Dewatering the lower feale: Explorations with a coupled high resolution 3-dimensional hydrological model and digital elevation model

Jasper A. Vrugt, University of Amsterdam, The Netherlands
A combined data assimilation - global optimization method for the identification of model structural errors

Alberto Montanari, University of Bologna, Italy
Optimality or equifinality? A review of uncertainty assessment techniques in rainfall-runoff modelling

Peter Troch, Wageningen University, Germany
The role of hillslopes in understanding flood generation under climate variability

16.55 **Coffee break**

17.20: **Second session: Meteorological and hydrological modelling for flood risk mitigation. Chairman: Ezio Todini**

Dionysia Panagoulia, National Technical University of Athens, Greece
An assessment of climate change impacts on flood forecasting

Joze Rakovec, University of Ljubljana, Slovenia
Orographic enhanced precipitation in fine scale: processes, monitoring, nowcasting and forecasting

Andras Bardossy, University of Stuttgart, Germany
The influence of the spatial variability of precipitation on uncertainty of discharge forecasts

Charles Obled, Institut National Polytechnique de Grenoble, France
Example of a complete operational forecasting chain for mountainous catchments: from nowcasting to medium term forecasts.

Kieran O'Connor, National University of Ireland, Galway, Ireland
A comparison of the 'perfect foresight' and the 'no foresight' input scenarios, to ascertain the value of having good quantitative precipitation forecasts over the forecast lead-time

Baldassare Bacchi, University of Brescia, Italy
Flood forecasting via combined use of meteorological and hydrological models

19,45: **End of afternoon presentations**

21,00: **Workshop dinner in Bologna**

Saturday, 25 October, 2003

8,40 **Third session: Real-time flood forecasting systems and flood modelling. Chairman: Renzo Rosso**

Ezio Todini, University of Bologna, Italy
The present status of real time flood forecasting

Gabor Balint, Hydrological Institute VITUKI, Hungary
Different lead times and different approaches in flood forecasting and warning. Case studies from northern Hungary

Luis Garrote, Universidad Politecnica de Madrid, Spain
A framework for making probabilistic forecasts using deterministic rainfall-runoff models

Elena Toth, University of Bologna, Italy
Use of spatially-distributed or lumped precipitation inputs in conceptual and black-box models for runoff forecasting

Dan Rosbjerg, Technical University of Denmark, Denmark
Data assimilation in the MIKE 11 flood forecasting system using Kalman filtering

Jan Szolgay, Slovak University of Technology, Slovak Republic
Multilinear discrete cascade model for river flow routing and real time. Forecasting in river reaches with variable wave speed

Paul Bates, University of Bristol, United Kingdom
Computationally efficient modelling of flood inundation extent

11.00 **Coffee break**

11.30 **Fourth session: Design storm and flood estimation in gauged and ungauged catchments. Chairman: Elena Toth**

Demetris Koutsoyiannis, National Technical University of Athens, Greece
On the appropriateness of the Gumbel distribution for modelling extreme rainfall

Pierluigi Claps, Politecnico di Torino, Italy
Peak Over Threshold Analysis of flood and rainfall frequency curves

Athanasios Loukas, University of Thessaly, Greece
Peak flow estimation in ungauged watersheds

Ralf Merz, Technische Universität Wien, Austria
Austria Flood Regionalisation and Regional Flood Process types in Austria

Rafael Garcia Bartual, Universidad Politecnica de Valencia, Spain
Synthetic flood scenarios for risk assessment in large dams

Renzo Rosso, Politecnico di Milano, Italy
Firefloods

13,30: **Closure of the workshop: Armando Brath and Lucien Hoffmann**

3. Scientific resume

In the last decades several inundations have occurred in Europe causing loss of lives and financial damages, which have been aggravated, in some cases, by the intense urbanisation of flood prone areas. Considering the Italian case and some of the most considerable events only, in a few years the Po River has been affected by two remarkable floods (1994 and 2000); catastrophic inundations have occurred in Piedmont (1994), Valle d'Aosta (2000), Tuscany (1996), Liguria (2000) and Calabria (2000).

After these disasters, the question has often been raised about the possibility that the apparent increase in the flood frequency is due, at least partially, to climate change or to an increased vulnerability due to recent land use change. These concerns have increased the interest of the scientific community in the effects of climate change and human activities on the river flow regime.

In several cases, the availability of real-time flood warning systems would have allowed a timely implementation of civil protection measures and thus a remarkable mitigation of the damages. For small and medium-sized catchments, especially in mountain areas, where the steep slopes further contribute to shorten the response time of the catchment, a lead time sufficiently long to implement efficient flood control measures may be allowed only with the modelling of the rainfall-runoff transformation process, where the hydrologic forecast is derived from observations of precipitation on the upstream catchment. The need to extend the forecast lead-times, in order to allow the real-time implementation of civil protection measures, makes necessary the use of integrated methodologies, based on the use of both meteorological and hydrological forecasting models.

