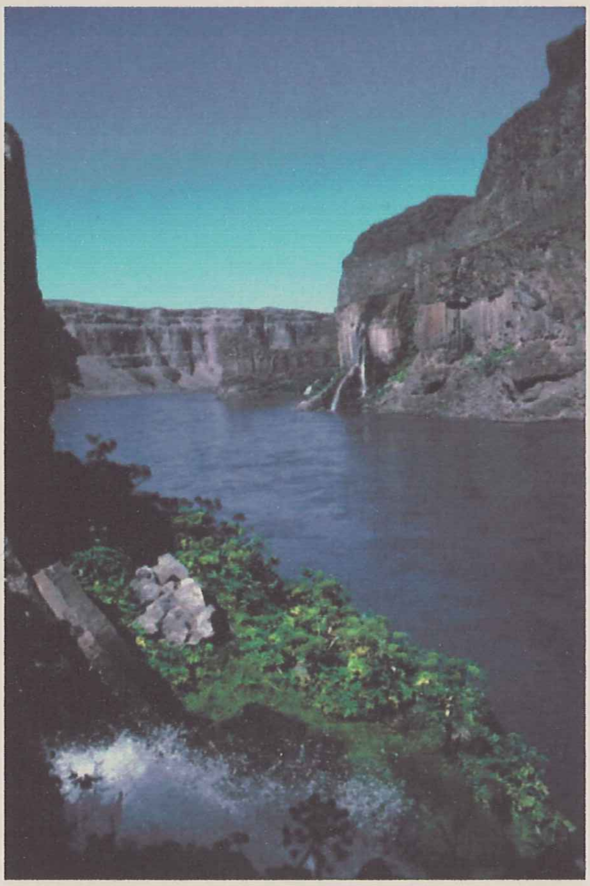
ORKUSTOFNUN

Hydrological Service

Extremes of the Extremes

July 17-19, 2000, Reykjavík, Iceland

Symposium abstracts



Editors: Helga P. Finnsdóttir, Elín Gudnadóttir

Co-convened with
The International Association of Hydrological Sciences

2000

OS-2000/036

ORKUSTOFNUN
Grensásvegi 9, 108 Reykjavík

Project No. 7860910

Helga P. Finnsdóttir, Elín Gudnadóttir (eds.)

The Extremes of the Extremes
July 17-19, 2000, Reykjavík, Iceland

Symposium abstracts

Hydrological Service, National Energy Authority (NEA), Iceland
& The International Association of Hydrological Sciences (IAHS)

OS-2000-036 July, 2000

NEA: Id. no. 500269-5379 - Tel. +354 569 6000 - Fax +354 568 8896
E-mail os@os.is - Home page http://www.os.is

ORKUSTOFNUN
Grensásvegur 9, 108 Reykjavík

Key page

Report no.:	Date.:	Distribution:
OS-2000-036	July 2000	☒ Open ☐ Closed until

Report name / Main and subheadings:	Number of copies:
The Extremes of the Extremes, July 17-19, 2000, Reykjavík, Iceland. Symposium abstracts	200
	Number of pages:
	92 + v
Editors:	**Project manager:**
Helga P. Finnsdóttir Elín Gudnadóttir	Árni Snorrason
Classific. of report:	**Project number:**
Symposium abstracts	7860910

Prepared for:

Cooperators:
International Association of Hydrological Sciences (IAHS)

Abstract:
This report contains the *as is* abstracts of contributions to the symposium held in Reykjavik, Iceland on July 17-19, 2000.

Keywords:
Hydrology, Extremes, Extraordinary, Floods, IAHS, Iceland

ISBN-no:
9979-68-054-7

Project manager's signature:
Árni Snorrason

Reviewed by:
Kristinn Einarsson

LISTOF CONTENTS

SESSION 1-2: PHYSICAL PROCESSES RELATED TO FLOODS

SESSION 3: PREHISTORIC FLOODS

SESSION 4: FLOODS: CASE STUDIES

SESSION 5: GEOMORPHOLOGICAL AND ENVIRONMENTAL QUESTIONS RELATED TO FLOODS

SESSION 6: STATISTICAL ANALYSIS OF FLOODS

SESSION 7: STATISTICAL ANALYSIS AND FLOOD FORECASTING

SESSION 1-2

PHYSICAL PROCESSES RELATED TO FLOODS

FLOOD PREDICTION IN PERMEABLE CATCHMENTS

A. L. Vetere Arellano[1], P. Samuels[2] and P. Webster[3]

[1]School of Civil Engineering, The University of Birmingham, Edgbaston, Birmingham, B15 2TT, UK
e-mail: a.l.veterearellano@bham.ac.uk
[2]HR Wallingford Ltd., Howbery Park, Wallingford, Oxon, OX10 8BA, UK
e-mail: pgs@hrwallingford.co.uk
[3]School of Civil Engineering, The University of Birmingham, Edgbaston, Birmingham, B15 2TT, UK
e-mail: p.webster@bham.ac.uk

Extraordinary flood events rarely occur on permeable catchments, and there is still much uncertainty regarding their prediction. However, when they do occur, the impact is considerable and communities are often unaware of and unprepared for the associated impacts. For example, the recent flood-related events in Europe, such as those in Chichester and villages in the Hampshire area (UK), and Sarnoand Bisagno areas (ITALY) occurred on permeable catchments. Damage to local infrastructure and economic loss can be severe and accordingly these rare events should not be neglected in river basin management, land planning and by local community governments. This paper presents a realistic endeavour to understand the flooding phenomenon on permeable catchments and to offer an alternative, structured and concise approach to their prediction.

Permeable catchments tend to influence flood frequencies, volumes and durations in a different manner to their more impermeable counterparts. Thus, when operational and design aspects of flood risk are required, existing methodologies do not account for the marked discontinuity of runoff processes in such catchments. Conventional frequency analysis involves the use of observed data in the estimation of flood frequency relationships. Since noteworthy floods on permeable catchments are rare, they make a limited contribution to the flood frequency curves. An analysis of these extreme floods suggests the combined influence of the following parameters: characteristics of rainfall event (antecedent and storm rainfall), catchment wetness (soil related) and groundwater conditions (geology related). Whilst these above parameters are important in flood estimation for most catchments, they assume much greater significance on permeable catchments. For example, the combined effect of transmissivity and storativity, properties inherent to the hydrogeology of the aquifer, dictate the catchment's behaviour to a given rainfall event.

This paper briefly discusses the current methodologies used for flood frequency estimation in permeable catchments and describes an alternative approach. The proposed methodology comprises a suite of methods based upon: modification of flood frequency analysis[2], conceptual deterministic model and detailed numerical modelling. A few case studies are described that also demonstrate how the prediction of extreme floods in permeable catchments is still a challenge for any hydrologist or engineer. Furthermore, the need for a multi-disciplinary approach for this interdisciplinary challenge is stressed in this paper.

River Lavant Flood Investigation, Posford Duvivier (July 1994)

[2] *Review of Floods and Flood Frequency Estimation in Permeable Catchments*, R. B. Bradford and D. S. Faulkner, Institute of Hydrology (June 1997)

[3] Although the disaster which occurred in May 1998 was caused by landslides, the Sarno area has a history of floods. *Evaluation of floods in Campania*, F. Rossi and P. Villani, National Research Council, Italy (December 1994). (in Italian).

[4] *Overview of the geomorphological, climatological and hydrological analysis of the Bisagno River basin (Genoa, Italy) carried out after the 1953 and 1970 disastrous floods and landslides-preliminary results*, Hydrological and hydrogeological risks (ECE publication), L. Perasso (1996)

FACING A CHANGEABLE HYDROLOGICAL REGIME IN A MEDITERRANEAN COUNTRY

G. Batini and M. Benedini

Department of Technical Services, Rome, Italy
e-mail: marcello.benedini@dstn.it

Italy is located entirely within the Mediterranean basin and undergoes all the consequences of a typical climatic pattern that now seems characterised by new trends, difficult to explain on the basis of a mere interpretation of the long series of historical records. The occurrence of floods seems in particular to cause more worry than in the past years, with higher peak values and a changed frequency. This is due to several factors, ranging from a modified climatic pattern and including an irrational land use that has often accompanied the economical development in most recent times. A changing precipitation regime now characterises the Mediterranean, some effects of global concern, like an increasing drought, seem to have altered the existing hydrological cycle. Intensive precipitation causes sudden and unforeseeable floods that threaten a territory in which an increased population density, urbanisation and infrastructures have deeply affected the natural water pattern.

The Department of Technical Services, in line with its mandatory countrywide activity, has promoted an ad hoc investigation in order to improve and the inner mechanisms governing the high precipitation and flood regime more up-to-date. The outlines of such an investigation and the results so far achieved are reported in this paper, stressing the main points that can be of interest for a revised national policy of flood control.

A substantial part of the Department's activity is in hydrological surveys, for which a monitoring system, based on the most advanced technological breakthrough, has been put into operation. Such a system is also briefly described.

EXTREME ICE JAM FLOODS ALONG THE SAINT JOHN RIVER, NEW BRUNSWICK, CANADA

S. Beltaos[1], S. Ismail[2] and B. C. Burrell[3]

[1]Research Scientist, National Water Research Institute, Environment Canada,
P.O. Box 5050, Burlington, Ontario, Canada L7R 4A6
e-mail: spyros.beltaos@cciw.ca
[2]Senior Engineer – Hydraulic, New Brunswick Power Corporation, Mactaquac Generating Station, Mouth of Keswick, New Brunswick, Canada E0H 1N0
[3]Hydrotechnical Engineer, New Brunswick Department of the Environment,
P.O. Box 6000, Fredericton, New Brunswick, Canada E3H 5H1

Extreme ice jams, and the resulting floods and ice runs destroy property and infrastructure, disrupt transportation, inhibit hydro-power generation, affect aquatic life and habitat, and create a risk of human injury or death. During the past three decades, combinations of hydrological and climatic conditions have resulted in several extreme ice jams that have resulted in severe flooding of vulnerable communities along the Saint John River. The physical processes involved with five such events are described, with particular attention given to the devastating ice jams and ice runs of 1987 and 1991.

As ice jams create partial blockages to flow, they result in much higher water levels than those occurring under open water conditions for the same river flows do. Along the upper and middle reaches of the Saint John River, ice jam floods have resulted in more severe flooding than open water events, and have affected areas never or seldom flooded by open water events. Recurrent ice jamming locations along the river have been identified and attempts made to determine flood frequency. Using the results of comprehensive data collection programs, numerical modelling has been carried out to analyse ice-jam water levels. At present, efforts are underway to implement predictive models in flood forecasting and emergency response operations.

Upon release of an ice jam, the resulting surge of water can cause very rapid inundation of low-lying downstream lands and propel ice floes against infrastructure and onto the flood plain. The fast-flowing water and the moving ice rubble, often accompanied by high suspended concentrations, can alter aquatic habitat and be harmful or lethal to fish and other aquatic life. Radio telemetry to remotely measure the rapidly changing surge water levels has been used experimentally on the Saint John River as a preliminary step toward predicting surge characteristics.

Prompted by global warming concerns, historical hydro-climatic records have been analysed in two recent studies. The available evidence suggests the Saint John River is becoming subject to more frequent mid-winter breakups and higher April peak flows, both of which augment the potential for major jamming.

EXCEPTIONAL RAINFALL IN THE SOUTH WEST OF TUNISIA DURING THE PERIOD FROM 21 TO 23 JANUARY 1990

Z. Benzarti

University of Tunis, Department of Geography, Arts Faculty of La Manouba, 6, Rue Borj Bourguiba, Denden 2011, Tunisia
e-mail: zbnzarti@planet.tn

Tunisia is situated between a desert zone and a temperate zone. Its climate, a Mediterranean climate, is very irregular and precipitation is very variable. So, we have registered many events of extreme floods, for example in 1969, 1973, 1982 and 1995, but every event concerned specially one area of the country.

The purpose of this paper is to present the exceptional rainfall in the southwest of Tunisia during the period from 21 to 23 January 1990.

The southwest of Tunisia experienced an exceptional rainy event from 21 to 23 January 1990. This event was due to a meteorological situation called « East-Back » that persisted during the three days in the same region. An atmospheric disturbance came from Sahara and set in the Mediterranean sea off the coasts of Tunisia. This situation provided humidity from the sea, which precipitated on land during the three days. This situation generated some remarkable precipitation by its duration, its continuity, its quantity and its weak intensity. It was followed by heavy floods, which caused some damages to equipment, infrastructure and resulted in some casualties.

I would like to present in this paper a study of the meteorological situation, the distribution of regional rainfall mean, maximum of daily rainfall, and for this extreme event: intensity of rainfall and frequency of the extreme values of precipitation.

Some maps and graphics of precipitation illustrate this presentation.

MAXIMUM RAINFALL IN POLAND (A DESIGN APPROACH)

E. Bogdanowicz and J. Stachy

Institute of Meteorology and Water Management, 61 Podlesna str.,
01-673 Warszawa, Poland
e-mail: Ewa_Bogdanowicz@imgw.pl

Heavy rainfall data are used extensively for designing engineering works that control storm runoff. The main design characteristic is the maximum precipitation depth fallen in different time intervals with a given probability of occurrence.

In Poland, the problem of heavy rainfalls has always been duly appreciated. In the early fifties Lambor presented an empirical formula for a maximum rainfall intensity evaluation. Baszczyk has cited a similar formula. In the presented studies series of annual maximum precipitation depths in time, ranging from 5 minutes to 72 hours (14 time intervals), were established for the period 1960-1990 from 20 meteorological stations and posts. Data were processed in accordance with the World Meteorological Organisation - WMO recommendation. Generalisation of the rainfall information was done by means of regional description. The following definition was adopted: region of a maximum rainfall in time is a coherent area in which there is no basis to reject the hypothesis that the annual maximum precipitation depth series (in individual points of the area) belong to the same population. The regions were established by means of hierarchical agglomerated cluster analysis. Three regions were distinguished: 1. North - western, lakeland, 2. Central, 3. Southern, with coastal area. According to the definition of a region and the idea of a station-year method, substantially not differing annual maximum precipitation depth series taken from meteorological stations may be combined into regional series. It was assumed that the annual precipitation depths might be described by Weibull distribution (Extreme Value type 3 - EV3) with three parameters. Parameters of the regional series were estimated by maximum likelihood meted. Scale parameter and the lowest bound parameter are strongly correlated with time. Shape parameter can be taken as constant and common for all time intervals and all regions.

The result of the performed work is the system of equations for calculating the maximum precipitation depth in a given time and for a chosen probability of occurrence. The system was verified using fully independent, quasi-independent and dependent data. Credibility of the system was stated 2E.

A CATASTROPHIC FLOODING IN THE CZECH REPUBLIC AFTER JULY 5TH, 1997

A. Chlebek and M. Jarabac[1]

[1]U sportoviste 1165, CZ-708 00, Ostrava-Poruba, Czech Republic
e-mail: mjarabac@iol.cz

Forests cover one third of the territory of the Czech Republic and two thirds of the mountains, which have a higher sum of precipitation and outflows. The influences of forests on water balance have been investigated in this area for over 100 years. It has been assumed that poor management of forests in mountainous watersheds damages the budget of water regime, increases the intensity of erosion, the loss of nutrients and decreases the slowdown of high outflows.

In 1927 two representative watersheds on forest hydrology, followed by another two small experimental watersheds in 1953, were set in progress in this region. All measurements with calibration and renewal processes, including air pollution, were not finished till now. They give very interesting results, showing that the relationship between precipitation (rainfall) and outflows in headwaters (torrents) depend more on interrelated natural (climatic, geographic) fluctuations of elements than on methods of forest management. During the last three years we took flooding into rapt attention.

The heavy rainfall in part of the Czech Republic between July 5th-9th, 1997, was the greatest one for over 100 years. The highest sums were 233.8 mm on July 6th and 585.7 mm between July 5th-9th. It caused a very dangerous and long flooding, not only in headwaters, but also in the Morava - river emptying into the Danube and the Odra - river in Poland and Germany. About 2.3 km^3 of rainwater fell on a 10,000 km^2 territory of the Czech Republic. This heavy flooding caused a very intensive transport of sand, gravel, trees etc. with serious threats for the stability of bridges, railways, roads, adjoining lands and houses. Fifty people were drowned in the area.

We have registered this great rainfall in our fully forested watersheds very well. We are able to prove that the capacity of forests, especially of forest soils, to intercept the water is naturally limited. Our experiences showed that torrent control works have to be made in this very civilised region all the time. We have to take appropriate measures of the forest management to help the protection of lives and property, but they depend on common budget.

INFLUENCE OF CLIMATE ON THE FLOOD FREQUENCY DISTRIBUTION WITHIN A WIDE REGION OF SOUTHERN ITALY

P. Claps[1], M. Fiorentino[1] and V. Iacobellis[2]

[1]Dipartimento di Ingegneria e Fisica dell'Ambiente, Università degli Studi della Basilicata, Contrada Macchia Romana, 85100, Potenza
e-mail: fiorentino@unibas.it
[2]Dipartimento di Ingegneria delle Acque, Politecnico di Bari,
via E. Orabona 4, 70125, Bari
e-mail: vitoiacobellis@hotmail.com

Based on the theoretical model proposed by Iacobellis and Fiorentino (1999), the identification of the prevailing mechanisms that control the formation of partial contributing areas and the hydrologic losses within the flood runoff generating process finds a meaningful match with important features of the probability distribution of extreme floods.

The main features of the Horton and Dunne models show a strong climatic peculiarity, which is reflected in the probability distribution of the partial area that makes a contribution to the peak flood (partial contributing area). In the model, the partial contributing area is considered as an independent stochastic variable with statistical distribution dependent on the climatic, geological and soil use features of basins.

In the model, floods are considered as being due to storms of a critical duration (the characteristic basin lag-time). In this framework, a threshold f_A of effective precipitation is used to discriminate if runoff is generated or not.

The application of the model to basins of a wide region in southern Italy, with an extensive set of available data of hydrologic interest, sheds new light on the topic and furnishes interesting results. In particular, the threshold f_A shows a strong relation to the climate of the region where the basin is placed. Part of this behaviour is probably related to the climate by way of the vegetation coverage. But in arid regions f_A is found to be much less sensitive to climate and to be strongly controlled by the total area of the basin. This suggests that in these regions the main losses are related to the storage capacity of the soil, which is usually very dry because of the long average time between storms.

With regard to the contributing areas, large values (sometimes as large as the total basin area, especially for small watersheds) are found when runoff is of the infiltration excess type. This is typical of arid zones, where the geologic control of the size of the contributing areas is also highlighted. Instead, in humid basins, the contributing areas are usually small and concentrated near the channel network. Nevertheless, in some cases the boundaries between Horton and Dunne schemes begin to shade off because the partial contributing area may be due to both mechanisms, playing together in a puzzled discrete space-time pattern.