In addition, the accurate estimation at a given location of the potentially dangerous peak flows, through the identification of the flood magnitude associated with the recurrence interval T (the so-called T-year flood) is crucial for designing flood mitigation structural measures and for the implementation of non-structural measures, such as flood insurance planning.

The workshop aimed to promote an international overview and discussion about on going research studies investigating the possibility to reduce flood risk and flood induced damages. In detail, the aim of the meeting was to present and discuss the results of innovative research activities addressed to the achievement of four main objectives: (1) the improvement of existing methodologies and the development of innovative approaches based on the combined use of meteorological models, remote sensing techniques for rainfall estimation and hydrological models for real-time flood forecasting purposes; (2) the improvement in the performances of rainfall-runoff models to be used for flood forecasting, through the development of more advanced modelling schemes, able to accurately representing the processes governing the rainfall-runoff transformation; (3) the proposal of guidelines for transferring the forecast information to the real-world users, in order to improve the practical implementation of real-time structural and non-structural measures for mitigating flood-induced damages; (4) the comparison of the different techniques used in the European Countries for the estimation of the peak rainfall and river flow associated to a given recurrence interval.

The workshop was opened by a short presentation given by Lucien Hoffmann, the European Science Foundation representative, who talked about the structure of EFS and the funding opportunity EFS offers. Subsequently, an introductory talk was given by Armando Brath, from the University of Bologna, who was the Chair of the Organising Committee. He focused on the development of the flood risk in the last 50 years, with

particular reference to the Italian context. He emphasized that it is unquestionable that an increase of the vulnerability of the flood prone areas took place in the last decades, due to reasons which are not completely clear yet. On the one hand we assisted to a remarkable development of urbanisation that increased the economic value and vulnerability of the alluvial plans. On the other hand, it is alleged that the flood frequency has been increased by climate and land-use change, the latter therefore acting not only indirectly (in terms of economic value of flood prone areas) on the flood risk but also directly affecting the river flow regime. Armando Brath reviewed the results of some recent studies on such impact, in the majority appeared on the scientific literature, since the hydrologic community is currently extremely interested in evaluating the hydrological effects of land-use change. Although these studies appear to agree in recognising that only extensive man-made changes can significantly affect the risk of flood, one should also not forget the relevant role played by local changes of the river banks geometry. As a matter of fact, in the Italian case these changes are frequent. They are typically the consequence of bridge constructions or interventions made in order to protect flood prone river banks of significant economic value, that were formerly used as facilitated inundation areas. Therefore these areas lost their capability of temporarily store a portion of the flood volume, increasing the flood discharge with respect to the former situation. These kinds of intervention are often not considered by the scientific community, yet they are sizeably effective on the inundation frequency.

The first session of the workshop was entitled “Advanced techniques for hydrological processes modelling” and was chaired by Armando Brath. Six talks were given within this topic. First speaker was Manfred Ostrowsky (Darmstadt University of Technology), who focused on the capability of linear models to provide a satisfactory schematisation in hydrological modelling. Second speaker was Stefan Uhlenbrook (University of Freiburg) who talked about the use of tracer data for refining the predictive capability of rainfall-runoff models. Philp O’Kane and Luca Migliori followed, from the University College of Cork, who spoke about an application of a three dimensional hydrologic model. Two talks were subsequently given about uncertainty estimation in rainfall-runoff modelling. This is an issue which is gaining increasing attention from hydrologists; the talks were given by Jasper Vrugt (University of Amsterdam) and Alberto Montanari (University of Bologna) and raised a long discussion among the speakers, that was focused at comparing the peculiarities of different uncertainty estimation techniques. Peter Troch (Wageningen University) spoke about an hillslope-storage model derived from the Boussinesq equation.

The second session was devoted to “Meteorological and hydrological modelling for flood risk mitigation”, a relevant issue in the field of flood hazards mitigation and forecasting. The session was chaired by Ezio Todini and was composed by six talks. The first one was given by Dionysia Panagoulia (National Technical University of Athens) who spoke about climate change effects on flood forecasting. An interesting contribution was given by Joze Rakovec (University of Ljubljana) who was the only ‘pure’ meteorologist present at the workshop. His presentation focused on rainfall modelling and forecasting and highlighted the benefits, in terms of flood forecasting capability, that can be gained by promoting a joint research effort among meteorologists and hydrologists. Andras Bardossy (University of Stuttgart) focused on the effects of rainfall spatial variability on the uncertainty of discharge forecasts while Charles Obled (Institut National Polytechnique de Grenoble) presented a simple flood forecasting model based on the availability of a quantitative precipitation forecasting. A coupled meteorological-hydrological model, developed within the framework of the Mesoscale Alpine Programme, was presented also by Baldassare Bacchi (University of Brescia), while Kieran O’Connor (National University of Ireland) spoke about the possibility to profit from the availability of a statistical quantitative precipitation forecasting when issuing real time flood discharge predictions.

The third session, “Real-time flood forecasting systems and flood modelling” was chaired by Renzo Rosso. Seven talks were given addressing this topic. The session was opened by Ezio Todini (University of Bologna) who presented the research results obtained within the framework of the MUSIC project, leaded by him and financed by the European Community within the fifth framework programme. Purpose of the research project is to develop a ready-to-use integrated precipitation and flood forecasting package. Gabor Balint (Hydrological Institute, Water Resources Research Centre VITUKI, Budapest) presented a review of interesting case studies of flash-floods occurred in Hungary. Luis Garrote (Universidad Politécnica de Madrid) then spoke about a framework for providing probabilistic flood forecasts using a deterministic rainfall-runoff model. The third talk was given by Elena Toth (University of Bologna) who analysed the influence of spatial variability of rainfall input in conceptual and black-box rainfall-runoff models. Dan Rosbjerg (Technical University of Denmark) spoke about an application of the Mike 11

flood forecasting systems, produced by the Danish Hydraulic Institute. River flow routing was dealt with by Jan Szolgay also (from Slovak University of Technology) while Paul Bates (University of Bristol) provided an interesting comparison among different approaches for flood inundation modelling.

The last session, titled “Design storm and flood estimation in gauged and ungauged catchments” was chaired by Elena Toth, was made up by six talks and addressed the problem of flood prevention via severe storms and peak discharge estimation in ungauged catchments. The first presentation was given by Demetris Koutsoyiannis, from National Technical University of Athens, who spoke about the appropriateness of the Gumbel distribution in modelling extreme rainfall. An interesting discussion was raised by his talk, about the opportunity to use upper bounded probability distributions in hydrological modelling. While part of the audience was agreeing in recognising that hydrological extremes should be treated as upper bounded random variables, some of the participants noted that it is presently not possible to provide an estimate for the upper limit of hydrological extremes. The session was carried on by Pierluigi Claps (Politechnic of Turin) who presented a recently developed method for examining peak over threshold series of hydrological extremes. Athanasios Loukas (University of Thessaly) presented a simulation method for the evaluation of the flood frequency. Ralf Merz (Technische Universität Wien) talked about regionalisation of flood peaks in Austria, while Rafael Garcia Bartual (Politechnical University of Valencia) provided a presentation that focused on the analysis of hydrological safety of large dams. Finally Renzo Rosso (Politechnic of Milan) talked about the effects on the flood regime of land-use changes originated by fires.

The workshop was concluded by a short summary presented by Alberto Montanari, who tried to draw a first conclusion. The main feedback the workshop provided was the feeling that an advance in flood risk prevention and mitigation can be gained by promoting a deep interaction among meteorologists, hydrologists and end-users. As a matter of fact, many limits still exist in the integration of meteorological predictions into efficient flood forecasting systems, that can be effectively run by end-users in practical applications. The systematisation of the different approaches can be carried out only by promoting a closer link among all those who are involved in the attempt of reducing the flood risk. A lot of work still remains to be done in hydrology: even if the research activity in this field is significantly increased in the latter years, further efforts are required in order to gain a better understanding of the intrinsic dynamic of hydrological processes. As a matter of fact a considerable uncertainty is still associated with hydrological predictions: there is an urgent need to reduce and quantify it, therefore providing the end-user not only with a best-estimate but also with an indication of its reliability. Last but not least, the workshop participants identified the link between hydrological and flood propagation models as one of the challenging research attempts for the near future.

A few words of conclusion were also given by Lucien Hoffman, who appreciated the workshop and the discussed topics. He regretted that the schedule was perhaps too tight, since he would have liked much more time allowed for discussions. He invited the workshop participants to consider the possibility to set up a ESF network working about the mitigation of the hydrological risk.

A closure was provided by Armando Brath, who thanked ESF for supporting the workshop, the National Group for the Prevention of the Hydrogeological Disasters of the National Research Council of Italy for supporting the publication of the workshop proceedings and the University of Bologna for hosting the meeting.

4. Abstracts of presentations

The abstracts of the contributions presented by the speakers are herein attached.