ASSESSMENT OF POSSIBLE JÖKULHLAUPS FROM DEMMEVATN IN NORWAY

H. Elvehøy[1], J. Kohler[2], R. V. Engeset[1], L. M. Andreassen[1], H. Björnsson[3] and Y. Gjessing[4]

[1]Norwegian Water Resources and Energy Directorate, Box 5091 MAJ, N-0301 Oslo, Norway
e-mail (R. V. Engeset): rue@nve.no
[2]Norwegian Water Resources and Energy Directorate, now at Norwegian Polar Institute, Polarmiljøsenteret, 9296 Trømsø, Norway
[3]Science Institute, University of Iceland, 107 Reykjavík, Iceland
[4]Department of Geophysics, University of Bergen, 5007 Bergen, Norway

Written sources describe severe late-summer floods in the valley Simadalen, which is located downstream from the glacier Hardangerjøkulen in western Norway, as far back as 1736. These floods originated from the lake Demmevatn, dammed by Rembesdalskaaki, which is an outlet glacier from the icecap Hardangerjøkulen. After a reduction in glacier thickness, the largest recorded flooding occurred in 1893 exposing Simadalen to severe damages. During this incident, a volume of about 35 x 10^6 m^3 of water was drained from the lake in 24 hours. After this flooding, a rock tunnel was constructed to artificially drain the lake and prevent floods. However, a further decrease in glacier volume inflicted another two serious floods, occurring in 1937 and 1938. In response to this, a second rock tunnel was constructed with an intake near the bottom of the lake.

To assess the impact of possible jökulhlaups, a model for discharge through an ice tunnel from the lake to the glacier snout was established. The model was based on a description of the glacier surface and bottom topography, lake bottom topography, calculations of drainage divides for the lake and for the glacier outlet, modelling of glacier response to climatic change in terms of glacier dynamics and mass balance, and observations of previous floods.

The model simulated possible future jökulhlaups from Demmevatn, and was used to provide an assessment of future scenarios of jökulhlaups given an obstruction of the rock tunnel presently draining the lake. The maximum discharge during a jökulhlaup depends on the volume of water stored in the lake and the drainage mechanism, the discharge dependent on the thickness of the glacier and thus the glacier response to a change in climate. The described approach could also be used to assess the impact of jökulhlaups from other glacier-dammed lakes with or without artificial drainage tunnels.

SIMULATION OF THE JÖKULHLAUP ON SKEIÐARÁRSANDUR IN NOVEMBER 1996 USING MIKE 21 HD

C.G. Eskilsson, J.I. Árnason and D. Rosbjerg

Department of Hydrodynamics and Water Resources (ISVA), Building 115, Technical University of Denmark, DK-2800 Lyngby
e-mail: dan@isva.dtu.dk

The jökulhlaup (glacier outburst flood) on Skeiðarársandur, in the southern part of Iceland, was generated by a subglacial volcanic eruption beneath the glacier Vatnajökull. On the 5th of November 1996 the flood wave started propagating down onto the outwash plain, reaching a total peak discharge of approximately 50,000 m^3/s. The jökulhlaup caused severe damage, sweeping away two bridges and several kilometres of public roads.

In the present study a MIKE 21 HD model was set up and calibrated for simulation of the jökulhlaup. The aim of the study was to investigate if the discharges estimated during the progression of the event were realistic. The model covers an area of 1,000 km^2 including the entire area subjected to flooding, roughly 750 km^2. Snapshots of the inundated area, as well as measurements of maximum water levels in the upper part of the area, were used to calibrate the model.

THE ESTIMATION OF FLOOD FREQUENCY IN A MEDITERRANEAN ENVIRONMENT DUE TO EXTRAORDINARY COMBINATIONS OF HYDROLOGICAL AND CLIMATIC CONDITIONS

S. Gabriele[1] and P. Villani[2]

[1]IRPI-CNR, Roges di Rende (CS), Italy
e-mail: gabriele@gndci.cs.cnr.it
[2]Dipartimento di Ing. Civile, Univ. di Parma, Italy

In the past, in Mediterranean regions, events of intense precipitation and high floods have been observed, that were extraordinary also when compared with the historic series of the annual maximum values.

Recent meteorological studies seem to show that extraordinary extreme hydrological events are produced by the combination of climatic, topographical and local hydrological conditions present in some Mediterranean areas.

At the present state of research, it is not possible to make an a priori typological identification and classification of the cause of an extreme hydrological event. Traditional regional frequency analysis techniques are not always able to take into account the probability of an extreme event of an extraordinary nature occurring, since the base hypotheses of all the traditional models consider a stochastic homogeneous process.

A model that has been demonstrated to be capable of explaining the presence of exceptional extreme events has been adopted in Italy within the framework of a national project for the evaluation of maximum natural flood discharge (VAPI Project). This model is based on the schematisation of the flooding process as a mixture of two independent compound Poisson processes, whose distribution of the annual maximum is the so-called two-component distribution (or TCEV). The parameters of this model all have a clear conceptual representation, being the average magnitude of the peak process over a threshold and the mean annual number of the same, for each component.

In order to be practicable, a regionalization model must be identified, together with the probabilistic model that synthetically describes the process in a site, to explain parameter variability of the probabilistic model from one site to another of the region. A three-level hierarchical-type regionalization model has been adopted, that generalises the most common index flood method. The application of this model leads to the identification of homogeneous areas, with respect to a distribution parameter, with an increasingly reduced spatial extension as the statistical order of the parameter itself is gradually reduced. The final results show that it is possible to refer to a more general regionalization model, taking into account continuous random spatial variability: in this approach the homogeneous region hypothesis is only a distinctive case and a first approximation.

The application of geostatistical analysis techniques, together with robust on–site parameter estimating techniques, such as those referring to probability weighted moments (PWM), over the entire national territory, seems to show that the spatial variability of the parameters of the TCEV model can be correlated with external variables, such as distance from the sea and from mountainous barriers, exposure of the slopes, and so on. Such relationships, because of the conceptual meaning of the probabilistic model parameters, are susceptible to conceptual interpretation. The case study we present covers the whole of Italy and consists of more than 3,000 rain gauge stations with at least 30 years of observation: it is an application of the regionalization procedure previously outlined and areas with different hydrometeorological risk were pointed out.

THE ROLE OF WIND ON SHALLOW LANDSLIDES TRIGGERING

B. Gozzini[1], G. Menduni[2], F. Meneguzzo[3], R. Rosso[4] and M.C. Rulli[5]

[1-3]La.M.M.A. - Laboratory for Meteorology and Environmental Modelling Meteorology and Climatology Subsystem. Tuscany Government.
[2-4-5] Department of Hydraulic, Environmental and Surveying Engineering Hydraulics, Fantoli Lab Building Politecnico di Milano.
e-mail (M.C. Rulli): cristina.rulli@polimi.it

To better understand the physical processes controlling shallow landslides and to design appropriate land use strategies, it is necessary to evaluate slope stability and predict the occurrence of landslides both in space and time because of the distributed properties of the site variables. As we consider shallow landslides triggered by severe rainstorm events, rainfall space distribution can be a major factor in determining the local occurrence of scars. This space variability, in its turn, can be due to the general meteorological framework evolution if the basin space scale is large enough. Furthermore the action of wind can strongly concentrate the occurrence of rainfall on particular hillslopes as a function of their aspect. Over the long term, areas of high relief generally experience greater precipitation amounts on their windward sides and by the summits, producing a sort of rain shadow on the lee side. This point can be of outstanding importance in the case of small mountainous catchments during extreme events. The consequent effect on landslide triggering is, however, rather neglected in the literature where attention is essentially focused on spatially uniform rainfall fields. To predict this effect and even to estimate it *ex post*, can really be a hard task if the area is ungaged. In this paper we recall the event occurring in Versilia, Italy, in June 1996, where an extreme rainfall event caused a large number of shallow landslides and debris flows. We particularly describe these processes on a case study basin, which we analysed, via photogrammetric interpretation and fieldwork. We show how the occurrence of different types of scars and debris flows is strongly correlated with the local aspect and slope. An estimate of the local wind direction and intensity is then performed by physical considerations supported by a conceptual model. The results show that the aspect of the major part of the scarred hillslopes corresponds to the main direction of wind whose maximum velocity is estimated to have been in the order of 60 knots. These observations confirm that wind plays a major role in determining the occurrence of landslides and, consequently, we must focus the attention on the role and predictability of these atmospheric processes.

MULTIFRACTAL TAMING OF EXTREME HYDROMETEOROLOGICAL EVENTS

P. Hubert[1], H. Bendjoudi[2], D. Schertzer[3] and S. Lovejoy[4]

[1]UMR Sisyphe, Ecole des Mines de Paris (Fontainebleau-France)
e-mail: hubert@cig.ensmp.fr
[2]UMR Sisyphe, Université Pierre et Marie Curie (Paris-France)
[3]Laboratoire de Modélisation en Mécanique, Université Pierre et Marie Curie (Paris-France)
[4]Physics Department, Mac Gill University (Montreal-Canada)

For hydrologists, scaling is some kind of a Philosopher's stone, which has been the object of research for a long time. There exists in the literature an enormous amount of empirical work about extreme rain and floods, their mutual relationship and their dependence upon observation time-step and/or catchment size. Yet in spite of so much effort the subject is far from being closed. Multifractal approaches, originating from turbulence studies and which are based upon the Navier and Stokes equation symmetries, have allowed putting such studies in a new perspective and giving them a rational ground. They permit giving prominence to spatial and temporal scale invariance of hydrometeorological processes and so to put in the same conceptual framework normal and extreme events. Furthermore, multifractal approaches suggest that extreme events, both rainfall and discharge ones, are ruled by algebraic statistical laws, rather than by exponential ones, as has been generally postulated up to now. In spite of the uncertainty weighing on the estimation of the parameters of these laws, it appears, from empirical evidence and in agreement with the multifractal theory, that these parameters are independent of the time scale and of the geographical location of the series under study. The theoretical and practical consequences of such conjectures and results are highly significant, especially taking into account hydrological risk for land use planning or water structure design, as they lead to assign to the so-called exceptional events a return period much shorter than classical approaches.

APPLICATION OF THE HIGH RESOLUTION ATMOSPHERIC MODEL RAMS FOR QUANTITATIVE PRECIPITACION FORECASTING

F. Meneguzzo[1], S. Pagliara[2], B. Gozzini[3], G. Messeri[4], M. Pasqui[4], M. Rossi[4], D. Grifoni[3] and G. Zipoli[3]

[1]FMA - Applied Meteorology Foundation, Via Einstein 35, 50013 Campi Bisenzio, Italy
e-mail: meneguzzo@lamma.rete.toscana.it
[2]Dipartimento DI Ingegneria Civile – Università di Pisa, Via Gabba 22, 56126 Pisa, Italy
[3]IATA-CNR, Institute for environmental Analysis applied to Agriculture - National Research Council, Via Caproni 8, Firenze, Italy
[4]LaMMA-Laboratory for Meteorology, climatology and Environmental Modelling, Tuscany regional administration

Model RAMS (Regional Atmospheric Modelling System) has been optimally configured for the accurate quantitative prediction of rainfall occurring during severe meteorological events. The basic RAMS equations are the standard non-hydrostatic Reynolds-averaged primitive equations; thus the prognostic and the other variables represent grid-volume-averaged quantities. The vertical structure of the model grid is built according to the "terrain-following" scheme: the upper part of the domain is flat and the lower one follows the terrain. The surface fluxes, which account for the surface-atmosphere exchanges, are driven by the representation of the lowest (land and water) surface, which is one of the distinct features of model RAMS. It associates to each grid point three distinct values that represent the percentage of area covered by water, bare soil and vegetation. As for the sea surface, since the typical simulation times (36 – 48 hours) are short as regards to time scales of change of the sea surface temperature (SST), this last quantity is hold constant in time but spatially distributed. The SST fields are derived from satellite observations (AVHRR sensor on board NOAA polar satellites). Soil temperature and moisture are prognosed by means of a multi-layer model, whose inputs come from atmospheric quantities and radiation, accounting for the overlying vegetation layer. The vegetation is partitioned into different classes identified by typical values of albedo, emissivity, and roughness. The vegetation status is taken into account by means of the vegetation type and the season, after which the temperature and moisture in the vegetation layer and the moisture uptake from the soil by the roots are computed (BATS, Biosphere – Atmosphere Transfer Scheme). While the parameterisation of the short- and long-wave radiation and of the turbulent diffusion are relatively classic, it's worth to mention the parameterisation of the cumulus convection, since it deeply affects the representation of a large class of atmospheric structures in a wide range of space and time scales. This parameterisation assumes that the convection occurs at a sub-grid scale as a result of the consumption of the conditional instability provided by processes occurring at the grid scale. RAMS uses a scheme derived from a modified formulation of the well known Kuo scheme, in such a manner that all the relevant fields (mass, energy, momentum) are always in equilibrium. The cloud microphysics is carefully accounted for in the thermodynamic equations and has been extensively tested during several years of experimentation and campaigns.

To achieve a high spatial resolution, needed to represent all relevant atmospheric structures (such as deep convection), RAMS offers very advanced nesting capabilities. In the case studies analysed in this paper, several grids are nested into one another: each grid interacts with the following nested one feeding the boundary values and with the previous (larger) grid giving back to it the updated atmospheric fields. Model RAMS has been configured and is operationally applied in the central-western Mediterranean area and at high resolution over a part of Italy. It is nested into the ECMWF (European Centre for Medium Range Weather Forecasts) global model and runs every day for 72 hours simulations. RAMS produces reliable and accurate rainfall forecasts at least up to 36 hours lead-time at a spatial horizontal resolution of 8 km and even better performances are attained at higher resolutions. This conclusion is achieved by means of a careful validation against a large number of rain gauge observations: the statistical indices of performance are discussed, after which the model capabilities and limitations are identified, besides possible actions to reduce the mispredictions. Some flood case studies are presented and the coupling with a hydrological model, which produces discharge forecasts, is analysed and discussed. The accuracy of rainfall forecasts in space and time needed by hydrological forecasting systems is analysed and the fulfilment of these features by model RAMS is investigated. It is concluded that the use of RAMS quantitative forecasts leads to a decisive anticipation of the warnings with low risk of misdetection and false alarm.

HOW OFTEN DO EXTREME EVENTS OCCUR?

F. Naef

IHW, ETH Hoenggerberg, CH 8093 Zuerich
e-mail: naef@ihw.baum.ethz.ch

Extreme floods have a great impact on the affected communities. However, the important question of how often such events might occur cannot be answered adequately. The estimated return period of a given event may vary from between less than 100 years to 500 years or more, depending on the method used. The limited length of the discharge record usually hampers the estimation of the return period based on flood frequency analysis alone. Often, the observed extreme flood is much larger than all the other floods on record and is considered to be an outlier. The analysis of large floods of the past of which some knowledge exists adds valuable, but not accurate, information. Rainfall-runoff models are usually calibrated with minor flood events with return periods between 5 to 50 years. Therefore it is not known whether such models really represent the important processes during extreme events.

The estimation of the return period of extreme events can be improved by combining historical data, rainfall runoff modelling and flood frequency analysis. The discharge record can be extended when historic events are considered. Sometimes the flood history of several hundred years can be reconstructed. Taking into account the relevant runoff formation processes in a catchment during extreme rainfall events could further diminish the uncertainty of the statistical extrapolation. However, the runoff forming processes of differently structured soils during very extreme events are not well understood. To improve our understanding, plots of 60 m^2 with different soils and geology were exposed to artificial rains of up to 100 mm per hour for several hours. Surface and subsurface flow, as well as the water budget of the plot, was monitored. The knowledge gained makes it possible to delineate areas with different reactions to precipitation in a catchment. Extreme runoff computations based on these areas help to improve the statistical extrapolation to extreme events. Examples from several catchments are presented, where historic event analysis and flood frequency analysis, together with modelling based on plot data have been combined to improve the estimate of the return period of extreme floods.

CONTROLS ON THE DEVELOPMENT OF SUPRAGLACIAL FLOODWATER OUTLETS DURING JÖKULHLAUPS

M. J. Roberts[1& 2], A. J. Russell[2], F. S. Tweed[1] and Ó. Knudsen[3]

[1]Division of Geography, Staffordshire University, College Road, Stoke-on-Trent, ST4 2DE, England
e-mail: m.j.roberts@staffs.ac.uk
[2]School of Earth Sciences and Geography, Keele University, Keele, Staffordshire, ST5 5BG, England
[3]Klettur Consulting Engineers, Bíldshöfða 12, IS 112 Reykjavík, Iceland

Theoretical studies of glacier outburst floods (jökulhlaups) assume that: (i) intraglacial floodwater is efficiently transported in isolated conduits; (ii) floodwater exits glaciers through pre-existing ice-marginal outlets; and (iii) the morphology and positioning of outlets remains fixed during flooding. Direct field observations, together with numerous historical jökulhlaup accounts, confirm that floodwater frequently bursts through the surface of glaciers during jökulhlaups, suggesting that the above assumptions are not always correct. The aims of this paper are to: (i) present new evidence for temporal and spatial changes in outlet morphology and location during single flood events; and (ii) identify controls on the development of supraglacial jökulhlaup outlets. Field observations are presented from two contrasting Icelandic glaciers: Skeiðarárjökull and Sólheimajökull. Both glaciers have experienced recent jökulhlaups that were documented; this provides us with an excellent opportunity to evaluate our current understanding of intraglacial floodwater routing and outlet development. Changes in floodwater routing and outlet morphology and positioning were revealed by video footage and vertical and oblique photographs, which were taken before, during and after the Skeiðarárjökull jökulhlaup in November 1996 and immediately after the Sólheimajökull jökulhlaup in July 1999. Post-flood fieldwork at both glaciers included detailed surveys of jökulhlaup outlets. Our findings confirm that glaciers cannot transmit floodwater as effectively as previously assumed. Temporary increases in basal water pressure in excess of ice overburden can lead to hydrofracturing and the formation of glacier-surface floodwater outlets. The process of hydrofracturing can control the position and morphology of outlets, influencing the form of the jökulhlaup hydrograph and the spatial impact of flooding. Hydrofracturing provides a new mechanism for ice-block release and the rapid elevation of water and debris into glaciers.

A HYDROCLIMATIC ANALYSIS OF THE 1997 FLOOD AT GRAND FORKS, NORTH DAKOTA (USA)

P. E. Todhunter

Department of Geography, University of North Dakota, Grand Forks, ND 58202-9020, U.S.A.
e-mail: todhunte@badlands.nodak.edu

The Grand Forks flood of April 1997 was the most costly flood on a per capita basis for a major metropolitan area in United States history, resulting in nearly $3.6 billion in damages ($US). The Red River of the North drainage basin experiences a severe spring snowmelt flood hazard because of a combination of unique geological features. The main stem of the river lies within a glacial lakebed and is undersized relative to the contributing flows from its tributaries. The slope of the main channel is extremely low, ranging from 0.25 to 0.04 m/km. Channel slopes for the tributaries in the glacial terrain to the east and west of the main channel, however, are significantly higher. Ice jams in the north-flowing river can produce short-term fluctuations in river stage of 1 m. The basin's heavy clay soils have a very limited infiltration and soil moisture storage capacity. The flood hazard at Grand Forks is especially acute because of its location at the confluence of two major rivers at a site upstream from a natural backwater effect along the main channel.

The severity of flooding in any given year depends upon five major contributing factors: (1) the amount of fall precipitation, (2) the thickness of the seasonally frozen soil layer, (3) the depth of the winter snow cover, (4) the rate of spring snowmelt generation, and (5) the presence of spring rain-on-snow events. During the winter of 1996-97 the first four of these factors occurred at either historic or extreme levels to produce a flood estimated at approximately a 250-year recurrence interval.