LINEARITY OF HYDROLOGICAL MODELS AND RELATED UNCERTAINTY

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ABSTRACT

Hydrological models are frequently used to predict extreme floods through extrapolation with return periods far beyond the sample size of observed flows which is used to "calibrate" and verify these models. Mathematicians have a clear opinion of what hydrologists are doing: It is not acceptable to use such models for that purpose. Unfortunately, mathematicians often do not know that engineers have to predict such uncertain extreme floods as an important base for decision making. A critical issue of model application for extrapolation is the question of linearity. In the past it has often been argued that limited scientific knowledge, data shortage and lack of adequate computer resources made linear models more or less compulsory. However, it can now be argued that the availability of additional hydro-meteorological information, of geographic data with high spatial resolution and of high performance computers render linear models superfluous in the future. The paper will briefly discuss the basic problem, give an example and close with some recommendations.

THE VALUE OF PROCESS DATA FOR FLOOD MODELLING

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ABSTRACT

The generation of extreme floods is not understood well enough, in particular before detailed investigations are carried out. The combination of experimental and modelling investigations is a suitable method to gain further insights into the formation processes. This is the basis to make more reliable runoff predictions, which is essential for an improved protection of the environment, live and human infrastructure.

This paper summarizes recent research projects are that were carried out at meso-scale Dreisam basin in the southern Black Forest Mountains, Germany. It is demonstrated that tracer methods in combination with classical hydrometric techniques are suitable tools to investigate flow pathways and residence times of the water at catchment scale. The understanding of hydrological processes gained at small scales (plot scale, headwaters etc.) must be regionalized to larger scales and translated into the space of a hydrological model. As a process-transfer tool a spatial delineation of dominant runoff generation processes is proposed. The delineation procedure in combination with the model TAC^D offers a possibility to translate the results of experimental studies into a distributed, process-based hydrological model. Finally, it is illustrated how the uncertainty of the runoff predictions can be reduced by incorporating additional experimental data.

DEWATERING THE LOWER FEALE: EXPLORATIONS WITH A COUPLED HIGH RESOLUTION 3-DIMENSIONAL HYDROLOGICAL MODEL AND DIGITAL ELEVATION MODEL

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ABSTRACT

A pump experiment is ongoing in one of the 15 polders making up the lower Feale Catchment. The lower Feale catchment is a low-lying peaty area of 200 km2 situated in southwest Ireland which is heavily affected by floods. Each polder within the catchment can be considered as hydraulically independent. The main purpose of this study is to monitor and evaluate the effectiveness of the pump experiment for eventual implementation in a flood mitigation strategy in the remaining part of the catchment.
The effectiveness of the system is monitored by a number of state-of-the-art, high-frequency instruments. A second set of instruments is located in an adjacent non-pumped polder, which provides a control for the experiment. The instruments include: an eddy correlation station to measure water vapour and carbon dioxide fluxes, radiometers, soil temperature and soil water content probes, ground water level gauges, water level gauges and rainfall gauges. An electrical resistivity investigation and a ground-penetrating radar survey were carried out to collect subterranean data. A number of deep boreholes were drilled to calibrate the two surveys.
A dynamic geographical database, built in ArcGIS (ESRI) software, stores the wide range of collected data and the results of the different surveys carried out. The data are fed into a 3-dimensional hydrological model of the two polders. The model is developed using Mike SHE coupled with a Mike11 model of the surface drainage network and hydraulic controls, and integrated with a high-resolution digital elevation model. The hydrologic/hydraulic model includes features of the hydraulic infrastructure such as sluiced culverts, back-drains and channel embankments. This paper will discuss in detail current results.

MERGING THE STRENGTHS OF GLOBAL OPTIMISATION AND DATA ASSIMILATION TO SIMULTANEOUSLY ESTIMATE PARAMETER VALUES AND STATE VARIABLES IN HYDROLOGIC MODELS

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ABSTRACT

In recent years significant progress has been made in the development and application of global optimisation and data-assimilation techniques to increase information retrieval from measured time series of catchment discharge data. In the present paper we combine global optimisation and data-assimilation methods to simultaneously estimate parameters and state variables in hydrologic models. The approach is demonstrated in a pilot study using data from the Leaf River Watershed in the USA and hydrologic model with typical conceptual components.

ASSESSING THE UNCERTAINTY OF RAINFALL-RUNOFF SIMULATIONS THROUGH A META-GAUSSIAN APPROACH

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ABSTRACT

Rainfall-runoff models have received a great deal of attention by researchers in the last decades. However, the analysis of their reliability and uncertainty has not been treated as thoroughly. In the present paper, a technique for assessing the uncertainty of rainfall-runoff simulations is presented, which makes use of a meta-Gaussian approach in order to estimate the probability distribution of the model error conditioned by the simulated river flow. The proposed technique is applied to the case study of two Italian river basins, for which the confidence limits of simulated river flows are derived and compared with the respective actual observations.

THE HILLSLOPE-STORAGE BOUSSINESQ MODEL AS A TOOL FOR UNDERSTANDING HILLSLOPE AND NETWORK STRUCTURE

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ABSTRACT

In this work an extension of the recently developed hillslope-storage Boussinesq (hsB) model is presented. The model's behaviour is evaluated by comparing it to a full three-dimensional Richards based model and to a hillslope-storage kinematic wave (KW) model. The evaluation is conducted on a set of nine characteristic hillslopes and two slope angles. The hsB model is then used for landscape evolution modeling in order to better understand the spatio-temporal structure of landscape properties.

AN ASSESSMENT OF CLIMATE CHANGE IMPACTS ON FLOOD FORECASTING

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ABSTRACT

The forecasting of Acheloos river floods at the outfall of the mountainous Mesochora catchment in Central Greece was assessed under scenarios of global climate change. The climate change pattern was simulated through a set of hypothetical and monthly GISS (Goddard Institute for Space Studies) scenarios of temperature increase coupled with precipitation changes. The daily outflow of the catchment, which is dominated by spring snowmelt runoff, was predicted by the coupling of snowmelt and soil moisture accounting models of the US National Weather Service River Forecast System. Two threshold levels were used to define a flood day: the double and triple long-term mean daily streamflow. In this case the flood parameters (occurrences, duration, magnitude, etc) were determined. Despite the complicated response of floods to temperature increase and threshold, both hypothetical and monthly GISS representations of climate change resulted in more and longer floods for climates with increased precipitation. All climates yielded larger flood volumes and greater mean values of flood peaks with respect to precipitation increase. The lower threshold resulted in more and longer flood occurrences, as well as smaller flood

volumes and peaks than those of the upper one. The combination of higher and frequent floods could lead to greater risks of inundation and possible damage of structures. Furthermore, the winter swelling of the streamflow could increase erosion of the river bed and banks and hence modify the river profile.

OROGRAPHIC ENHANCED PRECIPITATION IN FINE SCALE: PROCESSES, MONITORING, NOWCASTING AND FORECASTING

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ABSTRACT

A short overview of basic precipitation processes is given, with special emphasis on orographically enhanced precipitation. Methods of forecasting precipitation are described and some evaluation scores are presented for global forecasting models over larger and smaller areas. Limited area models' forecasts are considered and for these evaluation scores are given as well. Methods for downscaling precipitation forecasts are described, the one based on dynamical downscaling in greater detail. Regarding nowcasting and monitoring are different techniques and operational applications based mainly on satellite, radar and lightning detection data.

THE INFLUENCE OF THE SPATIAL VARIABILITY OF PRECIPITATION ON UNCERTAINTY OF DISCHARGE FORECASTS

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Precipitation is the most important input into hydrological models. Due to the systematic measurement errors and the high spatial variability of precipitation this input is very uncertain. In this paper the uncertainty resulting from the spatial variability of precipitation is considered. To quantify discharge forecast uncertainty daily rainfall amounts series of 30 years daily precipitation is considered. For each wet day an experimental variogram is calculated. Subsequently it is fit by a theoretical variogram after a monotonisation of the experimental curve. This variogram is then used to generate a set of realisations using turning band simulation. The realisations are conditioned on the observations, and thus represent possible real rainfall fields. These fields can then be used as an input into a rainfall runoff model. The uncertainty of discharge prediction depends on the spatial resolution of the hydrological model. A coarse resolution leads to a model with low sensitivity to precipitation variability, but cannot be well fitted to the observations. In contrast a high resolution model can be reasonably well fit to observations but is very sensitive to the spatial variability of rainfall. This fact is demonstrated with the HBV model applied to upper Neckar catchment. The results show, that interpolated rainfall leads to an underestimation of the peak discharges. Further there is an optimal spatial model resolution depends on the density of observations and the typical variability of rainfall.

A SIMPLE PROBABILISTIC FLOOD FORECASTING CHAIN WITH FOCUS ON THE USE OF QPF's

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ABSTRACT

This paper considers a hydro-meteorological framework dedicated to flood forecasting in medium-sized catchments (around 500 km²), and adapted to welcome different input data and information. It is subdivided in two parts: an observational one includes a telemetering system to collect the observed data, while a forecasting one is based on connections with providers of precipitation forecasts, such as nowcasting and short or medium term Probabilistic Quantitative Precipitation Forecasts (PQPF), which are supposed to drive then a hydrological model. However, given the different time-steps used by the different subsystems, some aggregation or, more often, disaggregation procedures are necessary to fit the time step hydrologically appropriate. This merging and pre-processing of informations are essential and must be done upstream of the hydrological model. It can be performed by a simple stochastic rainfall generator, constrained to integrate in the form of scenarios all the informations available about the past and the expected future rainfalls. Then a simple hydrological model transforms these rainfall scenarios into discharge scenarios. The resulting 'spaghetti-like' plots are interpreted into probabilistic forecast ranges for discharges at different lead-times. Finally, the paper considers which are the weak ingredients which still prevent such systems from being more widely implemented.