Heavy fall rains of between 100-250 mm (200-250% of normal) produced high antecedent soil moisture conditions throughout the basin. Near record low winter air temperatures resulted in deep freezing of the moist surface soil layer which greatly reduced the spring soil moisture storage potential. Eight winter blizzards produced record snowfalls throughout the Red River Valley. Liquid water-equivalents ranged between 200-500 mm (200-300% of normal), and were especially high in the southern headwaters of the basin. A late spring snowmelt season was interrupted on 4-6 April by one of the most severe winter storms in the region's history. The blizzard added an additional 40-60 mm of liquid water-equivalent, caused a weeklong cessation of snowmelt generation, and greatly complicated flood-forecasting efforts. The blizzard was followed by a very rapid transition to spring weather conditions marked by the advection of warm and humid air into the basin. Routed flood peaks from the Red River to the south and the Red Lake River to the east, along with locally-generated runoff converged simultaneously onto Grand Forks. The peak river stage of 16.57 m was 1.67 m higher than the previous flood-of-record, while the peak discharge of 3,905 cm was 62% greater than the previous record. Only the absence of spring rains prevented an even more catastrophic flood disaster from occurring
Keywords: Grand Forks, North Dakota, USA; snowmelt flooding; hydroclimatology

INTERANNUAL AND INTERSEASONAL VARIATION OF THE MOISTURE TRANSPORT IN MONSOON REGION OF ASIA AND AUSTRALIA

N. A. Vyazilova

Russian Research Institute of Hydrometeorological Information - World Data Centre 6, Korolyov St., Obninsk, Kaluga region, 249020, Russia
e-mail: vjaz@meteo.ru

This study presents the interannual and interseasonal variations in the field of water vapour fluxes in the tropical atmosphere during warm and cold events of ENSO for boreal summer and winter. Numerous studies of the interannual variations of monsoon rainfall over South - East Asia found that, during warm phases of ENSO the rainfall over the monsoon region was significantly below normal and during cold phases rainfall was above normal. In the past two decades some years had a significantly strong deficit of monsoon rainfall, that is the years 1982, 1986, 1987, 1994 and 1997. Summer monsoon seasons in 1982, 1986 and 1997 coincide with starting of a warm phase of ENSO and summer monsoon seasons in 1987 and 1994, when strong droughts were observed in different regions of Asia, coincide with a prolonged period of warm conditions. On the other hand in 1983, 1988 and 1995 a strong increase of the monsoon rainfall compared to a normal year was observed.

The analysis is based on mean monthly and climatic wind and humidity fields derived from 1981-97 National Centre for Environmental Prediction /National Centre for Atmospheric Research re-analysis. The following characteristics have been calculated for the centres of the 5x5(squares: mean monthly and mean seasonal water content anomalies in the atmospheric column, mean monthly and mean seasonal values of the zonal, meridional and resulting water vapour fluxes and cross-equatorial water vapour flux.

The study found that in years of below average summer monsoon rainfall the strong eastward shift of west monsoon moisture transport in the Asian monsoon region is associated with a strong decrease of east moisture transport due to weakening east trade and negative water vapour content anomalies in the atmosphere in South Tropical Ocean (main source of moisture for summer Indian monsoon). An especially strong decrease was observed for the summer of 1987. In the field of meridional flux a significant weakening of south flux in Western Indian Ocean and intensification of it in Eastern Indian Ocean and Western Pacific was observed. In years of strong monsoon (cold seasons in 1983, 1988 and 1995) in the Western Pacific and South Tropical Indian Ocean a strong increase of east moisture transport due to intensification of east trade and high moisture content in the atmosphere was observed.

During boreal winter monsoon seasons in years before warm events of ENSO (1981-82, 1990-91, 1996-97) and prolonged warm events (1986-87, 1993-94) in Northern Hemisphere over Western Pacific near Philippines there were observed strong northerly water vapour transport anomalies and strong westerly water vapour transport anomalies in equatorial zone of Southern Hemisphere. In years before cold events (1982-83, 1987-88, 1997-98) a significant weakening of north flux compared to normal year in Northern Hemisphere was observed. It supports the hypothesis that a strong winter Asian monsoon usually precedes a drought Asian summer season and likewise, a weak Asian winter monsoon can induce a wet Asian summer season. During winter seasons before warm events (1981-82, 1990-91, 1996-97) an early beginning of Australian monsoon (a strong west water transport over North Australia in December) was observed. During warm events of ENSO (1982-83, 1986-87, 1997-98) a strong eastward shift of west moisture transport in equatorial zone to Western Pacific and a late beginning of Australian monsoon was observed. Before cold events of ENSO west moisture transport over North Australia is weak.

Significant water vapour transport anomalies in South Tropical Ocean and Western Pacific may be the main reasons for the significant deficit and heavy rainfall during warm and cold phases of ENSO in the monsoon region over Asia and Australia in boreal summer and winter.

SESSION 3

PREHISTORIC FLOODS

RECENT EXTREME FLOODS ON MARS

D. Burr[1] and A. McEwen[2]

[1]Department of Geosciences, University of Arizona, USA
dburr@pirl.lpl.arizona.edu
[2]Lunar and Planetary Laboratory, University of Arizona, USA

Recently acquired high-resolution images from the Mars Orbital Camera (MOC), on Mars Global Surveyor (MGS), reveal new details on the large and well-preserved channels near the Cerberus plains and in Marte Vallis (McEwen et al., in preparation). Streamlined islands, longitudinal grooves, terracing, and anastomosing patterns suggest that these channels were formed by fluvial activity. Discharge estimates based on MGS measurements and Manning's equation modified for Martian gravity (Carr, 1979, J. Geophys. Res., 84, 2995) indicate that tens of millions of cubic meters per second flowed through these channels. While this discharge is not as great as that calculated for Mars' giant circum-Chyrse outflow channels (Baker, 1982, The Channels of Mars), it is larger than any current flooding on Earth and comparable to the largest known terrestrial paleofloods (Baker, 1973, Geol. Soc. Am. Sp. Paper 144; Baker et al., 1993, Science, 259, 348). The morphology and topography suggest that water flowed from the highlands north of the Cerberus plains southward into the plains, continued to the northeast through Marte Vallis, then spread out over the extremely flat northern plains. The channels are cut into a surface dated by crater counts to ~200-500Ma (Plescia, 1993, Icarus 104, 20). Lava flows possibly as young as 10Ma (Hartmann and Berman, submitted) are also found in this region, which embay the channels in Marte Vallis and may completely bury the channels in the Cerberus plains. Some of these seemingly very young lavas may have been further modified by fluvial activity. This stratigraphy suggests a genetic relationship between volcanic and fluvial activity. The floods may have resulted from the melting of large amounts of ground ice by extensive magmatic activity (Squyres et al., 1987, Icarus, 70, 385). A mechanism for the sufficiently rapid release of the channel-forming meltwater is poorly understood, but may be related to the emplacement of dikes (McKenzie and Nimmo, 1999, Nature, 397, 231). Rootless cones (or pseudocraters) found on the Martian lava flows indicate further interaction between lava and ground ice (Lanagan et al., 1999, Am. Geophys. Union abstract). Iceland provides excellent analogues for Mars, with extraordinary flooding over volcanic terrains. There are morphologies in the MOC images that we do not understand; we hope to find similar features in Iceland. We also plan to modify and apply step-backwater models to the well-observed jökulhlaups in Iceland, for calibration of the model prior to application to paleofloods on Earth and Mars.

PALEODISCHARGES OF THE LATE PLEISTOCENE MISSOULA FLOODS, EASTERN WASHINGTON, U.S.A.

C. J. Harpel[1], R. B. Waitt[2] and J. E. O'Connor[3]

[1]Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM, 87801, USA
e-mail: charpel@nmt.edu
[2]USGS, Cascades Volcano Observatory, 5400 MacArthur Blvd., Vancouver, WA, 98661, USA
[3]USGS, Water Resources Division, 10615 S.E. Cherry Blossom Dr., Portland, OR, 97216, USA

Peak discharges for four main channels of the Late Pleistocene Missoula floods through eastern Washington State have been estimated using the U.S. Army Corps of Engineers HEC-2 Water Surface Profiles program. The channels are Columbia River, Moses Coulee, Grand Coulee, and Cheney-Palouse scabland tract via proxy. HEC-2 uses hypothetical discharge in a step-backwater routine to develop water-surface profiles along a channel, which are then compared to field evidence for high water. Such field evidence includes ice-rafted erratics, giant current dunes and other flood deposits, upper limit of scabland and breached divides, and lower limit of cut loess scarps. The water-surface profile that best fits field evidence is inferred to represent the peak discharge through the channel during the Missoula flood events. Columbia River is modelled along 291 km from Sentinel Gap to just upstream of Grand Coulee Dam. Grand Coulee is modelled for 50 km from Dry Falls to the same point above Grand Coulee Dam as Columbia River. A 30 km stretch of Moses Coulee is modelled from its confluence with Columbia River up to Dry Coulee. The Cheney-Palouse scabland tract is too wide and shallow to be modelled directly, but this water drained through Snake River and Washtucna Coulee. Therefore discharge from these two channels is used as a proxy for peak discharge of Cheney-Palouse scabland tract. Snake River is modelled along 51 km between the towns of Page and Ayer Junction, and Washtucna Coulee is modelled for 45 km between the towns of Connell and Washtucna.

The peak discharges derived for the channels that best fit field data are: Columbia River at 10 million m^3/s, Moses Coulee at 11 million m^3/s, Grand Coulee at 12–14 million m^3/s, Snake River at 5.5–7 million m^3/s, and Washtucna Coulee at 2 million m^3/s. The composite peak discharge for Cheney-Palouse scabland tract is 7.5–9 million m^3/s. The model also indicates that when Columbia River was at peak discharge the water surface was high enough to overflow into Grand Coulee. But under this condition flow through Grand Coulee was only 5.5 million m^3/s. By knowing peak discharge through each channel along with published discharge values into and out of the channelled scablands it is possible to investigate the dynamics of the Missoula flood events and their interaction with the Okanogan lobe of the Cordilleran ice sheet. These are further discussed in the abstract by Waitt *et al.*

COMPREHENSIVE PALEOFLOOD HYDROLOGY OF THE VERDE RIVER, ARIZONA: CONSTRAINING THE LIMITS OF EXTREME FLOODS IN THE HOLOCENE

K. House[1], D. R. Levish[2], D. R. H. O'Connell[3] and R. P. Denlinger[4]

[1]Nevada Bureau of Mines and Geology, Reno, NV 89557, USA
e-mail: khouse@unr.edu
[2]United States Bureau of Reclamation, Denver, CO 80225
[3]United States Bureau of Reclamation, Denver, CO 80225
[4]United States Geological Survey, Vancouver, WA 98661

Recent innovations in applied paleoflood hydrology demonstrate that Quaternary stratigraphy and fluvial geomorphic history can be used in concert to fully characterise and encapsulate the Holocene flood histories of rivers in the western United States. A new, comprehensive approach has evolved that combines detailed stratigraphic records of large floods occurring over millennia with physical geomorphic evidence that constrain the upper limit to magnitudes of the largest floods on the river over a comparable, or longer, period.

A detailed study of the lower Verde River, Arizona, illustrates the application of this approach. In an isolated bedrock canyon setting, a detailed stratigraphic record of large floods spanning much of the Holocene has been compiled through analysis of slackwater flood deposits. The Holocene flood stratigraphy constitutes positive evidence of the occurrence of extreme floods over time and provides essential information about the frequency of large floods on this river. The slackwater site occupies a small portion of a ~2 km study reach that is being analysed geologically and hydraulically. This reach of the river is a bedrock channel flanked by a suite of Quaternary fluvial terraces. The terraces parallel the river at discrete elevations and document long-term Quaternary downcutting by the river. Each terrace level represents channel or floodplain surfaces abandoned by the Verde River during this interval of progressive downcutting. Each surface that has not been impacted by significant flood-related erosion or deposition since its abandonment and stabilisation represents a paleohydrologic bound—a flood level that has not been exceeded since the surface was abandoned. The lowest abandoned surface that can be identified and dated provides the most useful information in this context.

Paleohydrologic bounds on the lower Verde River are exemplified by the presence of uneroded, well developed soils and datable, relict fluvial deposits in hydraulically vulnerable locations. Such deposits would not be present had their elevation been exceeded by an adequate depth of flow and associated stream power expenditure. The specific flood hydraulics that substantiate the bounds can be accurately calculated by routing flows through detailed channel topography using a robust, two-dimensional hydraulic flow model. The same model is also used to assign discharges to individual flood events recorded in slackwater deposit stratigraphy.

The comprehensive approach to paleoflood hydrology involves establishing maximum bounds on extreme flood magnitudes over long periods of time while also enumerating floods that have approached that limiting discharge over a comparable time period. The utility of this type of information to flood risk evaluation, floodplain management, and basic hydrology and geomorphology is enormous. The comprehensive study of the lower Verde River substantiates this and illustrates the value of thorough geologic and hydraulic analysis for understanding the characteristics of extreme floods.

JÖKULHLAUP DEPOSITS AT ÁSBYRGI, NORTHERN ICELAND: SEDIMENTOLOGY AND IMPLICATIONS ON FLOW TYPE

Ó. Knudsen[1] and A. J. Russell[2]

[1]Klettur Consulting Engineers, Bíldshöfða 12, IS 112 Reykjavík, Iceland
e-mail: oskar@vedur.is
[2]Department of Earth Sciences & Geography, Keele University, Keele, Staffordshire, ST5 5BG, UK
e-mail: a.j.russell@keele.ac.uk

The spectacular subglacial volcanic eruption beneath the Vatnajökull in October 1996 resulted in the release of nearly 4 km^3 of meltwater in a southerly direction to the Skeiðarársandur in early November 1996 as a glacier outburst flood or 'jökulhlaup'. Had the October 1996 eruption been slightly further north, jökulhlaups would have resulted on the northern margin of the Vatnajökull. To date, most research into the impact of jökulhlaups on Icelandic fluvial systems has concentrated on large relatively unconfined outwash plains on the southern margin of Vatnajökull such as Skeiðarársandur. As such there is only a limited picture of the magnitude, rheology, geomorphic impact and sedimentology of floods draining the northern margin of the Vatnajökull where the present river channel is deeply incised within flood excavated bedrock gorges.

This paper presents sedimentary evidence of jökulhlaup deposits at Ásbyrgi, 1 km north of the spectacular Ásbyrgi canyon. A small gravel pit located less than 1 km from the mouth of the western channel of the Ásbyrgi canyon provides excellent exposures into a large boulder-covered terrace surface, which slopes away from the bedrock gorge which holds the present day course of the Jökulsá á Fjöllum. The sedimentary succession consists of large-scale sandy trough cross-bedded units capped by a boulder-rich unit. The boulders are contained within a structureless matrix, which is occasionally channelised. Sediments show signs of syn-depositional slumping and dewatering. These deposits are interpreted as the product of a hyperconcentrated flow and are similar to sediments south of Mýrdalsjökull associated with Katla eruptions. The location of the pit and the boulder surface suggests these flows emanated from the present course of the Jökulsá á Fjöllum. The last period of jökulhlaup activity within the Jökulsá á Fjöllum was in the early-mid 18th century when a series of large jökulhlaups inundated the lowlands north of Ásbyrgi. Historical accounts suggest that these floods may have been of similar magnitude to the November 1996 jökulhlaup at Skeiðarárjökull. The fact that the historical floods within the Jökulsá á Fjöllum were hyperconcentrated suggests that these floods may have been volcanically generated. This is particularly worrying for both communities and infrastructure along the Jökulsá á Fjöllum as it is acknowledged that we are entering a period of renewed volcanic activity in the Vatnajökull area.

JOINT ANALYSIS OF PRE-HISTORIC AND OBSERVED FLOODS AS TEST FOR MAIN STOCHASTIC INVARIANT

V. A. Lobanov

AMFONP, State Hydrological Institute, 23, Second Line, St. Petersburg, 199053, Russia
e-mail: lobanova@hm.sici.ru

Modern stochastic approach for analysis of extreme events (floods, droughts) is based on the conception of general totality and sample from it. It is necessary that the general totality be homogeneous and stationary and the sample (or observed time series) be homogeneous and stationary too. General totality is used for the assessment of errors of parameters and quantiles of distribution function for the particular observed sample (time series). Practically, in conditions when the information about general totality is absent, they use many observed samples over the area instead of the longest time series, for example as in case of the PMP/PMF rainfall-runoff method. This is the assumption of the main stochastic invariant: the longest time series over the time (general totality) instead of many short time series over the space.

For proving this main assumption the time series of restored annual runoff for the Dnieper River - site Lotsmanskaya Kamenka has been used with the common size of more than 4100 years. This time series has been restored on the basis of silt sediment columns in the Sakskoye lake in the Crimea. The relationship between silt sediment time series and observed annual runoff was close enough with a correlation coefficient 0.85. The relationship between annual and maximum runoff for the site Lotsmanskaya Kamenka has correlation coefficient about 0.94 and is used for the restoration of "general totality" of daily spring maximums. Some dozens observed time series in the Dnieper River basin and in the nearest basins (Upper Volga, Oka, etc.) have been chosen. The influence of man's impact was eliminated.

The paleo-historical restoration and observed time series have been analysed together for assessment of homogeneity and stationarity of distribution functions, design maximum floods and their random errors. For this aim the "general totality" has been divided into a number of samples with different size for assessment and for testing in the future period of water project separately. The processes of four temporal scales have been extracted from "general totality" - interannual, decadal, centennial and millennial and their generalised and cyclic parameters have been determined. The following main results have been established:

main stochastic invariant took place for processes of inter-annual and decadal scales only and main stochastic constants have been given;

the contribution of centennial component (long-term climate change) is significant and increasing with the sample size;

the errors of design floods obtained by theoretical and empirical ways can differ in some cases and their values are given.

EVIDENCE FOR PROVINCE-WIDE WATER STORAGE AND CATASTROPHIC DRAINAGE BENEATH THE LAURENTIDE ICE SHEET, ALBERTA, CANADA

M. J. Munro-Stasiuk

Kent State University, Kent, OH 44242-0001
e-mail: mmunrost@kent.edu

South-central Alberta, Canada, is dominated by an extensive suite of fluted and hummocky landforms which formed beneath the Laurentide Ice Sheet near the last glacial maximum. Accepted theories indicate that hummocks represent ice marginal, or near-marginal moraines, and fluted terrain represents subglacial deformation. However, sediments found in the hummocks are atypical of processes associated with ice-marginal sedimentation: in situ bedrock, thrust bedrock, lodgement till, melt-out till, sorted sand and gravel, rippled sand, rhythmically-bedded sand, silt, and clay, and pervasively sheared beds (Munro and Shaw, 1997). Also, undeformed fluvial gravels that predate glaciation preclude ice deformation as a mechanism of fluted terrain formation. Similar surface trends in both landform types indicate that their geneses are likely linked. Other similarities are:

1. Both landform types have erosional surfaces, which cut into disturbed and undisturbed substrates, and therefore their surfaces represent a regional landscape unconformity;
2. Widespread boulder lags sit on the landscape unconformity and demonstrate that fluvial processes were instrumental in their formation;
3. Surface trends in the landforms are transverse to the last recorded local ice flow direction preserved in sediments indicating that ice was unlikely the erosional agent;
4. Both landform types have morphologies, which are analogous to fluvial bedforms.

The implications are that the landforms were eroded by a continuous sheet of meltwater flowing beneath the Laurentide Ice Sheet, which was as wide as the fluted and hummocky terrain belt (150 km). Where was the origin of this meltwater? By inference the water had to partially originate from upglacier. However, there is also significant sedimentary evidence preserved within the erosional landforms for extensive subglacial reservoirs in south-central Alberta, suggesting that the water source was also local. This water initially built up in the preglacial valley drainage network but expanded beyond that network. It is proposed that this water gradually migrated towards the ice margin as the reservoir was expanding. The implications are that much of south-central Alberta was inundated by subglacial water near the last glacial maximum which can also explain the low ice-sheet profiles determined for the region. When this pressurised water finally contacted the margin, it was released catastrophically resulting in extensive erosion across the landscape previously occupied by the reservoir. This erosion resulted in the hummocky and fluted terrain formation. This is a radical reinterpretation of landforms traditionally associated with direct ice processes, and it has major implications for the reinterpretation of modern and ancient glaciated environments.

Munro, M., and Shaw, J., 1997, Erosional origin of hummocky terrain in south-central Alberta, Canada. Geology, v. 45(11), p. 1027-1030.

CATASTROPHIC FLOODS IN ICELAND

H. Tómasson

National Energy Authority, Grensásvegur 9, 108 Reykjavík, Iceland
e-mail: ht@os.is

Glaciers are a part of the solid earth. They move relatively fast, much faster than other parts of "terra firma". This, in connection with volcanism under the glaciers, causes rapid changes and unstability in the landscape, as well as release of energy, hardly known elsewhere in nature. The fastest movement and energy release takes place from ice-dammed lakes or ice-covered volcanoes.

Catastrophic floods defined as a peak flow larger than 100 000 m^3/s occur twice a century in Iceland. They transport huge volumes of eruption material and deposit it on the sandur extending the shoreline several km seawards. The last episode of this kind was the eruption of Katla on the 12th of October in 1918. Several km^3 of water and ice were transported by the burst, and over 0,5 km^3 of magma surfaced in the Katla caldera. The peak flow is estimated at 300 000 m^3/s. Some floods have flowed over bedrock at considerable slope. They cause a change in the landscape through eroding deep and wide canyons. At least one such came from the Katla caldera, eroding the magnificent Markarfljótsgljúfur.

Catastrophic floods occurred near the end of the last glaciation in the basin of the Hvítá river in Southern Iceland. The flood originated in an ice-jammed lake at Kjölur on the upper reach of Hvítá. A fairly detailed picture of alternating accumulation and release of water in enormous floods is found. The peak flow was 200 000 m^3/s.

A catastrophic flood occurred in Jökulsá á Fjöllum some 2500 years ago. In this flood the huge Jökulsá canyon was eroded and also dry waterfalls such as in Ásbyrgi. The total erosion in rock amounted to 0.55 km^3 and the peak flow was 450 000 m^3/s. This is the biggest of the catastrophic floods in Iceland. The origin is most likely the Bárðarbunga caldera in Vatnajökul.

VARYING ROUTINGS OF REPEATED COLOSSAL JÖKULHLAUPS THROUGH THE CHANNELLED SCABLAND OF WASHINGTON, U.S.A.

R. B. Waitt[1], J. E. O'Connor[2] and C. J. Harpel[3]

[1]USGS, Cascades Volcano Observatory, 5400 MacArthur Blvd., Vancouver, WA, 98661, U.S.A.
e-mail: waitt@usgs.gov
[2]USGS, Water Resources Division, 10615 S.E. Cherry Blossom Dr., Portland OR, 97216, U.S.A.
[3]Department of Earth and Environmental Science, New Mexico Tech, Socorro, NM, 87801, U.S.A.

Stratigraphy, regional geomorphology, and hydraulic modelling suggest different routings of floods at different times during ~100 separate last-glacial Missoula floodings. Though >1.5 km wide, Wallula Gap was a bottleneck for the Missoula floods, ponding water faster than it could be discharged. Incoming discharge via Rathdrum valley was >17 million and perhaps 25–30 million m^3/s, plus >1 million m^3/s that skirted north. The Columbia at and below Wallula Gap discharged 10 million m^3/s, so 8 to >21 million m^3/s could pond hydraulically in Pasco basin.

When the NW part of the Columbia valley was not blocked by Cordilleran ice, Missoula floodwater discharged 10 million m^3/s that way. Field evidence shows the peak flood descends from 485 m near Wenatchee to 366 m at Wallula Gap. Projected water profiles (abstract by Harpel *et al.*) suggest that some high scabland tracts to the east were then little flooded. Highest levels of flood down Grand Coulee *require* an ice-blocked Columbia. Between these stages Moses Coulee drew off 5–11 million m^3/s, leaving that much less to flood eastern tracts. At Grand Coulee's head the highest field indicators of flood stage at 750 m are 110 m above a computed water-surface altitude 640 m. These high-flood limits could only occur when the Okanogan lobe blocked Columbia valley, forcing *all* Missoula floodwater into the Channelled Scabland. At this high level, flow down Grand Coulee had a steep profile (4.4 m/km) and discharge of 12–14 million m/s.

Cheney-Palouse scabland tract spilled into Snake valley, shedding great gravel bars *up* the valley and slackwater silt to altitude 397 m, 30 m above the highest level of such silt in Pasco Basin. Thus floodwater from Palouse valley alone hydraulically ponded the Snake upvalley. From this spillover, peak-flood limit slopes down Snake valley to Pasco Basin from 400 m near the Palouse confluence to 330 m near Snake River Junction, a profile graded to 325 m at Wallula Gap, 40 m *below* the highest down-Columbia flood limit there. Peak floodlines down the Columbia and Snake cannot be coeval. Upstream of the Gap, peak-flood limit across the system was by several great floods, a composite representing no one flood.

Inferred discharges* for peak floods from glacial Lake Missoula.

Floodway	Income	Outgo w/o icedam		w/ icedam
Rathdrum	17–30			
North	1?			
Columbia		10	0	
Grand Coulee		5.5		12–14
Moses Coulee		?	0–11†	
Cheney–Palouse		3?		7.7–9‡
Telford–CrabCreek	?	2?		
18–31	>18.5		>31	
Lower Columbia	10	10		

* Values in 10^6 m^3/s, see abstract by Harpel *et al.*
† Ice-margin conditions for this discharge ambiguous
‡ Composite lower Snake and Washtucna, proxy for Cheney-Palouse

HUGE LATE HOLOCENE FLOOD, JÖKULSÁ Á FJÖLLUM, NORTH ICELAND

R. B. Waitt

U.S. Geological Survey, 5400 MacArthur Blvd., Vancouver, WA, 98661, U.S.A.
e-mail: waitt@usgs.gov

Jökulsá á Fjöllum, a large glacial river, drains from Vatnajökull icecap 200 km northward to the sea along Iceland's active volcanic belt. Many erosional and depositional features along this path are alien to normal volcanic, fluvial, or glacial landscapes but are like those of catastrophically floodswept tracts. Evidence of floodflow variously as deep as 10 to 95 m is strewn atop late-Holocene lava flows in a tract 1–10 km wide along Jökulsá. Field evidence of great flood includes: eroded scabland up to several meters in relief; dry falls, one of them (Ásbyrgi) 1.2 km wide, 3.5 km long but many others far smaller; gravel bars as large as 8 m high, ½ km wide, 1 km long; giant-current dunes; and scattered outsized water-tumbled boulders 0.5 to 5.2 m in diameter.

Stratigraphy reveals just one late Holocene great flood down Jökulsá á Fjöllum—well after the Hekla H3 tephra fell, some time between 2500 and 1500 yr. ago. By step-backwater computation, the great late Holocene flood discharge peaked between about ½ and 1 million m^3/s—$1/30^{th}$ to $1/60^{th}$ the largest late Wisconsin jökulhlaups through Washington's Channelled Scabland. An early scabland-carving great flood had swept down lowermost Jökulsá just after deglaciation and before Hekla tephra H5 fell, some time between 9000 and 8000 ^{14}C yr. ago. But stratigraphy disproves earlier hypotheses of several great floods between 6000 and 3000 yr. ago.

Source of the great late Holocene flood is ambiguous. Some water emerged from Kverkfjöll to anastomose through moderate-relief landscape, but even this discharge was too small to account for the flows downvalley as deep as 90 m. A more western source—subglacial Bárðarbunga caldera or fissures northeast—may have melted, stored, and suddenly released most of the water for Jökulsá's great flood. Renewed subglacial volcanism in northern Vatnajökull could trigger another great Jökulsá flood.

SESSION 4

FLOODS: CASE STUDIES

THE MOST SEVERE FLOODS OF TIBER RIVER IN ROME

M. G. Alessandroni[1] and G. Remedia[2]

[1]via di Grotta Perfetta, 343 00142 Roma, Italia
e-mail: nardim@ing.univaq.it
[2]Università di L'Aquila, Monteluco di Roio 64070 L'Aquila, Italia

After a review of *deluges* of rain which caused floods in Rome during the long period from 414 BC to the 19th century and a survey of *extraordinary* floods (peak discharge over threshold Q (2000 m^3/s) during the 20th century until December 1999, the dynamic development of the Roma-Ripetta Gauging Station, both Hydrological Zero and rating curve, is taken into account.

The analysis of storms and most severe floods during 20th century shows that the catchment inflows change their space and time placement very much and always. This study examines the relationship between river peak discharge and rain, distributed among three different periods:
1) *preparatory period:* during some months, about three to four, before the month of the flood;
2) *antecedent period:* during several days, about five to ten, until three to five days before the flood peak;
3) *contemporary period:* during some days, about three to four, the last days before the flood peak.
Correct forecast for future floods must take into account not only the contemporary precipitation, but also the moisture of the soil, due to the first and second period rain.

This study attempts to find the statistical and functional relationship between the peak discharge values and the mean inflow of the three different periods, regarding only *extraordinary* severe floods (reaching or surpassing the threshold of 2000 m^3/s) occurring since 1922, from which time there is ample data, rain gauge recorded data from many stations in the drainage-basin, and hydrological data, from Roma-Ripetta Gauging Station. Although the size of the extraordinary floods sample is small, mathematical and statistical model estimates fit the data well: the variance "explained" by the model reaches 90% of total variance.

FLASH FLOODS, THEIR ANALYSIS AND FREQUENCY (LEARNING FROM CASE STUDIES IN NORTHERN HUNGARY)

G. Balint and L. Szlavik

Hydrological Institute, Water Resources Research Centre (VITUKI), Kvassay 1, Budapest H-1095, Hungary
e-mail: balint@vituki.hu

Under the climatic conditions of the Central Danube Basin flash floods are a relatively rare phenomena. The majority of floods go almost unnoticed on most of the small ungauged creeks in the 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 flash flood events in Central Europe (Czech Republic, Hungary, Slovakia, Rumania) in recent years are reviewed. The June 23rd, 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 Matra Hills. The role of slope conditions, antecedent moistening and high intensity of short period precipitation was clearly shown. Available gauge records on Kemence creek together with post flood investigations proved the significant role of sediment and floating matter transport and jamming. Heavy erosion and associated destruction and losses of property cannot be fully assigned to the natural flood wave owing to the failure of an upstream reservoir dam. The superposition of the natural flood and the sudden wave caused by instant reservoir release lead to the highest flow velocities. Flood frequency analysis was mostly based on disaster records of this century, and frequency analysis of precipitation events. In case of the Matra Hills flood records at the lower reaches of the Zagyva catchment were also used. Investigations in most cases proved the seemingly exaggerated media reports and public judgement: recent events were rare, extraordinary phenomena for the region with return periods of 40-130 (and more) years. The necessity of regional tackling of frequency issues was recognised. Limitations of empirical relationships used for the estimation of design floods were clearly revealed. Meteorological conditions of different events show some parallels, but these findings have only limited prognostic value. This fact also emphasises that beside (or instead of) real time forecasting and warning wherever it is possible, proper planning and building codes and construction standards should be emphasised.

EXTRAORDINARY FLOOD IN SUMMER SEASON IN KARST AREA CASE STUDY - CROATIA

B. Berakovic[1] and K. Cesarec[2]

[1]Faculty of Civil engineering, University of Zagreb, Kaciceva 26, 10000 Zagreb, Croatia
e-mail: Boris.Berakovic@public.srce.hr
[2]Meteorological and Hydrological Service, Gric 3, 10000 Zagreb, Croatia

In July 1999 a sudden flooding in the Ogulin area in Croatia surprised even water management experts. The town of Ogulin is situated in a karstic area. Waters from this area are effluents of the river Sava through a number of sinks.

In this paper a review of earlier flooding is given; the works to prevent flooding is described including a hydroelectric power plant which reduces water flows to the sinks. An analysis of the 1999 extreme flooding is given as well as flows in the river and at the hydroelectric power plant structures. Also damages caused by the flooding and measures to improve protection are described.

RECENT EXTREME WEATHER EVENTS IN THE NEPAL HIMALAYAS

S. R. Chalise[1] and N. R. Khanal[2]

[1]Mountain Natural Resources Division, International Centre for Integrated Mountain Development (ICIMOD), G.P.O. Box 3226, Kathmandu
e-mail: chalise@icimod.org.np
[2]Central Department of Geography, Tribhuvan University, Kathmandu

Extreme weather events and natural disasters induced by them are seen to be on the increase in the Himalayas in recent years. If glacial lake outburst floods (GLOF) are occurring more frequently in the high mountains, then floods and landslides events are more frequent in the middle hills and on the lower plains. Such disasters associated with extreme weather events cause widespread damage to life and property. They also destroy the costly infrastructures in the mountains and the adjoining plains every year, severely affecting the pace of development in the Hindu Kush-Himalayan (HKH) countries. Although precipitation is the principal triggering factor for such disasters, the fragile and active geology of the HKH, highly steep slopes and the recent indiscriminate changes in land-use and land cover further exacerbate the problem.

Recent reports from Nepal and other countries of the HKH on rapidly growing glacial lakes, general retreat of glaciers and widespread deglaciation can be considered as evidences of the increasing impacts of atmospheric warming in this region. The implications of such deglaciation in the HKH, which is the source of six major rivers of Asia, viz., the Indus, the Ganges, the Brahmaputra, the Mekong, the Yangtze and the Yellow river, (Myint and Hofer, 1998) on the hydrology and water resources would be enormous and devastating for the nearly 500 million people living in these river basins, who depend on these rivers for their sustenance. The trend of increasing frequency of high rainfall events and floods in recent years could be considered to be broadly in accordance with the IPCC scenarios on potential impacts of climate change in the region (Chalise, 1994), although uncertainty in the occurrence of such events is predominant.

Recent studies in Nepal have clearly shown that glacial lake outburst floods are occurring more frequently and glacial lakes are growing rapidly both in size and numbers (Ives, 1985; Yamada, 1998). The impending threat of the bursting of the rapidly growing Tso Rolpa glacial lake in the Rolwaling Himalayas in east Nepal has necessitated the establishment of early warning systems. Arduous engineering works are in progress at Tso Rolpa at elevations above 4500 m at very high costs to protect the life and property and a 60 MW hydropower station downstream which is nearing completion.

An increasing number of extreme events associated with intensely high rainfall (up to 540 mm within 24 hours) have been reported from the middle hills of Nepal in recent years (Chalise and Khanal, 1999). Floods, landslides and debris flow associated with these events in the middle hills cause widespread damage even in the lower plains, as was seen during the disaster in Central Nepal in July 1993 in which 760 persons were killed (Dhital et al, 1993). During the same event the catastrophic floods deposited about 5.19 million m^3 of sediment in the reservoir of Kulekhani hydropower station reducing its life span by half. Excessive sediment transport which occur during such extreme floods events are difficult to quantify and are usually underestimated (Hofer, 1998; Sthapit 1996). Similarly during the August 1998 disasters in Western Nepal, 246 people died and damage exceeded 100 million dollars (Khanal 1998).

The paper briefly reviews the general issues associated with extreme events in the HKH region and discusses some case studies of recent extreme events from Nepal Himalayas in the three physiographic regions viz., the high Himalayas, the middle hills and the lower plains.

FLOOD RISK ASSESSMENT AT THE LOWER AND MIDDLE RIVER RHINE - LESSONS LEARNT FROM HISTORY

P. Krahe, H. J. Liebscher and K. Wilke

Federal Institute of Hydrology, Kaiserin-Augusta-Anlagen 15-17, D-56068 Koblenz, Germany
e-mail: krahe@bafg.de

Flood events in the Middle and Lower Rhine basin between AD 1000 and the present were reconstructed by interpretation of historical records. As an indicator for climate variability in the Rhine basin from Basel to Cologne, time series of a thermic index were established on the same basis. Observation series of air temperature and streamflow are available from the late 18th century onwards.

The analysis of the time series reveals that already in early centuries damage-inflicting flood events occurred in winters and summers in the Rhine basin. Some of them were even more extreme than the events that hit the Middle Rhine region in the winters of 1993/94 and of 1995. Single periods stand out, when heavy and extreme winter as well as summer floods occurred in increased frequency. During the marked cold periods of the climate period under consideration here, one notes a decrease in the frequency of heavy and extreme floods, while the so-called ice floods became dominant.

Since the mid-14th century, the frequency of extreme floods has increased. This can be explained partially by a widespread change in soil properties that had set in at the beginning of this century, if not earlier. Large-scale erosion processes are known to have occurred as a consequence of deforestation in the High Middle Ages and the occurrence of climate-induced extreme heavy rainfall in summers.

In the second half of the 20th century an increase in frequency of extreme floods can again be noted. The maximum was reached in the 1940s, and it has remained on a high level for the rest of the century. The increased number of floods in this period is mainly due to the higher number of warm precipitation-rich winters.

For our present understanding of flood risk assessment it is evident to take into account the extremes of the extremes in the past.

THE FLOOD OF THE FLOODS? POLAND, SUMMER 1997

Z. W. Kundzewicz

Research Centre of Agricultural and Forest Environment, Polish Academy of Sciences, Bukowska 19, 60-809 Poznan, Poland
e-mail: zkundze@man.poznan.pl

The flood that occurred in the summer of 1997 in Poland, hitting the drainage basins of the Odra and the Vistula has been labelled the largest natural disaster in the 1000-year history of the country. It caused 54 fatalities and material losses of the order of billions of US$, in this latter category being an all-time high. The flood struck a large part of the country and caused inundation of 665,000 ha of land. The number of evacuees was 162 thousand. The rhetoric used in Polish media refers to the Great Flood of 1997 as an event whose scale exceeded all imagination about the possible size of the disaster. During the Great Flood of 1997, historic maxima of river stage and flow rate were considerably exceeded. From the hydrological point of view, this flood was a very rare event, with return period in some river cross-sections of the order of thousand of years and more. Discussion of the anatomy of the flood, its meteorological causes and hydrology is offered and comparison to other flood events is made. As for several years before 1997 only minor floods had occurred in Poland, the awareness and preparedness of the nation was weakened and the country was taken by surprise. The Odra flood attracted much international attention. One reason for this is the international character of the river Odra, shared by three riparian countries: the Czech Republic, Poland and Germany. Moreover, this natural disaster occurred in a dynamically developing country-in-transition (where expenditure on flood preparedness was low, under a long-term absence of disastrous floods). The transition from the rule of a communist party and centrally planned economy towards democracy and market economy is a unique and novel exercise, of significant interest. Therefore, a holistic view on the destructive Odra flood is presented. This includes discussion of flood impacts on the politics and the role of the media. A conclusion is clear that the disaster could not have been avoided; yet there are many elements of the flood-preparedness system, whose improvement would have significantly reduced the losses.