A COMPARISON OF THE LEAD-TIME DISCHARGE FORECASTS OF THE 'PERFECT' AND 'NAÏVE-AR' QUANTITATIVE PRECIPITATION FORECAST (QPF) INPUT SCENARIOS, TO ASSESS THE VALUE OF HAVING GOOD QPFs

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ABSTRACT

Seven discharge forecasting scenarios for both simulated real-time and real-time river flow forecasting applications are defined. One involves the application of linear and non-linear forms of naïve discharge forecasting models (using observed discharge values only), three involve substantive rainfall-runoff models without consideration of updating, while the remaining three employ models involving some form of discharge forecast updating. The two scenarios which use substantive meteorological forecasts of inputs (i.e. the meteorological 'quantitative precipitation forecasts (M-QPFs)' supplied by the meteorological agencies) in real-time, one involving updating and one not, are excluded from the study. The concentration of this study is on the forecasting efficiency (based on the R^2 efficiency index) of models operating in 'updating mode', the primary objective being an assessment of how important QPFs are (even naïve N-QPFs based on a time series model of the precipitation) in achieving high discharge forecasting efficiency, for a range of forecast lead-times of one to six time steps. This is attempted by comparing the updated forecasting efficiencies of models using N-QPFs with those using the 'perfect foresight of input over the lead-time scenario'(P-QPFs), assuming that each R^2 value for the M-QPF case lies between those of the other two cases.

Using daily data of two Irish catchments (areas 1,207 km² and 562 km²), the performances of a total of eight updating models are compared, involving four of the seven defined scenarios. For use in those updating models requiring the non-updated outputs from a substantive rainfall-runoff model as inputs, two model variants of the SMAR (Soil Moisture Accounting & Routing) conceptual model are employed, one on each catchment. The relative abilities of the model forecasts, for various lead-times, to match the highest observed flood of one catchment, is also presented graphically. The overall results of this study confirm the hypothesis that even naïve N-QPFs are better than none and that the P-QPFs lead to

substantially better discharge forecasts than the N-QPFs, indicating the value of having good QPFs for lead-time discharge forecasting.

The Galway Flow Modelling and Forecasting System (GFMFS) software package, developed at the Department of Engineering Hydrology, National University of Ireland, Galway, Ireland, is used for the application of all models considered in this study.

EXPERIENCES ON THE USE OF COUPLED MESOSCALE METEOROLOGICAL AND HYDROLOGICAL MODELS FOR FLOOD FORECASTING

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ABSTRACT

The paper shows some examples of coupled use of the meteorological BOLAM mesoscale model with a distributed hydrological model. These models have been tested in the past four years in some research projects framed, to a large extent, within the RAPHAEL EU research project and the activities within the National Group for the Prevention of Natural Hazards of the CNR. The investigation presented here is related to test potentials and limits of flood forecasting schemes in the study area of the Toce river, a sub-basin contributing to the Lago Maggiore system. The basin is located on the southern side of the European Alps where orographically enhanced precipitation is often very intense. Six major flood events of the past decade were simulated for the Toce river basin. Objective performance indexes of the coupled flood-forecasting system against available detailed measurements of precipitation, runoff and water volume stored in reservoirs are presented and discussed.

FLASH FLOOD CASE STUDIES IN HUNGARY, DIFFERENT LEAD TIMES AND DIFFERENT APPROACHES IN FLOOD FORECASTING AND WARNING

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ABSTRACT

Under climatic conditions of the Central Danube Basin flash floods are relatively rare phenomena. The majority of floods go almost unnoticed on most of small ungauged creeks in hilly and undulating regions of Hungary. Only the extreme events causing substantial damage to slopes and valleys have been recorded to some extent. Case studies of recent years flash flood events in Central Europe (Czech Republic, Hungary, Slovakia, Rumania) are reviewed. The June 22-23, 1999 flood on Kemence creek 70 km North East of Budapest is analysed in details together with some similar events in July 1999 in the Mátra Hills. The role of slope conditions and antecedent moistening, high intensity of short period precipitation was clearly shown. Meteorological conditions of different events show some parallels, but these findings have only limited prognostic value. Lumped and semi distributed rainfall-runoff models were applied by using as input the mean rain-gauge rainfall to carry out hindcast experiment .Model performance criteria plotted against the normalised by concentration time lead times were analysed. The present approach may help to define limits of predictability along the creeks and delineate the applicability of the large scale regional riverine forecasting system.