A MILLENNIUM OF CATASTROPHIC FLOODS ON MÝRDALSSANDUR, SOUTH ICELAND

G. Larsen

Science Institute, University of Iceland, IS-101 Reykjavik
e-mail: glare@raunvis.hi.is

The largest flood events of the past 10-11 centuries in Iceland were caused by eruptions on the partly ice-covered Katla volcanic system in S-Iceland. Hydroexplosive basaltic eruptions have occurred with an average frequency of two per century since the 12^{th} century, when volcanic activity was resumed after a repose of some 200 years following the largest known Holocene event on the Katla system, the 10^{th} century Eldgjá eruption.

All known Katla eruptions of the past 500 years have been accompanied by jökulhlaups through the Kötlujökull pass onto the Mýrdalssandur flood plain. The flood routes and the damage inflicted were documented, allowing mapping of main routes and estimates (relative) of magnitude. An increase with time is suggested by the data. Katla eruptions of this period are often referred to as Kötluhlaup, the flood exemplifying the whole event.

Katla eruptions of the 12^{th} to 15^{th} centuries are less well documented and any evidence of jökulhlaups - if they did occur - is lost. The scant descriptions refer to the Katla eruptions as such and do not - with a single exception - mention floods.

Katla jökulhlaups are multiple events. Jökulhlaups can occur throughout an eruption and may also occur for some time after an eruption is over. Jökulhlaups on the first day of eruption are usually the largest and transport the greatest "ice-load" onto the flood plain and into the sea. Velocity of the flow front may vary from 6 to 20 km/hour. Peak discharge of the 1918 jökulhlaup has been calculated to be as high as 300.000 m^3/s. Later floods may partly flush the ice from the sandur plain seawards, establishing flood channels and modifying deposits left by the early ones.

Two categories of jökulhlaups are apparent from the descriptions. In some instances, the first phase of the jökulhlaups breaks up through the ice well inside the glacier terminus ("midways up the glacier") and discharges onto the sandur at the south, east and north periphery of the Kötlujökull outlet glacier. In other instances the first phase emerges at or from beneath the glacier terminus along the south periphery of the glacier. The first category floods larger areas, including the northern part of the outwash plain.

About 400 km^2 can be flooded to a greater or lesser extent in a major Katla jökulhlaup, including some 50 km^2 that have been added to the south shore since the Eldgjá eruption. Raising of the sandur surface along the edge of the Eldgjá lava on Mýrdalssandur amounts to at least 20 m, if the edge was of similar height as that of the Eldgjá lava east of the flood plain.

HISTORIC EXTREME FLOODS AS INPUT TO DAM SAFETY ANALYSES

G. H. Midttømme[2] and J.K. Tingvold[1]

[1]Glommen and Lågen Water Management Association (GLB), Oslo, Norway
[2]Dept. of Hydraulic and Environmental Engineering (NTNU), S. P. Andersens v 5, N-7491 Trondheim, Norway
e-mail: grethe.midttomme@bygg.ntnu.no

In a case study for River Vinstra in south-east Norway descriptions and data for two historic extreme floods have been collected to make a foundation for contingency planning to ensure dam safety. There are 6 reservoirs in the Vinstra river catchment from Bygdin at 1057 m a.s.l. to Olstappen at 668 m a.s.l. The reservoirs are all situated on a mountain plateau surrounded by high peaks and glaciers to the west/north rising to about 2300 m a.s.l. The river is a tributary to River Gudbrandsdalslågen (Lågen) and the two rivers meet at Vinstra about 225 m a.s.l. The most extreme flood documented is the famous "Storofsen" in 1789, which hit several of the largest river catchments in South-Norway leading to approx. 200 fatalities. Another example of an extreme flood is the flood of 1938 in the tributaries to River Lågen (including Vinstra) which is estimated to have been a 500-year flood. The 1938-flood is fairly well documented by meteorological and hydrological data as well as eyewitness descriptions. By combining a discharge simulation with information about secondary effects in the catchment (landslides, floating debris etc) we can get a realistic scenario of how the 1938-flood would affect the various dams today. In the case of the 1789-flood eyewitness descriptions and reports are available estimating precipitation which is used in simulations of runoff. The descriptions give important information about secondary effects, which may have strong influence on the dam owners' capability to operate dams safely during an extreme flood

A STUDY OF EXTREME EVENTS IN THE ATHENS GREATER AREA

M. Mimikou, E. Baltas and E. Varanou

Department of Civil Engineering, Division of Water Resources, Hydraulic and Maritime Engineering, National Technical University of Athens, 5 Iroon Polytechniou 157 73 Athens, Greece
Email: (E.Varanou): E.Varanou@chi.civil.ntua.gr

Flood phenomena in Greece in the last 100 years have caused more loss of life than any other natural hazards, i.e. earthquakes. The dominant factor in flood genesis are the intense rainstorms produced by the passage of depressions possibly accompanied by cold fronts, approaching from W, SW or NW. A convectional weather type, characterised by a cold upper air mass that produces dynamic instability, is also responsible for many intense storms, especially in the summer period. The current study focuses on the severest flood of the last years, which occurred on 21 – 22nd of October 1994, in the greater Athens area. The flood caused the loss of 9 human lives and damages of about 14 MEURO.

The sensitivity of Athens in flooding can be explained by examining the climatological, geomorphological and anthropogenic factors influencing flood generation. The climate of Athens is dry, with a mean annual rainfall depth of about 400 mm and a high evaporation rate. However, the intense flood producing rainstorms are as high as in other parts of Greece, where the mean annual rainfall is 3–5 times higher. The existing river networks are not significant and the cross sections of the streams are small. The area is covered by small catchments with small runoff concentration times. Moreover, the urban development of Athens, which occurred in the last 50 years, affected the flood rate seriously. The increase of residential, commercial and industrial areas and the diminution of natural parks and farm lands resulted in reduction of inundation areas.

The event of October 1994 was indeed very severe and resulted in an extensive inundation, damage of streets, houses and commercial and industrial areas, as well as the overflow of water courses in a big part of Athens

EXTREME FLOODS OF INDIA

K. S. Murty

101 Sneh Chaya Apts, 28 Hindustan Colony, Amravati Road, Nagpur 440010, India
e-mail: ankush99_99@yahoo.com

Mythologies mention a catastrophic flood, similar to Noah's that took place between the end of one cycle of eras (four) and the beginning of another. It is also believed that a great flood in the Indus or the then existing Saraswati river was the cause for the submergence of areas marked by the Mohenjo-daro and Harappa civilisation. In modern India, floods have been fairly frequent, with an occasional extreme one in between. The problem of floods faced by India is unique in that it has a varied climate and rainfall pattern in different parts of the country. Of the total geographical area of about 328 million hectares, about 41 million hectares, or nearly one-eighth is considered flood-prone. Though most of the floods occur during the north-west monsoon season, that extends from June to September and accounts for about 80 percent of the total annual precipitation, inundation of inhabited land even in other parts of the year, too, is not uncommon. There are occasions when one part of the country is experiencing floods while another is in the grip of severe droughts. The problem is most acute and complex in the Brahmaputra and the Ganga Basin states like Assam, Uttar Pradesh, Bihar and West Bengal. It is also formidable in the river systems of Orissa and Central India. River systems, such as Mahanadi, Godavari (delta area) and Krishna also face measuring flood menace. Over Rs. 27,040 million were spent on flood management till the end of the seventh plan. One major cause of floods is hydro-climatological. There are examples of excess flow due to heavy rainfall and cloud burst, melting of snow on a large scale with attendant bursting of dams built on ice blocks, sudden and excess release of impounded water behind dams, and bursting of man-made or land-slide-built dams, in India. Cloudbursts have been reported in the Himalayas, Orissa and central India and in western India. In 1978, the Morvi area in Saureshtra experienced sudden, heavy and incessant rains, resulting in the collapse of the Machu dam II. Consequently water gushed out and flooded the area, killing 1419 people. Similarly, the Luni river had sudden floods in Rajasthan in 1967 and the Kosi river in Kumaon, described as the Sorrow of Bihar, flooded a large area in 1978. The Panchet and Khdakvasla on the Mula river destroyed part of the city of Pune in 1961. A 4 km stretch of the valley of Kanodia got blocked following a cloud burst in the great Himalayan range and consequent slipping of a colossal volume of morainic debris down the stream. This resulted in the formation of a 3-km long and 3m-deep lake. The debris moved down and blocked the passage of the Bhagirathi river, forming a mighty dam. This dam burst 14 hours later and caused calamitous floods, wiping away the hamlets of Gannani and Dabrani on the pilgrim path to Gangotri and causing wide-spread havoc Uttarkhashi. The Narayani and Kosi rivers suffered a reduction in their carrying capacity due to heavy silting and caused extensive flooding in eastern U.P. and northern Bihar. Examples are abundant.

FLASH FLOODS AND THEIR IMPACT ON COMMUNITY IN SRI LANKA

P. Patabendi

Team for Disaster Prevention and Sustainable Development (Team DPSD), 231/G/3,Vihara Mawatha, Hewagama, Kaduwela 10640, Sri Lanka
e-mail: patabedi@slt.lk

Flash floods are regarded as the number one disaster in Sri Lanka. It has 103 river basins of which about 10 rivers are considered as major. Among these major rivers Kalu, Kelani, Nilwala and Mahaweli are vulnerable to floods. Of the factors that are conducive to the creation of floods, one of the principle causes is encroachment or development on the flood retention areas and extraction of sand from riverbeds.

Floods in Sri Lanka are mainly due to excessive rainfall during monsoons. The rainfall distribution in Sri Lanka is subject to spatial and temporal variations leading to distinct patterns of seasonality, regionality and interannual variability in the climate. The average annual rainfall ranges from around 500 mm to 800 mm. The highest rainfall of 805 mm within 24 hours was experienced in 1897 and a great flood submerged the capital city of Colombo on 5th June 1992 due to a rainfall of 494 mm.

Meteorological calculations have shown that April is usually the driest month in the year. The overhead sun contributes positively to drought conditions. The average temperature in Colombo revolves between 33 to 35 degrees centigrade. This high temperature brings about severe discomfort for the people. Profuse sweating is common with many people suffering "prickly heat". Children are the worst affected victims.

However due to climate changes, which occurred during early April 1999, the whole picture started to change. Heavy rains started on April 5th and continued up to the 6th. The rains were not the usual inter-monsoonal showers, but it was due to the forming of an Inter Tropical Convergent Zone (ITCZ). The usual pattern was to have sunny days after the showery days. But something unexpected happened. There was rain again. The rains came in torrents. It persisted for several days. There were floods in many parts of the country. Many of the trunk roads and by-ways in the city of Colombo were inundated and were impassable. There were landslides too in number of areas in the country. The casualties were high this time compared to the past. At least 20 persons were reported killed due to floods while 50,000 families were rendered homeless.

HIGHEST FLOODS IN INDIA

P. R. Rakhecha

Indian Institute of Tropical Meteorology, Pune, India
e-mail: p_rakhecha@hotmail.com

The summer monsoon period (June – September) is the main rainy season in India. During this period cyclonic storms from the Bay of Bengal and the Arabian sea move over the Indian land and produce the most heavy widespread rainfall in different parts of the country. On a particular day, the heavy rains associated with these storms are distributed roughly over an area of 400,000 km^2. The heavy rains cause severe floods of varying intensity in the Indian rivers and produce a wide range of environmental and human related issues. In some years larger floods overflowed the river banks and inundated vast areas of land. Some extraordinary floods have even broken the levee systems and destroyed dams causing heavy loss of life and property. For example, an extraordinary flood on Machhu river in August 1979 that occurred from heavy rains destroyed the Machhu – 2 dam in the Gujarat region. Such large floods are very important events, not only in terms of environmental consequences but also are of value in design flood work for important projects especially at a site where stream gauging data are not available.

With this in view, an attempt has been made in this paper to assemble information on the highest ever recorded floods in the Indian rivers. Data on the magnitudes of the highest floods observed showed that eleven major rivers in India at about 29 sites recorded the highest floods. The magnitudes of the floods measured in different river catchments are:

Area (km^2)	Flood (m^3/s)	Area (km^2)	Flood (m^3/s)
133	1170	19600	15400
212	1177	19900	18100
328	3108	21800	16000
440	3981	22584	37000
699	5450	25491	33000
735	9340	43870	43800
1813	12900	67878	36800
1930	16307	62225	42475
2590	13450	88000	69400
2862	11950	127800	44827
4320	8160	257000	39000
5540	14150	309000	78686
6087	26052	404000	72700
11059	15947	935000	72900
17400	10800	-	-

The table shows that the rivers in India have experienced floods with peak discharges ranging from about 1170 m^3/s for a 133-km^2 area to about 72900 m^3/s for a 935000 km^2 area. The study has shown that the pattern of the highest flood distribution is influenced to a great extent by physiographic and meteorologic factors. Most of the highest flood events occurred in the northern and central parts of India and were caused from the high intensity and long duration rainfall associated with the cyclonic storms from the Bay of Bengal.

A comparison of the highest floods recorded in India has been made with the world highest floods so as to see the flood power of the Indian rivers. Results shows that the magnitude of the highest floods in India are comparable with some of the highest floods reported in other regions of the world or even exceeded the world record. The data on the highest flood reported here would be very useful for workers investigating design flood computations for water projects as well as in assessing the flood potentialities of a region in India.

THE LARGE FLOOD OF 1860 IN NORWAY

L. A. Roald

Norwegian Water Resources and Energy Administration, Box 5091 – Oslo, N0301 Norway
e-mail: lar@nve.no

The winter of 1859/60 was characterised by temperatures below normal and extremely heavy snowfall over much of Southern Norway. The spring was very late, and two large rainfall events occurred after the snowmelt had started. The resulting flood lasted from late May and into early July. The total runoff volume of June 1860 in River Glomma has been estimated at 7.3 km^3. The flood was expected, and a local chief of police issued a flood warning two months in advance based on the amount of snow at that time.

The extreme weather continued throughout the summer, causing extensive crop failure and a quite large autumn flood in River Glomma. The humid weather is reported to have occurred over large parts of Europe, while the United States experienced droughts and Northern Norway warm weather and abundant crops.

There are a number of water level series and one discharge series covering the event in the three largest rivers of South Norway. Discharge data has also been obtained from Sweden, which was also affected by the event. The current meter was introduced in Norway in 1858, and the peak discharge in river Glomma downstream the confluence with River Vorma was measured to 4000 m^3/s.

The flood damage was extensive, although not comparable with the flood of July 1789, when the flood level was generally higher, but the duration far shorter. The damage caused nevertheless a major migration of farmers from the Østerdal and Gudbrandsdal valleys to the Målselv and Bardu river basins in Troms County in northern Norway.

The paper will discuss the physical causes of the flood, based on some meteorological data, and look at the return period of the event. The flood occurred at a time when some glaciers advanced and some terminal moraines date to this time, which may be considered as a last return to the conditions of "the little ice-age" in Norway. Several large floods occurred in the early 1850's as well as in the 1860's. Later hydropower regulations have contributed to a reduction of the flood magnitude. The paper will also link the flood magnitudes to climatic variability and to the flood mitigating effects of later hydropower regulations.

THE USE OF A STOCHASTIC RIVER FLOOD CATASTROPHE MODEL FOR EXPLORING EXTREME FLOOD EVENTS IN THE UNITED KINGDOM

H. J. E. Rodda, A. Berger and R. Muir-Wood

Risk Management Solutions Ltd., 10 Eastcheap, London EC3M 1AJ, UK
e-mail (H. J. E. Rodda): hrodda@riskinc.com

This paper describes the development of a new stochastic model capable of predicting the depth and return periods of extreme flood events for both individual, and combinations of basins, within the UK. The model is based on analysing the meteorological controls of floods from a database of approximately 500 extreme historical events, which have occurred in the UK from 1870 to 1999. By utilising the variations in the controlling meteorological parameters (such as total rainfall, duration of rainfall, and the rate of storm movement), a stochastic set of characteristic extreme rainfall footprints was derived. Combining this set with a set of antecedent conditions, ranging from dry through saturated, to super-saturated (i.e. rivers already in flood), it was possible to explore the potential for flood events beyond 1000 year return periods. Antecedent conditions have been derived from information on soil moisture deficit and snow depth, over the whole of the UK, plus selected river flows. These rainfall events can then be transformed into river discharges and depths of floodwater by rainfall-runoff and hydrodynamic modelling.

The model predictions will be validated by replicating actual historical flood events, by comparing the measured and modelled discharges and extents and depths of floodwater. The results will then be used to predict the degree and location of damage and financial losses following an extreme flood event.

FLOODS ON THE TERRITORY OF RUSSIA

A. Taratunin

Russijanova 32-2-51, 220141, Minsk, Republic of Belarus
e-mail: ecogis@open.minsk.by

The report contains a brief summary of the book "Floods on the territory of Russia". The author who worked in the laboratory Flood prevention of the Central Research Institute for Complex Development of Water Resources for more than 25 years, collected and assessed data on floods and their damage with field surveys in the different regions of the country. The outcome was the book "Floods on territory of Russia" which is to be published in Russia at the end of 1999 - beginning of 2000. The book contains an inventory of floods with collected data and descriptions of more than 160 floods, which took place in different regions of Russia in different years. The data on floods, with illustrations, are given for all regions of Russia according to administrative and economic divisions. They show the distribution of floods according to the conditions of their origin and the distribution of damages in economic spheres. They also consider the main activities on protection and reduction of flood damages.

The report contains the main causes of flood forming, damage assessment and their distribution in the spheres of economic activities, data on the most catastrophic floods which took place on the territory of Russia during the present century, and also gives the concept of protection from floods and reduction of flood damage.

EXTREME FLOODS IN FINLAND

H. Virta

Department of Geophysics, Box 4 (Fabianinkatu 24 A), FIN-00014 University of Helsinki
e-mail: Hanna.Virta@helsinki.fi

This study analyses the floods that recur on the average once in 20, 50, 100 and 250 years. The data used is very comprehensive because every possible water stage and discharge gauging station is included. Two approximations are made: the annual maximum time series are considered to be homogeneous and are assumed to follow the Gumbel distribution (type I extreme-value distribution). The extreme floods are estimated from return period graphs plotted on Gumbel paper.

The estimated extreme flood flows HQ and the means of annual maximum flood flows MHQ are used to calculate ratios HQ (Tr)/MHQ for return periods Tr = 20, 50, 100 and 250 years and ratios HQ (Tr = 250 a)/HQ (Tr) for Tr = 20 and 50 years. Regression analysis is used to study the dependence of the ratios on lake percentage L and drainage area F. Times series length Ts and F are used to group the observations: 1) all stations included (167 - 324 stations), 2) stations with F < 15 000 km^2 included (152 - 294 stations), 3) stations with Ts (20 a included (165 - 268 stations), 4) stations with Ts (20 a and F < 15 000 km^2 included (150 – 238 stations) and 5) stations with Ts (20 a and F > 15 000 km^2 included (15 - 30 stations).

The HQ/MHQ values are comparable to earlier studies. The values of the ratios in the first four groups are fairly close to each other but in the fifth group the values are smaller and the relative change between different return periods is smaller than in the other groups. For example, in the fourth group the values are for HQ (Tr)/MHQ 2.11 (standard deviation = 0.259) and 2.35 (0.293) for Tr = 100 and 250 years, respectively, but in the fifth group the corresponding values are 1.85 (0.169) and 1.92 (0.198). Therefore, a large drainage area seems to smooth down the extreme flood flows. According to the regression analyses, the calculated ratios get their largest values with small L and F.

In a case that only MHQ can be estimated, HQ/MHQ values can be used to approximate extreme flood flows within the uncertainties and approximations of this study.

SESSION 5

GEOMORPHOLOGICAL AND ENVIRONMENTAL QUESTIONS RELATED TO FLOODS

RELATIVE ROLES OF GEOMORPHOLOGY AND WATER INPUT DISTRIBUTION IN AN EXTREME FLOOD STRUCTURE

C. Cudennec[1], F. Gogien[1], J. Bourges[2], J. Duchesne[3] and R. Kallel[4]

[1]ENSAR, Génie Rural, 35042 Rennes Cedex, France
e-mail: cudennec@agrorennes.educagri.fr
[2]IRD, Mission en Tunisie, BP 434, 1004 El Menzah, Tunisia
[3]INH, Dpt Paysage, 49045 Angers Cedex 2, France
[4]DGRE, Dir. Eaux de surface, 43 rue de la Manoubia, 1008 Tunis, Tunisia

A watershed can be seen as a complex system transforming water input into flow at the outlet. Whatever the origin of the dynamic water – directly from rainfall or through solid storage and melting –, the global evolution of the flood at the outlet is the integration of time and space variability and scaling properties within the watershed. This is particularly true for extreme events characterised by highly variable meteorological and hydrological processes. We discuss how this integration is mostly determined by geomorphology as the thalweg network has a main structural role of hillslopes drainage and fluvial routing, due to its particular geometrical and topological significance. We thus propose a transfer function of the watershed based on a mathematical description of this network organisation and its intricate connection with hillslopes, through GIS and image processing, which does not need any calibration. This function is in fact the river flow isochrone distribution of the watershed and appears to be an improvement on the width function or the area-distance function concepts. Indeed it distinguishes hillslope and thalweg processes, which characteristic time scales lead to global non-linearity.

By mapping the two-dimensional watershed area into this one-dimensional relevant function, we obtain a good synthesis of the watershed structure leading to fast flood modelling calculations. Moreover, this function has a geographical correspondence, which allows taking into account the water input spatial variability by crossing hydrologic and geomorphologic information. Such a crossing can be developed either for point measurement or mapping data and can be very robust for application in low-instrumented areas.

We apply this method for actual extraordinary floods under semi-arid climate, on a 192 km^2 watershed located in central Tunisia, in both an upland agriculture and a downstream civil security context. It validates the relevance of the geomorphology-based transfer function and illustrates how much taking into account rainfall spatial variability improves the modelling precision. Furthermore, these results confirm the physical interpretation we have of the relative roles of geomorphology and water input distribution in the flood structure. We then discuss how this method can be applied to other kinds of floods, and particularly to snowmelt induced events.

SURGE-ELATED FLOODS AT SKEIÐARÁRJÖKULL, ICELAND: IMPLICATIONS FOR ICE-MARGINAL OUTWASH DEPOSITS

T. A.G.P. van Dijk[1] and O. Sigurðsson[2]

[1]School of Earth Sciences and Geography, Keele University, Staffordshire ST5 5BG, UK
e-mail: ggd03@esci.keele.ac.uk
[2]Orkustofnun (National Energy Authority) and Vatnamælingar (Hydrological Service), Grensásvegi 9, 108 Reykjavík, Iceland

Floods in proglacial areas, or 'jökulhlaups', generated by the drainage of ice-dammed lakes and subglacial volcanic eruptions, are commonly associated with meltwater storage and release. Recent studies of surge-type glaciers reveal that changes in subglacial hydrology during surge allow large amounts of water to be stored within and underneath the glacier. The sudden release of water related to variations in glacier motion during surge generates floods. To date, surge-induced jökulhlaups have only been studied in terms of water discharge and sediment budgets. Surge-related landforms and sedimentary sequences still remain to be investigated. This paper therefore aims to document the spatial distribution and timing of the subglacially-generated floods induced by the 1991 surge of Skeiðarárjökull and to investigate the development of associated proglacial, fluvial sediments.

Vertical aerial photographs of the margin of Skeiðarárjökull show the close relationship between glacier surges and the development of proglacial, fluvial landforms and deposits. During surge photographic evidence allows constraint of the timing of tunnel outlet formation and deposition of prominent outwash fans at the glacier margin.

Surge fan surfaces are heavily kettled and have a gradient of 1°. Sedimentary sequences reveal inverse grading in poorly sorted sand and gravel, where fines are strikingly absent. Poorly-defined stratification is predominantly parallel to the fan surface. Imbricated clasts with their a-axes normal to the flow direction and dip angles up to 60° are abundant. These sedimentary characteristics suggest gradual fan aggradation by deposition from continuous and turbulent water flow, in which clasts are in traction transport immediately prior to deposition. The absence of ice blocks on photographs taken during the surge, contrasts with the heavily kettled surface observed on photos from 1996 and in the field, suggesting that ice blocks have been buried by surge-related, fluvial sedimentation.

This investigation recognises glacier surge-induced floods as a significant controlling factor on the development of proglacial fluvial deposits. However sediments of surge-induced floods show properties very similar to those of other types of jökulhlaups, criteria for distinction can include (a) evidence of continuous aggradation with sparse evidence of within-event discharge fluctuations, (b) the absence of cross-strata, indicating shallow flow depths and sheet-like flows, and (c) orientation of the clasts in poorly sorted units.

Improved understanding of surge-controlled fluvial deposition within modern ice-marginal environments is important for the identification of glacier surges within the sedimentary record of formerly glaciated areas.

REAL-TIME MONITORING OF GLACIAL RIVERS IN ICELAND

Sverrir Óskar Elefsen*, Sigvaldi Árnason*, Gunnar Sigurðsson*, Árni Snorrason*, Hreinn Haraldsson#, Sigurður Reynir Gíslason", Hrefna Kristmannsdóttir+.

*National Energy Authority, Hydrologic Service, Grensásvegur 9, 108 Reykjavík, #Public Roads Authority, Borgartún 5, 105 Reykjavík, "University of Iceland, Science Institute, Dunhaga 3, 107 Reykjavík +National Energy Authority, GeoScience Division , Grensásvegur 9, 108 Reykjavík,

The Hydrologic Service started the buildup of a real-time monitoring system of rivers in 1998. Prior to this, suitable equipment was chosen and the chemical composition of selected glacial rivers was studied.
Each station consists of a datalogger, some sensors, a mobile telephone and a modem, all driven by either a solar panel or a wind-mill. Data is collected from the office in Reykjavik, by calling the stations automatically on regular intervals. A software application, written in LabView, is used to collect and store the data and to view it either internally or on the internet.
For monitoring purposes, the Campbell CR10X datalogger was choosen. Water level is measured with Druck's PDCR-1830 pressure sensors. Electrical conductivity and temperature of the river water is measured with a prope provided by Campbell Scientific as well as air temperature. Relative humidity is measured with a Vaisala prope.
The dataloggers are programmed to call The Alarm Central in Reykjavik if either water level or electrical conductivity reaches questionable levels, previously defined by engineers at The Hydrologic Service. In case of an alarm, one of the engineers is contacted to check out what caused the alarm and possibly initiating further reactions by The National Civil Defence of Iceland.
Studies of the chemical composition of glacial waters, together with discharge measurements, analyses of total dissolved solids and grain size distribution, help engineers to understand the relationships between water level / discharge and electrical conductivity of the river water. As a key note, increase in water level caused by rainwater leads to decrease in electrical conductivity, whereas increase in water level caused by subglacial geothermal activity is most often detected after previous increase in electrical conductivity of the river water.
Furthermore, scientists have tried to use the chemical composition to decide, if the river water has been in contact with magma or not. At present, principal components like chlor, fluor and sulphate, alkalinity and pH are measured on regular intervals together with analyses of total dissolved solids, as part of running the real-time monitoring system.

As an example we take the station Gígjökull - Eyjafjallajökull. This site is particular in that the distance from the subglacial crater monitored is only about 6 km (4 miles). The station is situated at the mouth of the proglacial lake in front of the glacial terminus. The lake is covered with ice in the winter time. Carbon-dioxide is the main chemical compound, prooved to leak from the crater in measurable amounts. Close to the lake, the thickness of the glacier terminus is still about 100 m (330 feet). As glacial crevasses only reach about 30 meters deep (100 feet), great amounts of carbon dioxide dissolve in the glacial water, in accordance with CO_2*'s partial pressure beneath the glacier. As the ice on the lake-surface melts away in the spring, electrical conductivity of the water decreases due to greater evaporation of carbon-dioxide from the lake.*

FORMATION OF KETTLE HOLES FOLLOWING A GLACIAL OUTBURST FLOOD (JÖKULHLAUP), SKEIÐARÁRSANDUR, SOUTHERN ICELAND

H. Fay

School of Earth Sciences and Geography, Keele University, Staffordshire, ST5 5BG, UK
e-mail: ggd25@esci.keele.ac.uk

Glacier outburst floods or 'jökulhlaups' commonly involve the transport of ice blocks released from glacier margins. However, very little research has focused on post-jökulhlaup landform development within active fluvial systems. A volcanic eruption beneath the Vatnajökull ice cap in southern Iceland generated a jökulhlaup on November 5th 1996 that transported numerous ice blocks as large as 45 m in diameter on to Skeiðarársandur. The aims of this paper are (i) to present a detailed description of the post-jökulhlaup development of ice block related landforms and deposits; (ii) identify processes involved in the creation of the distinctive features; and (iii) present a model of post-depositional jökulhlaup landscape evolution.

Kettle holes have developed in lines parallel to flow. Individual ice blocks forming the lines grounded in the lee of previously grounded ice blocks where flow velocity was lower. Depressions created by ice block melt clustered in lines transverse to flow have coalesced to form large, elongate kettle holes. These ice blocks were grounded on bars in the more tranquil flow downstream of a hydraulic jump, which may have spanned the width of the bar. Melting of densely clustered ice blocks has resulted in the formation of hummocky topography. Large completely buried ice blocks have formed inverse-conical shaped kettle holes while smaller buried blocks have formed kettle holes with vertical to overhanging walls. Rimmed kettles have been formed by the deposition of flood sediment around grounded ice blocks, with only a thin drape (10-20 cm) of ice block diamict. Cone-shaped heaps of fluvial deposits on the sandur surface have been protected from aeolian erosion by a capping of diamict deposited from *in situ* ice block melt. Melting of sediment rich ice blocks within obstacle marks has resulted in the formation of 'till-fill' and 'rimmed' obstacle marks. During the ongoing development of kettle holes, partially buried ice becomes covered by sediment and insulated so that the kettle holes continue to develop long after a classic kettled landscape is formed.

A more detailed understanding of kettle hole formation will lead to a more representative assessment of jökulhlaup impact. This will aid the identification of historical sediment sequences, especially in distinguishing between flood and non-flood fluvial deposits. Widespread kettled topography of former outwash plains may be indicative of dynamic jökulhlaup origin rather than passive decay of glacier ice. Failure to include the jökulhlaup hypothesis in the interpretation of kettled outwash may result in invalid palaeoglaciological reconstructions.

CHARACTERISING THE FLASH FLOOD POTENTIAL ALONG THE RED SEA COAST OF EGYPT: WADI EL-ALAM

E. Ghoneim, N. Arnell and G. Foody

Department of Geography, University of Southampton, SO17 1BJ, UK
e-mail (E. Ghoneim): salma@soton.ac.uk

Mountains rising to more than 1500 m border the desert Red Sea coast of Egypt. Although the climate is arid, the region experiences occasional very heavy short-duration rainfall (often over 60 mm in a few hours). These storms create flash floods which run rapidly along the network of wadis draining the mountains, frequently causing severe flooding, death and injury, and damage to property and the road network: many of the towns in the region are located on alluvial fans at the outlets of the wadis. This study aims to assess the flood risk in a part of the Red Sea coast region, focusing on the Wadi El-Alam network near the town of Marsa Alam. This involves the characterisation of the main landscape features, which contribute to the flood risk. These include various aspects of the topography of the catchment (such as catchment shape, wadi density, wadi slope, and hillslope angles), the soil of the catchment and the wadi bed (affecting infiltration rates). Topographic characteristics are being quantified using a digital elevation model (DEM) and the ARC/INFO geographical information system. The DEM was created within ARC/INFO from contour line, spot height and wadi network data that were manually digitised from 1:50,000 scale maps. Some problems arose, as the standard interpolation procedures included in ARC/INFO for the creation of a DEM did not work very effectively in the angular desert environment. In general, the interpolation procedures tended to smooth the landscape: arid landscapes are distinguished by the sharpness of the junction between badlands slopes and adjacent alluvial surface, which may be created by erosion concentrated at the base of the slope. A range of solutions was found to these problems, and a final DEM has been constructed. Basin characteristics and many morphometric parameters have been defined and preliminary hydrograph characteristics calculated from the measured morphometric parameters.

EROSION AND DEPOSITION IN THE PROGLACIAL ZONE: THE 1996 JÖKULHLAUP ON SKEIÐARÁRSANDUR

B. Gomez[1], A. J. Russell[2], L. C. Smith[3] and Ó. Knudsen[4]

[1]Indiana State University, Terre Haute, IN 47809, U.S.A.
e-mail: gegomez@scifac.indstate.edu
[2]Keel University
[3]University of California, Los Angeles
[4]Klettur

Catastrophic glacier outburst floods, or jökulhlaups, have generated some of the largest known terrestrial freshwater flows, and in locales where large volumes of sediment are flushed from beneath glaciers they are instrumental in creating sandar. The November 1996 jökulhlaup on Skeiðarársandur was conspicuous for its short duration and extraordinary magnitude; ~3.8 km^3 of water were released on to the sandur over a 2 to 3 day period, and the estimated cumulative peak discharge was ~4.5 x 104 m^3/s. Aerial photographs obtained on November 6th, ~12 hr after the flood peak, and a synthetic aperture radar (SAR) image acquired during the hlaup, on November 7th, provide a synoptic perspective on the 1996 event. SAR interferometry was used to obtain quantitative measurements of jökulhlaup-induced proglacial topographic change, and pre- and post-flood ice surface velocities. Topographic maps constructed from aerial photographs taken in 1992 and 1997 detail the erosional and depositional impact of the jökulhlaup within the proximal area of Skeiðarársandur. Topographic surveys undertaken in the field immediately before and after the jökulhlaup provide ground truth. By comparing three independently derived measures of topographic change this paper affords the first detailed, macro-scale perspective on the erosional and depositional characteristics of a single jökulhlaup on a sandur.

Erosion and deposition occurred in all areas, but most channel change occurred in the proximal zone of Skeiðarársandur. Major proximal deposition occurred in front of conduit outlets within a large proglacial trough. Channel widening also occurred within the proglacial trough in response to higher discharges. Localised deposition at conduit mouths was accompanied by lesser amounts of downstream erosion and deposition. Complex erosion and deposition documented by this study can be attributed to glacier retreat since the turn of the century, which stimulated development of the proglacial trough and multiple active conduit outlets distributed around the 23 km long glacier snout. The presence or absence of proglacial trenches may act as a major control on patterns of erosion and deposition during high magnitude jökulhlaups. We therefore expect the proximal geomorphic impact of jökulhlaups to vary considerably between periods of glacier advance associated with sandur aggradation and periods of glacier retreat characterised by trough formation.

THE SKEIÐARÁR FLOODING IN 1996, AN EXAMPLE OF A SELF DILUTED DENSITY CURRENT

Á. Höskuldsson

South Iceland Institute of Natural History, Strandvegur 50, 900 Vestmannaeyjar, Iceland
e-mail: arm@eyjar.is

During the eruption of Gjálp in Vatnajökull in 1996, glacial melt water was accumulated in a nearby subglacier caldera, Lake Grímsvötn. A total of some 3 km^3 of water was stored in the Grímsvötn caldera before the glacier damming up the lake gave away and the melt water escaped. In the evening of the 4th of November 1996 the seismometer at Grímsfjall started showing irregularities indicating that the ice dam was starting to give way and that melt water was draining from Lake Grímsvötn. The melt water flowed subglacially for some 30 km until it reached the tip of Skeiðarárjökull at about 08:00 and was consequently spread out on the plains of Skeiðarársandur. Measurements of sediment suspension load (Snorrason et al. 1997) show that in the beginning of the flood the melt water was heavily charged with particles. Estimated density of the slurry was around 1120 kg/m^3 at that time. Density decreased as the flood continued and had reached a value of 1020 kg/m^3 shortly after midnight on November the 6th. Analysis of the discharge and density of the slurry indicate an inverse relationship in the beginning of the flood. As the discharge increased the density decreased, this was observed until early morning on the 6th of November. At that time the water discharge and density followed closely indicating equilibrium conditions. During the first hours of the flood, the slurry's density was much higher than the density of the sea (density of the sea being about 1069 kg/m^3). At the flood entrance to the sea, a giant circular shaped mudplume was observed in the sea. At around 12:35 on November the 5th this plume had reached a diameter of about 1 km being centred about 1 km from the slurry's entrance. In this presentation it is reasoned that the sharp decrease in density with increasing discharge is due to self-dilution of the slurry by increased melt water. It is further reasoned that when the slurry runs into the sea, sedimentation from the slurry begins. Due to sedimentation the density of the slurry decreases until it becomes lighter than the surrounding sea. The plumes observed offshore to the slurry's entrance to the sea are believed to be generated by sedimentation of the slurry and possibly mixing with seawater. As the flood continued slurry's density decreased until finally the slurry became much lighter than seawater and thus flowed on top of it.

References:

Á. Snorrason, P. Jónsson, S. Pálsson, S. Árnason, O. Sigurðsson, S. Víkingsson, Á. Sigurðsson and S. Zóphaníasson. Hlaupið á Skeiðarársandi haustið 1996. In: Hreinn Haraldsson (ed), Vatnajökull, Gos og hlaup 1996. Vegagerðin 1997, p 79-138. (in Icelandic).

GEOCHEMICAL WARNING FOR SUBGLACIAL ERUPTIONS BACKGROUND AND HISTORY

H. Kristmannsdóttir[1], Á. Snorrason[1], S. R. Gíslason[2], H. Haraldsson[3], Á. Gunnarsson[1], S. Hauksdóttir[1] and S. Elefsen[1]

[1]Orkustofnun, Grensásvegur 9, 108 Reykjavík, Iceland
e-mail (H. Kristmannsdóttir): hk@os.is
[2]Science Institute, University of Iceland, Dunhagi 3, 107 Reykjavík, Iceland
[3]Public Roads Authority, Borgartún 5, 105 Reykjavík, Iceland

Orkustofnun (The National Energy Authority of Iceland) has for many years, in co-operation with the Public Roads Authority, investigated the chemical changes occurring in water of the glacial rivers on Skeiðarársandur south of Vatnajökull. Chemical changes in the glacial river water have been observed in advance of jökulhlaups from Skeiðará. During the volcanic event in Vatnajökull in 1996, chemical changes of the glacial river Jökulsá á Fjöllum were detected indicating runoff from the active area, but lack of proper background data made interpretation difficult. It is also considered likely that increased geothermal activity may proceed volcanic activity affecting the chemistry of the rivers. Early detection of the location of break-through of the runoff from a volcanic event may save both lives and road constructions. Due to the enormous investments in road construction and for public safety there should be considerable emphasis placed on the development of such devices.