A FRAMEWORK FOR MAKING PROBABILISTIC FORECASTS USING DETERMINISTIC RAINFALL-RUNOFF MODELS

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ABSTRACT

This paper presents a framework to include the knowledge encoded in deterministic rainfall-runoff models in computerised decision environments for the prediction and management of flash floods in real time. The emphasis is placed on providing decision makers with tools to perform a probabilistic qualitative analysis of a complex flash flood situation. The qualitative simulation of hydrologic processes is performed through causal relations quantified with conditional probabilities following a Bayesian network. The solution algorithm of Bayesian networks allows the computation of the expected probability distribution of unknown variables conditioned to the observations. A methodology for the development of Bayesian models using results produced by deterministic hydrologic simulation models is described. This framework is adequate for basins where the use of deterministic models as pieces of a probabilistic forecast procedure based on real-time Monte Carlo simulations is computationally unfeasible, because the computational burden of Monte Carlo simulations is transferred off-line.

USE OF SPATIALLY-DISTRIBUTED OR LUMPED PRECIPITATION INPUTS IN CONCEPTUAL AND BLACK-BOX MODELS FOR RUNOFF FORECASTING

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ABSTRACT

Spatially-distributed rainfall-runoff models are increasingly used in applied hydrology, also for river flow simulation and flood prediction. A spatially-distributed representation of rainfall input may be included either in a conceptual or in a black-box rainfall-runoff modelling approach, but it has not been demonstrated, yet, if such representation provides a better prediction in comparison with a spatially uniform precipitation field. The paper presents the application, for real-time runoff forecasting purposes, of two modelling approaches: a black-box model based on Artificial Neural Networks (ANN) and a distributed rainfall-runoff model with an high degree of conceptualisation, coupled with an output updating procedure. The case study is referred to a medium-sized (1050 km^2), mountainous catchment in Northern Italy. The two approaches are fed with both spatially-distributed and spatially-uniform rainfall fields: the models are parameterised with the same calibration data (one year) and their performances in forecasting hourly runoff for more than five years of validation data are compared. The comparison shows that the spatially-distributed precipitation representation results in a sensible deterioration with the ANN model, which is strongly penalised by the increased model complexity. Also for the conceptual modelling approach, the use of spatially-uniform precipitation allows slightly better forecasting performances. Such results indicate how, as far as the study area is concerned, a reliable estimate of rainfall volumes seems more crucial than the spatial organisation of the rainfall field.

DATA ASSIMILATION IN THE MIKE 11 FLOOD FORECASTING SYSTEM USING KALMAN FILTERING

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ABSTRACT

A procedure is presented for assimilation of water levels and fluxes in the MIKE 11 Flood Forecasting (FF) system. The implemented procedure is based on the ensemble Kalman filter that provides a cost-effective and efficient updating and uncertainty propagation scheme for real-time applications. Up to the time of forecast the model is updated according to the Kalman filter algorithm using the available measurements. In forecast mode, the Kalman filter provides an ensemble forecast that is used for estimation of water levels and fluxes in the river system and the associated uncertainties. A test example is presented where the MIKE 11 FF system is applied for flood forecasting in the Piedmont region in the north-western part of Italy. Application of the ensemble Kalman filter improves significantly the forecast skills as compared to forecasting without data assimilation.

MULTILINEAR DISCRETE CASCADE MODEL FOR RIVER FLOW ROUTING AND REAL TIME FORECASTING IN RIVER REACHES WITH VARIABLE WAVE SPEED

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ABSTRACT

The discrete cascade of linear reservoirs is used to build a multilinear model based on the time distribution scheme of model inputs. The linear sub-models are based on the discrete state space representation of the Kalinin-Miljukov model. The travel time parameter of the model is allowed to change according to empirically derived relationships between the flood wave speed and inflow to the reach. The performance of the multilinear model is compared with the results of the linear model on a reach of the Danube between Vienna and Bratislava. The results show, that without sacrificing the simplicity of the linear model, the inclusion of additional empirical information on the variability of the wave speed enables better prediction of the flood propagation process.

COMPUTATIONALLY EFFICIENT MODELLING OF FLOOD INUNDATION EXTENT

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ABSTRACT

This paper considers recent efforts to develop computationally efficient yet accurate hydraulic models for predicting flood inundation extent. This has been stimulated by the increased availability of high quality digital elevation data for floodplain zones and the consistent benchmark data sets, principally of flood inundation extent, that can be used to compare competing models. At the same time, increases in available computing power and the advent of desktop GIS technology have created the tools necessary to

analyse the problem of modelling flood inundation in detail. The paper demonstrates that when evaluating inundation models against sparse observational data, higher dimensional models do not necessarily produce better results than models with simplified dynamics. Moreover, prediction accuracies up to 85% of the floodplain area correctly classified as wet or dry can be obtained using simplified hydraulic codes with run times of the order of minutes. This raises the possibility that hydraulic models can now be integrated within real-time flood forecasting systems to aid disaster prevention and management.