After the subglacial eruption in Vatnajökull 1996 and subsequent giant jökulhlaup in Skeiðará forces were joined with the University of Iceland to develop a warning system based on chemical changes. The aim of the project was to develop an automatic warning system for subglacial eruptions by monitoring chemical changes in the water of glacial rivers from the Vatnajökull and Mýrdalsjökull glaciers. The first phase of the project was to collect background data from all the rivers concerned and determine seasonal and climatic variations. The second phase was the choice and design of appropriate detectors for the different locations of concern in co-operation with an Icelandic electronic development company.

Baseline data have now been obtained for the rivers, parameters selected for continuos monitoring and alarm values defined. It was clear from the beginning that conductivity was the simplest parameter to be monitored, even though it might be problematic in the rivers in wintertime and when the sediment loads were at highest. For many rivers conductivity monitoring was believed to be sufficient for warning purposes, whereas monitoring of an additional parameter indicating magmatic influence, like mercury or sulphurous gases, would be desirable in others. Three pilot stations for conductivity monitoring were constructed and additional three were put into operation during the test period when volcanic activity was suspected below the Mýrdalsjökull glacier. Appropriate detectors for hydrogensulphide and mercury were sought and methods to collect and accumulate samples for measurement were designed and tested.

SEASONAL CHANGES IN GLACIAL WATER CHEMISTRY IN ICELAND

H. Kristmannsdóttir[1], S. R. Gíslason[2], Á. Snorrason[1], H. Haraldsson[3], S. Hauksdóttir[1] and Á. Gunnarsson[1]

[1]Orkustofnun, Grensásvegur 9, 108 Reykjavík, Iceland
e-mail (H. Kristmannsdóttir): hk@os.is
[2]Science Institute, University of Iceland, Dunhagi 3, 107 Reykjavík, Iceland
[3]Public Roads Authority, Borgartún 5, 105 Reykjavík, Iceland

Water composition was monitored for one year in 11 rivers draining from the Vatnajökull and Mýrdalsjökull glaciers. The scope of the project was to develop an automatic warning system for volcanic eruptions within the glaciers. The aim of the first phase of the project was to obtain background data from all the rivers concerned and determine seasonal and climatic variations. Prior to this project, data on chemical composition of glacial rivers draining the Vatnajökull and Mýrdalsjökull glaciers was scarce compared to the measurements of their discharge and sediment load.

During the last fifty years water level has been measured continuously in some of the rivers draining the Vatnajökull glacier. Discharge, sediment load and total dissolved solids (TDS) have been measured several times a year and more frequently during jökulhlaups. Chemical data have been obtained during most jökulhlaups after 1976 in the river Skeiðará draining the Vatnajökull glacier. No continuous chemical monitoring has been pursued through any length of time, but frequent samplings were done in the years 1982-1983 and 1990-1991 and more sporadic at other times. Conductivity has been measured regularly in Skeiðará through shorter periods for monitoring purposes. Other glacier rivers falling from Vatnajökull and Mýrdalsjökull glaciers have not been monitored chemically and meagre information exists about seasonal changes in chemical composition and possible effects due to geothermal activity below the glacier.

In the project the components monitored were, total dissolved solids, pH, total carbonate, H_2S, main dissolved solids (SiO_2, Na, K, Ca, Mg, Cl, SO_4), selected trace elements and heavy metals (F, B, Br, Al, Cr, Mn, Fe, Cu, Zn, As, Cd, Hg, Pb), the isotopes (D, (^{18}O, (^{13}C and apparent ^{14}C age.

There is a clear relation between discharge and the chemical composition of the river water but the correlation is different for different rivers. There appear to be two main water components, water which has reacted with the subglacial bedrock for some time and meltwater with much lower TDS. In some rivers there is also a third component originating from subglacial geothermal systems. In some of the rivers the geothermal component is more or less continuously discharged into the rivers, in others it is seasonally dependent and in still others it only appears during jökulhlaups from ice dammed or subglacial lakes formed by geothermal activity. In all the rivers subglacial volcanic eruptions may affect the chemistry of the waters.

CRITERIA FOR DISTINGUISHING HIGH MAGNITUDE FLOOD EVENTS IN THE PROGLACIAL FLUVIAL SEDIMENTARY RECORD

P. M. Marren

School of Earth Sciences and Geography, Keele University, Keele, Staffordshire, ST5 5BG, UK
e-mail: gga52@esci.keele.ac.uk

Recognising high magnitude or extreme floods in the sedimentary record is of prime importance if estimates of their geomorphic and sedimentary significance over long time scales (i.e. hundreds to thousands of years) is to be made. Standard regime or palaeocompetance based palaeohydraulic approaches present one set of solutions to this problem. An alternative is to examine the sedimentary record to determine what the dominant depositional processes are in any particular environment. In particular, it is important to assess the role of high magnitude floods within the sedimentary record.

This paper presents a set of key criteria, which are designed to critically determine the magnitude - frequency regime of fluvial sediments. The key criteria were derived from an extensive literature review of the sedimentary impact of high magnitude floods and from field work in southeast Iceland. The key criteria are based on sediment architecture, geometry and structures, sediment fabric and geomorphology. Examples of the application of the key criteria are presented for a range of case studies taken from Iceland and eastern Scotland.

THE INFLUENCE OF CHANNEL FLOOD HISTORY ON THE IMPACT OF THE NOVEMBER 1996 JÖKULHLAUP, SKEIÐARÁRSANDUR, ICELAND

A. J. Russell[1] and Ó. Knudsen[2]

[1]School of Earth Sciences and Geography, Keele University, Keele, Staffordshire, ST5 5BG, UK.
e-mail: a.j.russell@keele.ac.uk
[2]Klettur Consulting Engineers, Bíldshöfða 12, IS 112, Reykjavík, Iceland.
e-mail: oskar@vedur.is

This study examines the extent to which observed large-scale stage variations are reflected in the proglacial landform and sedimentary record of the November 1996 jökulhlaup, Skeiðarárjökull, Iceland. Discrimination of rising from falling flood stage landforms and deposits is usually based upon the interpretation of the geomorphic and sedimentary record. Sedimentary successions in proglacial environments have been interpreted on the basis of vertical sedimentary characteristics, which are then linked to the flood hydrograph. Most research has considered efflux within channels active on both rising and falling flow stage where the resultant morphology and sedimentology are the product of the temporal variability of both water and sediment flux. Spatial segregation of rising and falling stage proglacial outwash during the November 1996 jökulhlaup provided a superb opportunity to examine the role of flow stage in the creation and preservation of distinctive proglacial jökulhlaup landforms and deposits.

Rising stage deposits contained finer, more poorly sorted sediment than found on falling stage successions and erosional surfaces. Rising stage deposits showed upward-coarsening successions, characteristic of progressive supply of coarser-grained sediment with stage increase, compatible with previous models of rising stage sedimentation. Some rising stage successions however, showed few signs of large-scale grading, and instead contained repeated cycles of sedimentation, recording individual sedimentation pulses. Distinctive upward-coarsening successions on a waning stage outwash fan were generated by sediment reworking and winnowing. The presence of an upward-coarsening succession alone is clearly not diagnostic of rising stage deposition.

Conduits occupied by flows on both rising and falling flow stages were characterised by initial rising stage fan deposition followed by falling stage dissection and exhumation of ice blocks and rip-up clasts deposited on the rising flow stage. Rising stage deposits contained both single upward coarsening successions as well as successions consisting of stacked upward-coarsening and normally-graded units. Where waning stage flows were routed through a single conduit, high sediment efflux and aggradation rates were maintained late into the waning stage. Winnowing and sediment starvation resulted in progressive bed coarsening from matrix-supported gravels to clast-rich armour.

This study illustrates the geomorphic and sedimentary significance of major within-jökulhlaup sediment reworking and ice-margin erosion over distances of 10^2-10^3 m. Ill-defined erosional, streamlined terraces reflect exhumation on the flood waning stage. This landform and sedimentary succession could easily be confused with the product of fluvial depositional and erosional cycles operating over longer timescales associated with more sedate rates of glacier retreat within former proglacial areas.

IMPACT OF THE JULY 1999 JÖKULHLAUP ON THE PROXIMAL JÖKULSÁ Á SÓLHEIMASANDI, MÝRDALSJÖKULL, SOUTHERN ICELAND

A. J. Russell[1], F. S. Tweed[2], Ó. Knudsen[3], M. J. Roberts[1 and 2], T. D. Harris[2] and P. M. Marren[1]

[1]School of Earth Sciences and Geography, Keele University, Keele, Staffordshire, ST5 5BG, UK
[2]Division of Geography, Staffordshire University, College Road, Stoke-on-Trent, ST4 2DE, UK
e-mail (F. S. Tweed): f.s.tweed@staffs.ac.uk
[3]Klettur Consulting Engineers, Bíldshöfða 12, IS 112 Reykjavík, Iceland

The characteristics and geomorphic impact of storage-release floods such as the November 1996 jökulhlaup at Skeiðarársandur have been investigated; however, few studies have focused on the impact of volcanically-generated jökulhlaups released directly into the proglacial zone. A jökulhlaup at Sólheimajökull in July 1999 provided an excellent opportunity to examine the immediate impact of a sudden volcanically-triggered event on a glacier and sandur that are thought not to have experienced a flood of this size since 1357 AD. This paper aims to outline flood flow conditions and to describe the immediate proglacial geomorphic and sedimentary impact of the jökulhlaup.

On July 17th-18th 1999, seismic activity within the Katla volcanic system underneath Mýrdalsjökull was accompanied by a jökulhlaup released from Sólheimajökull. The flood reached an order of magnitude peak of 10^3 m^3/s, destroying power lines and splashing over a bridge on Iceland's main road. Field data was collected on the day of the flood and in the following three weeks. Flood wash limits and river channel cross-sections were surveyed allowing the calculation of peak flood discharge. Within flood sedimentary structures, surface grain sizes and ice block grounding structures were measured.

The jökulhlaup burst from the glacier at a number of locations, ranging from supraglacial fracture outlets to ice-marginal conduits. Floodwater flowed from the western glacier margin up to 4 km from the snout, resulting in temporary ponding within former ice-dammed lake basins. Sedimentation within these basins comprised coarse-grained deltas proximally, and sandy bedforms capped by silts, distally. At the glacier snout, floodwater exited via two main conduits. Outflow from the western conduit dominated total flood discharge, transporting boulders up to 8 m in diameter and creating a new outwash fan ranging in thickness from 6 m proximally to 1 m distally. Deposition of ice blocks, boulders and finer-grained matrix occurred simultaneously, resulting in the development of kettle holes and large-scale obstacle marks. Sedimentary structures suggest that flows were sediment-rich during the rising stage of the flood, having entrained large amounts of subglacial debris.

The geomorphic impact of this flood was confined to a main proglacial channel incised into older moraines and jökulhlaup deposits, although zones of localised deposition occurred in front of the main tunnel outlet and within ice-marginal lake basins. This sudden flood had a distinctive impact on both glacier and proglacial zone, providing a record of a jökulhlaup that may be a precursor to a major Katla eruption.

SESSION 6

STATISICAL ANALYSIS OF FLOODS

DAM DESIGN FLOOD ESTIMATION BASED ON BIVARIATE EXTREME-VALUE DISTRIBUTIONS

Á. A. Aldama and A. I. Ramírez

Mexican Institute of Water Technology, Paseo Cuauhnahuac 8532, Col. Progreso
Jiutepec, Morelos, MEXICO. C.P. 62550
e-mail: aaldama@tlaloc.imta.mx and aramirez@tlaloc.imta.mx

Design floods for dams and reservoirs are often estimated on the basis of flood frequency analyses. Such analyses employ data of maximum annual discharges recorded at or near the site where the dam will be built. Even though fewer dams are under construction nowadays than in the past, it is also necessary to revise design floods from time to time, as new data become available, especially when retrofitting plans are underway. A design flood is fully characterised by a hydrograph, which is routed through the reservoir in order to determine its flood control capacity and the spillway design discharge. Nevertheless, flood frequency analyses rely upon the estimation of probability distributions associated with peak discharges only. The determination of the design hydrograph is made by employing arbitrary procedures, such as assuming that its form is the same as the one corresponding to the hydrograph of the largest recorded flood. The simplest characterisation of a hydrograph must involve, at least, its most important parameters, namely: peak discharge, time to peak and volume. The authors of this paper have developed a simple parameterisation of hydrographs, which is based on the use of Hermitian interpolates. Through the use of this parameterisation, they have performed a sensitivity analysis that shows that the most important parameters in characterising a hydrograph, in terms of the response of a reservoir, are the peak discharge and the volume. On the basis of this result, a new approach for estimating the design flood of dams and reservoirs 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. Thus, 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. Hence, in order to determine the design flood hydrograph, a non-linear optimisation problem is posed, whose solution represents the combination of values of peak discharge and volume that produces the worst effect on the reservoir for a given joint return period. An example involving the revision of the design flood of the "Huites" dam in Mexico is presented.

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

STUDY ON PARAMETER ESTIMATION METHODS OF P-III DISTRIBUTION IN FLOOD FREQUENCY ANALYSIS

Y. Chen

Department of Hydrology, Hohai University, Nanjing 210024, P.R.China
e-mail: yf.chen@jlonline.com

Based on the Monte Carlo experiments, the main parameter estimation methods of Pearson Type III distribution are discussed and comprehensively compared in the paper. Included are methods of moments, maximum likelihood, curve fitting, probability-weighted moments (PWM) and several weighted function moments, which have been developed recently in China (one method considering historical hydrological data is developed by author). In comparison, flood series with extraordinary floods are generated not only in Chinese given-number model, but also in Stedinger-Hirsch model (threshold model). The criteria for the evaluation of an estimation method are considered from two aspects. One is the impartiality and efficiency of the parameters and design flood with given probability; the other is the impartiality and efficiency of the probability of failure of design flood. Many calculations show that the PWM and curve fitting methods with absolute norm are the two best estimation methods of Pearson Type III distribution.

POT ANALYSIS OF DAILY DATA FOR EXPLOITING COMBINATIONS OF HYDROLOGICAL AND CLIMATIC CONDITIONS A FLOOD GENERATION

P. Claps[1] and Paolo Villani[2]

[1]DIFA - Università della Basilicata, C.da Macchia Romana, 85100 – Potenza, Italy
e-mail: claps@unibas.it
[2]DIC - Univ. Parma, Italy
e-mail: villani@parma1.eng.unipr.it

As an attempt to improve the prediction of flood risk through the knowledge of the combination of rainfall and flood characteristics we investigate basic properties of the stochastic processes of daily rainfall and discharge as related to flood generation mechanisms. We test a simple stochastic model of extreme precipitation in which a wet and a dry season can be distinguished. During the wet period the process of occurrences can be assumed to be Poissonian and the distribution of marks can be derived through analysis of the peak over threshold (POT) process. The watershed operates as a stochastic filter on the rainfall process, so floods behave as a filtered Poisson process: the theoretical analysis of the filter mechanism provides the relationships between stochastic parameters of maximum rainfall and flood. The simplest transformation is a threshold on precipitation that essentially limits the number of runoff events. Our interest concentrates on the relationships between the mean annual number of rainfall and flood peak events, which is one of the most important parameter for regional flood frequency analysis. We compare the results of an estimation of the threshold with two methods. The first uses a series of the annual maximum of flood peaks and daily rainfall and the second uses complete series of daily rainfall and discharges, on which a specific filtering is used to select distinct flood and storm events. Application of both techniques to some basins in Southern Italy allows us to test relations between the threshold and basin physiographic parameters. The same relations do not seem applicable for some extraordinary events. In these cases it is shown that the parameters of transformation are substantially different, allowing the threshold mechanism to reduce the mean annual number of peaks less than in ordinary flood events. The model we propose allows us to analyse the probability of occurrence of extraordinary rainfall events and addresses the links between basin physiographic characteristics and threshold mechanisms to discriminate areas prone to different flood risk.

ASSESSMENT OF A SIMPLIFIED RUNOFF MODEL USED FOR THE THEORETICAL DERIVATION OF THE PROBABILITY DISTRIBUTION OF FLOODS

G. Gioia[1], V. Iacobellis[1] and M. R. Margiotta[2]

[1]Dipartimento di Ingegneria delle Acque, Politecnico di Bari, via E. Orabona 4, 70125, Bari
e-mail: vitoiacobellis@hotmail.com
[2]Dipartimento di Ingegneria e Fisica dell'Ambiente, Università degli Studi della Basilicata, Contrada Macchia Romana, 85100, Potenza
e-mail: mrmargiotta@difa.unibas.it

The determination of the probability distribution of annual maxima of flood peaks has been extensively studied by means of standard statistical methods, more or less physically based. Iacobellis and Fiorentino (1999) proposed a theoretical method for derivation of probability distribution of floods based on a simple rainfall-runoff model. In the model, the peak discharge per unit contributing area is linearly related to the rainfall intensity i_d in the duration equal to a characteristic response time of the area itself. More precisely, i_d is chosen as the maximum average (in the duration) rainfall intensity in any event of whichever duration in a temporal lag equal to the response time of the partial contributing area. In this paper, the goodness of this choice is assessed by means of a numerical investigation. In particular, a number of synthetic time series of the base process of precipitation were generated, by means of stochastic models and a simulation of the rainfall runoff process was carried out. The resulting time series of floods was then analysed focussing on the statistical properties of the generated peaks.

The stochastic models used for the generation of the point precipitation process are the Poisson Rectangular Pulses (PRP) and the cluster-type Neyman-Scott rectangular Pulses (NSRP). The latter accounts for the arrival process as a compound of two levels, namely, the former controlling the occurrence of storms and the second simulating the presence of different bursts within the single storm.

The hydrologic response was modelled by way of a transform function of a Weibull type, which, according to Claps et al. (1994), results in the most probable response function of a fractal network. In that function, the shape parameter is equal to the topologic fractal dimension D_t of the river network and the position parameter is also function of D_t.

The results show that in most of the cases the probability distribution of the peak streamflow estimated by the model proposed by Iacobellis and Fiorentino (1999) was very close to that calculated by numerical experiments. In addition, an analysis of the rainfall occurring at the beginning of the storm, which in the model is not considered significant to flood peak generation, was also carried out. In particular the distribution of this rainfall was compared to the characteristic values of the hydrologic losses in humid and arid climates.

APPROACH FOR ESTIMATION OF FLOOD FREQUENCY IN CHANGING CONDITIONS

H. V. Lobanova

Russian State Hydrometeorological University, 98, av. Malookhtinsky,
St. Petersburg, 195196, Russia
e-mail: lobanova@hm.sici.ru

There are two main groups of factors which have an impact on flood events in changing conditions: modern climate change and anthropogenic influence on watersheds and in river channels (different kinds of regulation by dams, water intake and out-take, etc.). 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 usually not taken into account, is their non-regularity of appearance, that varies from several flood events during a year (storm floods) to some events during a century (as mud streams).