ON THE APPROPRIATENESS OF THE GUMBEL DISTRIBUTION IN MODELLING EXTREME RAINFALL

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ABSTRACT

For half a century, the Gumbel distribution has been the prevailing model for quantifying risk associated with extreme rainfall. Several arguments including theoretical reasons and empirical evidence are supposed to support the appropriateness of the Gumbel distribution. These arguments are examined thoroughly in this work and are put into question. Moreover, it is shown that the Gumbel distribution may misjudge the hydrological risk as it underestimates seriously the largest extreme rainfall amounts. Besides, it is shown that the three-parameter extreme value distribution of type II is a more consistent alternative and it is discussed how this distribution can be applied even with short hydrological records.

PEAK OVER THRESHOLD ANALYSIS OF FLOOD AND RAINFALL FREQUENCY CURVES

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ABSTRACT

An investigation of the rainfall-runoff transformation under heterogeneous geomorphoclimatic conditions is undertaken on 33 daily rainfall and discharge time-series from basins in north-western Italy. The analysis is performed by comparing the shape of the flood and rainfall frequency curves for each basin. These curves are obtained by applying a filtered peak over threshold procedure to the daily time series, aiming at the estimation of a shape parameter for each of the two distributions. The first results of this analysis are of empirical nature and show that for the majority of basins the shape of the rainfall and runoff distributions is statistically indistinguishable. A relevant deviation from this rule is represented by basins where the dominating flood production mechanism is snow melting: these basins are in fact characterised by a marked change in shape (reduced skewness) of the discharge probability distribution compared to the rainfall curve.

PEAK FLOW ESTIMATION IN UNGAUGED WATERSHEDS

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ABSTRACT

Two methods for the modeling of streamflow and the estimation of flood frequency are proposed. The first method uses the UBC watershed model with a universal set of parameters for water allocation and flow routing, and the precipitation gradients estimated from annual meteorological data as well as information on the distribution of orographic precipitation. This method can be applied to ungauged watersheds. The second method proposes the coupling of UBC watershed model with artificial neural networks (ANNs) and can be used in watersheds with limited streamflow measurements. The two proposed methods have been applied to four mountainous watersheds having various climatic, physiographic and hydrological characteristics. The results showed that the first method simulates satisfactorily the observed discharge and flood frequency assuming that the basins are ungauged. If limited streamflow data are available, the simulation of the runoff and the estimation of flood frequency are highly improved using the second method.

REGIONALISATION OF FLOOD RISK IN AUSTRIA

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ABSTRACT

We examine the predictive performance of various flood regionalisation methods for the ungauged catchment case, based on a jack-knifing comparison of locally estimated and regionalised flood quantiles for 575 Austrian catchments. The main result is that spatial proximity is a significantly better predictor of regional flood frequencies than are catchment attributes. A method that combines spatial proximity and catchment attributes yields the best predictive performance. A method that uses only spatial proximity performs second best. With a view of improving the regionalisation methods we then propose a typology for identifying causative mechanisms of floods which include long-rain floods, short-rain floods, flash floods, rain-on-snow floods and snow-melt floods. Based on a number of process indicators and diagnostic regional plots we identify the process types of 11518 maximum annual flood peaks in 490 Austrian catchments. In a preliminary analysis we use the flood types for estimating compound flood frequency curves from short records at gauged sites. Comparisons with longer records at the same site suggest that the flood type information can be used to extrapolate more reliably to large return periods than is possible without them. Future work will focus on making use of the flood types for flood regionalisation.

SYNTHETIC FLOOD SCENARIOS FOR RISK ASSESSMENT IN LARGE DAMS

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ABSTRACT

Hydrological risk assessment in large dams should incorporate analysis of the potential damages resulting from undesired extreme flood events. This should involve identification of the hazard and assessment of the probability of its occurrence. From a hydrological point of view, this outcome is significantly affected not only by the peak flow Qp of the inflow hydrograph, but also by its duration, volume and shape. Synthetic generation techniques based on stochastic space-time rainfall inputs are used in this research, providing a wide range of potentially risky situations for a given system, and improving the basis for a probabilistic assessment for reservoir safety. Effectiveness of the operational rules during flood situations for El Sancho dam (Huelva, Spain) are evaluated through reservoir routing of synthetic hydrographs, under different combinations of initial water surface levels and operational criteria.

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The Workshop Responsible

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