The suggested new approach allows taking all these peculiarities into account. The following main methods have been developed:

- statistical criteria for the assessment of extraordinary outlying observations which have been advanced for non-symmetric and auto-correlating flood time series;
- methods for the extraction of maximum runoff components connected with anthropogenic impact and restoration of "natural" flood runoff time series for different input informational conditions;
- methods for the extraction of homogeneous different time scale components in "natural" conditions including long-term component of modern climate change;
- methods for the 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 the calculation of empirical probability of non-regular extreme events;
- new effective criteria for the fitting of empirical distribution of floods by theoretical distributions;
- new approach for the assessment of design frequency of floods connected with period of exploitation of water projects in the future;
- methods for the empirical estimation of random errors of design floods in conditions of climate change and man's impact.

An application of the new approach has been given:

- for the determination of outlying observations in snowmelt and rainfall floods in the Russian rivers and their interpretation;
- for the analysis of time series of catastrophic rainfall floods in the Far East of Russia, which flood cities and take place several times during a year;
- for the computations of catastrophic mud floods in the mountain region of Alatau, which take place several times during a long-term period;
- for the restoration of "natural" time series of flood regulated by dams of the main power stations of Russia (the Volga, Don, Ob), which take place several times during a long-term period;
- for the application of cyclic characteristics of flood for the calculation of frequency of design floods in changing conditions;
- for the assessment of efficiency of empirical distribution fitting by different kinds of theoretical distributions;
- for the determination of design frequency and quantile errors by the suggested method and comparison with the results obtained on the basis of the longest time series of floods.

CLIMATE VARIABILITY AND EXTREME FLASH FLOODS: APPLICATION TO BISAGNO RIVER BASIN

C. de Michele and R. Rosso

DIIAR- Politecnico di Milano, P.zza L. da Vinci, 32, 20133 Milano
e-mail carlo.demichele@polimi.it and renzo.rosso@polimi.it

The present paper deals with the effects of climate variability on frequency estimates of maximum annual flood. These are investigated by combining a non-stationarity approach to maximum annual rainfall with a derived distribution approach to maximum peak flood. De Michele et al. (1998) showed that non-stationarity detected from the analysis of a long term rainfall time series, observed for four Italian maximum annual daily rainfall datasets with a length exceeding 90 years, can influence the evaluation of critical design storms. This result was found to be independent of the parent distribution of maximum rainfall. In the present paper we downscale the daily rainfall information to investigate short storm duration, which is important in the analysis of flash floods. The temporal variability is represented by a power-law relationship, derived from the assumption that storm rate increments are simple scaling (Burlando and Rosso, 1996). Assuming that this relation is time-independent, one can determine the T-year maximum annual rainfall depth for a specified duration from the T-year maximum annual daily rainfall depth. An approach based on the GEV distribution is developed for this purpose. Then, we introduce a simple derived distribution to analyse flood frequency at the basin outlet. This approach relies on the SCS-CN method to model storm abstraction and the Rational formula to transform the rainfall excess into peak flow. Accordingly the derived T-year flood quantile is investigated as a time-varying quantity to assess the potential variability of extreme floods as produced by the detected variability of rainfall input. An application to the Bisagno river basin, located in Thyrrhenian Liguria, Italy, is presented. The comparison of these results with the historical flood frequency estimates in the Bisagno river, as proposed by different authors, from 1906 until now, reflects the influence of climate variability.

Keywords: Climate variability, derived distribution, extreme floods

THE PROBABLE MAXIMUM FLOOD AT THE UKAI AND TAKHWAR DAM SITES IN INDIA

P. R. Rakhecha[1] and C. Clark[2]

[1]Indian Institute of Tropical Meteorology, Pune, India
e-mail: p_rakhecha@hotmail.com
[2]Charldon Hill Research Station, Shute Lane, Bruton, Somerset,
England, BA10 OBJ
e-mail: colin_chrs@hotmail.com

The design of impounding structures where failure would lead to catastrophic loss of life demands an estimate of the probable maximum flood. In India there are over 3000 dams and more are being built and planned in the future in order to meet the needs of the people for water supply and irrigation. Recently, revised estimates of the probable maximum precipitation have been published. These are based on the transposition and in situ maximisation of historic storms over the period 1880-1982. These new estimates are used, together with flood frequency data in a supportive role, to assess the safety of two dam sites in India. The first dam was built in 1972 in Maharashtra State. The PMP was used in a unit hydrograph technique to calculate the PMF hydrograph. This was then routed through the reservoir; the outflow hydrograph exceeded the design outflow by a factor of 2.25, leading to severe overtopping and likely dam collapse. The second dam is at present under construction in northern India. The estimated PMF also exceeded the design flow by a factor of 2.25, resulting in extensive overtopping for over 21 hours. The unit hydrograph analyses are supported by flood frequency analyses using a modified Gumbel scale. These results call for more attention to dam safety in the future. They also suggest that the estimates of PMF are subject to errors such as in the technique used to estimate PMP; the assumptions used in the method of converting the PMP to

PMF will lead to further uncertainties. However, when these uncertainties are considered, there is clear evidence that at least two dams in India have insufficient spillway capacity to safely pass the probable maximum flood.

ESTIMATION OF EXTREME-PARETO-QUANTILES USING UPPER ORDER STATISTICS

Ó. G. Sveinsson, D. C. Boes and J. D. Salas

Departments of Civil Engineering and Statistics, Colorado State University,
Fort Collins, Colorado, USA
e-mail (Ó. G. Sveinsson): oli@lamar.colostate.edu

Estimation of extreme hydrologic events is often done by fitting a probability density function to the sample record. The parent distribution of the hydrologic process is never exactly known, hence a fitted distribution may not well represent the extreme lower and upper tails.

A good fit in the tails is necessary, if the goal is to come up with accurate estimates of extreme quantiles in either tail. Improved fit in the tails of a distribution is sometimes achieved using probability paper and least-squares methods, where only the sample data that form an acceptable straight line in either tail are used. One could argue that low sample observations ought not be allowed to unduly influence the estimation of upper extreme quantiles.

Our interest is in the extremes of the upper extreme events of our process. In our study we assume that these extremes are distributed as a Pareto with two parameters (scale and shape). Parameters are estimated from minimal sufficient statistics, which are functions of the k largest order statistics of our sample record, using maximum likelihood. A consequence of fitting a Pareto is the so called power-law, which yields a straight line fit of event magnitudes and their return periods in log-log space. We select k so as to get a straight line in the upper tail. We use asymptotic theory to derive approximate mean-squared-error of our estimated quantiles.

Additional cases considered are: (1) quantile estimates from the k largest order statistics and a few historical events of known return periods, (2) quantile estimates from regional data using upper order statistics, and (3) quantile estimates from regional data using upper order statistics and some historical events with known return periods at each site within the region.

Procedures presented here are tested on extreme precipitation data from northeastern Colorado, USA. In some cases computer simulations are used to compare different procedures.

A STUDY ON THRESHOLD SELECTION IN POT ANALYSIS OF EXTREMAL FLOODS

S. Tanaka[1] and K. Takara[2]

[1]Water Resources Div., Japan Inst. Construction Eng., No.15 Mori Bldg., 2-8-10, Toranomon, Minato-ku, Tokyo, 105-0001, Japan
e-mail: s.tanaka@jice.or.jp
[2]Disaster Prevention Research Inst., Kyoto Univ., Gokasho, Uji, Kyoto, 611-0011, Japan
e-mail: takara@rdp.dpri.kyoto-u.ac.jp

In planning a flood protection system of a river basin which consists of embankment, dams and so on, it is necessary to determine a magnitude of flood corresponding to a specified exceedance probability. In Japan, watershed management plans have been established so that flood plains of A-class rivers should be safe against floods due to heavy rains with a return period of 100 - 200 years. Continuous reliable records of most A-class rivers began to be gathered in 1950s. Therefore, since the data sets are short, parametric extrapolation will be used to estimate such flood quantiles. The annual maximum series (AMS) procedure has conventionally been used so far. In a few basins, the biggest flood took place before the Second World War. As to data series of such rivers, instead of the AMS procedure, the peaks over threshold (POT) procedure becomes useful. It has been revealed that the POT procedure is more advantageous than the AMS one in case of short records. There remains, however, the crucial element of choosing threshold in POT analysis. This paper discusses methods of choosing the threshold in the POT analysis. Used distributions are the Exponential distribution and the Generalised Pareto distribution. Mean areal rainfall on river basins within short durations of 3, 6, 12 and 24 hours are used. Samples of rainfall have no clear predetermined physical threshold. In order to select the most desirable threshold, the authors have compared fluctuation of the following values due to change of the number of upper extremes: (1) parameters of distribution, (2) quantile corresponding to a exceedance probability of 1/100, (3) standardised least squares criterion, (4) jackknife estimator and jackknife error, (5) subjective judgement on an exponential probability paper, (6) automatic choosing method using shape parameter, and (7) mean excess function. Parameters are estimated using the L-moment method. Location parameters are estimated both by using the minimum value of each upper extremes of a sample and without using that one. The third and fourth items are criteria corresponding to goodness of fit and stability, respectively. The comparison has revealed:
(1) that none of the above items is independently good enough to determine the most desirable threshold,
(2) that some of the items can be used to reject a range of undesirable thresholds, and
(3) that synthetic judgement is necessary to determine the number of extremes best for the POT analysis.

SESSION 7

STATISTICAL ANALYSIS AND FLOODS FORECASTING

WATER LEVEL FORECASTS OF LAKE MANAGUA

K. Ahti and L. Palacios

Nicaragua – Finland Environmental Programme, Support Project for the Implementation of the UN Framework Convention on Climate Change
e-mail: cambiocl@ibw.com.ni or liisaahti@hotmail.com

After hurricane Mitch, October 1998, the water level of Lake Managua was so high that there was evident risk of a serious flood in some communities near the lake. There was a need for forecasts of the water level. There were no telemetric hydrological data available. So the only possibility was to use precipitation data from existing regular reporting meteorological stations and water level observations of Lake Managua. There was water level data from 1980 and precipitation observations from 1959. These statistics were used.

The first attempt was to develop a model for the rainy season to forecast monthly changes of the water level and to find a minimum amount of stations that would be needed for this type of forecast. The work started by calculating the balance value of monthly areal mean precipitation in the cases when there was no change in the water level. When this balance value had been calculated the relation (k) between precipitation over the balance level and observed rise of the water level was calculated. It was found that two meteorological stations were enough for this purpose but for the flash flood forecast it was necessary to have observations of three meteorological stations. These three stations have been used for the monthly forecasts as well. The rise of the water level in a month is the average area precipitation over the balance level multiplied by k.

The physics of the model has been tested using observed monthly precipitation of the last rainy season (June 1999-November 1999). The correlation coefficient between values calculated by the model and observed water levels of Lake Managua was r=0.988. The only real problem is to forecast monthly mean area precipitation. To improve this statistical forecast, mean average monthly precipitation was calculated for three types of months: cold (La Niña), normal and warm (El Niño) using 41 years of statistics. These average means will be used in the future. It is known that in Nicaragua the El Niño year is dry and the La Nina year is wet. But in this study it has been found that the effect is totally different in the beginning of the rainy season (May-June) than at the end of the rainy season (August-October). This difference has not been found earlier in Nicaragua. During the calculations it was observed that in very heavy rains (in flash flood situations) almost all the precipitation enters the lake in four days. Now k is close to its natural value: the area of the water basin divided by the area of the lake. The daily forecast for the next four days based on these facts was developed.

The daily model has been tested during the most rainy period in 1999 (Sep 19th -Oct 14th) using daily precipitation observations and the water level observations of Lake Managua. The correlation coefficient between the water level forecast of 24 hours by the model and observed water levels of the lake was r=0.996. The daily model has also been tested by using observations during Hurricane Mitch when the water level of Lake Managua rose almost 4 meters. The correlation coefficients between calculated values by the model and water level observations were r=0.869 for the one day forecast and r=0.794 for the two day forecast. The forecasting was significantly under the observations after the heaviest rains. When the case was studied more carefully it was found that a neighbouring river flooded over the watershed to the water base of Lake Managua. To calculate amounts of the water from the neighbouring river the same philosophy as in the daily model was used to calculate corrections for the forecasts. When these corrections had been made in the forecasts correlation coefficients were r=0.997 for the one day forecast and r=0.984 for the two day forecast. Also a monthly forecast for the dry season has been developed.

All three forecasts are ready for routine use after the approval of the local authorities.

RADAR TECHNOLOGY FOR LEVEL AND VELOCITY MEASUREMENTS OF EXTREME FLOOD CONDITIONS

H. Baur

OTT-Company, PO Box 2617 D-87417 Kempten, Germany
e-mail: Heinrich.Baur@ott-hydrometry.de

Extreme floods are a natural phenomenon. They become dangerous, if they endanger human life. This risk is growing since more and more people live in areas, where natural disasters can occur. To protect these people, forecasting-systems are necessary.

Extreme floods are dangerous, because

- They are often not predictable
- They destroy most of the infrastructure, such as streets, power supply networks, buildings etc.
- The time of warning is short

Therefore a forecasting-system

- Has to warn as early as possible
- Has to measure water-quantity as a function of time
- May not use buildings below water-surface to measure
- Has to deliver information about water-quantity as online-data
- Should use redundant systems of data-transfer to avoid data-loss

Such a system can be installed using radar-technology. OTT Germany produces a radar-sensor (Kalesto) which can measure water height and flow-velocity of the water-surface without touching the water. Because the maximum distance between Kalesto and the water-surface can be 30 m, the sensor can be installed in a save area (bridges etc.), even at extremely rising water levels. The sensor can't be destroyed by debris, stones etc.

Because of low power consumption, a solar panel can normally guarantee enough power over a long time. This makes the system independent from infrastructure.

The measured data can be transmitted via GSM or satellite to one or more receiving stations all over the world. An alarm management allows the sensor to send data only when an extraordinary event occurs. The decision-making authority then has to react.

The system is cheap, easy to handle and can be used even far away from human settlement. Therefore it should be possible to install it in areas where big floods originate. This prolongs the time of early warning. It will not be costly, but effective when a quick and early warning can save human life.

FLOOD INUNDATION MAPS - MAPPING OF FLOOD PRONE AREAS IN NORWAY

H. Berg[1], Ø. Høydal, A. Voksø and E. Øydvin

[1]Norwegian Water Resources and Energy Directorate, Postboks 5091 Majorstua
0301 Oslo, Norway
e-mail: hbe@nve.no

The flood inundation map project is funded by the Norwegian government and ruled by NVE. Areas prone to flooding and where there is a high risk of economic loss will be mapped. The aim of the project is to improve land use planning and emergency action (reduced flood damage). In all 188 river stretches covering 1750 km of river length are identified and they are divided into three priority classes depending on the severity of flood risk. The maps are produced using digital methods and accurate digital maps. Flood frequency analyses and hydraulic simulation of the river reach is included. Six different floods are mapped; i.e. the 10, 20, 50, 100, 200 and 500 year floods. The project was started in 1998 and is planned to go on until 2007.

The background for the project was the extreme flood in south-eastern Norway in June 1995. A presentation will include major events during the flood and examples of damages. The poster will present the project and focus on the different methods used: generation of digital elevation models, centre line and cross sections in a database, digital flood surface and the final maps and reports as they will be presented for each of the 188 projects.

PRINCIPLES OF SHORT-TERM FORECASTING OF EXTREME FLOODS

V. A. Kuzmin

Department of Hydrology, Russian State Hydrometeorological University, Malookhtinski 98,
Saint-Petersburg 195196, Russia
e-mail: kuzmin@solaris.ru

There are many known methods of runoff forecasting which work well in ordinary conditions but are useless in catastrophic ones. The main cause of the low quality of the forecast methods is the incorrect utilisation of data samples. Forecast equations, laws, relations and coefficients can not be defined statistically by analysis of preliminary data. What we need we should find in an operational regime by a stochastic self-training mechanism.

The idea is based on the mode of a probability distribution, which is transforming in time. The evolution of the shape of distribution can be obtained by the sum of the functions of the first, second and third moments. This is the order of the forecast make-up:

The first moment is found from the main forecast equation, which must be based on an equation of motion, an equation of continuity, or on an equation of water balance.

The function of measured discharges or water levels gives the second moment.

The third moment can be determined by analysis of the observed errors of recent forecasts.

The mode can be calculated as a function of defined moments. A GIS-based presentation of the results is recommended.

The fluctuations of runoff are better reflected by mode than by other statistics. The suggested method is very useful in case of the absence of preliminary data, in regions with sparse data, in areas where there are no stations for measurements, in changed basins, in expeditions, etc. It is mainly used in the most difficult situations. This method showed good results in all geographic zones. That is why it is suitable for extreme and catastrophe cases in any country of the world.

Keywords: extreme, flood, forecasting, stochastic, probability, distribution, mode

APPLICATION OF THE STOCHASTIC SELF-TRAINING METHOD FOR THE MODELLING OF EXTREME FLOODS

V. Kuzmin[1], P. van Gelder[2] and H. Aksoy[3]

[1]Department of Land Hydrology, Russian State Hydrometeorological University, Malookhtinski 98 Saint-Petersburg 195196 Russia
e-mail: kuzmin@solaris.ru
[2]Delft University of Technology, Faculty of Civil Engineering, Room 3.87,
P.O. Box 5048, 2600 GA Delft, The Netherlands
e-mail: P.vanGelder@ct.tudelft.nl
[3]University of California at Davis, Dept. Civ. & Env. Eng. Everson Hall, Davis, CA95616, USA
e-mail : haksoy@ucdavis.edu

Key words: floods, stochastic self-training method, statistical moments, Bartin river.

1 Introduction

There are many methods of runoff forecasting which work well in ordinary conditions but are useless in catastrophic runoff conditions. The main reason of the low quality of the forecast methods is incorrect use of the data samples. Forecast equations, laws, relations and coefficients cannot be determined with a statistical accuracy for extreme river flow conditions by the analysis of data from ordinary runoff conditions. In this paper we therefore propose the use of a stochastic self-training mechanism (SSTM) to avoid this problem.

2 SSTM

The idea of SSTM is to take into account the mode of a probability distribution, which is transformed in time (Kuzmin, 1998). The evolution of the shape of a distribution can be obtained by the sum of the functions of first, second and third moments. The use of the fourth and higher moments is not required. The forecast procedure is as follows:

1. The first moment is found from the main forecast equation, which must be based on the equation of motion, or on the equation of continuity, or on the equation of water balance.
2. The function of measured discharges or water levels gives the second moment.
3. The third moment can be determined by analysis of the observed errors of recent forecasts.
4. The mode can be calculated as a function of the moments found in step 1 to 3.

3 Preliminary Results

The fluctuations of runoff are reflected better by the mode than by other statistics. The suggested procedure is very useful in the absence of preliminary data, in regions with sparse data, in areas where there are no stations for measurements at all, in changed basins, in expeditions, etc. The method showed good results in different geographic zones. It is suitable for using in extreme and catastrophic cases in many countries in the world.

SSTM was applied for the forecasting of extreme runoff of the rivers Volga, Oka, North Dvina, Pechora, Irtish (Russia), Mississippi, Missouri (USA), and the Bartin river (Turkey). The floods in these rivers were generated by different factors (snowmelting, rainfall, etc.), however the suggested method gave good results in every case. A number of interesting properties of the mode forecasting are to be marked:
The accuracy of the forecast method increases for higher discharges.
The probability of mode decreases on small rivers where the influence of secondary factors on the runoff is large.
Hydraulic models perform better than rainfall-runoff models.

THE REGION OF INFLUENCE APPROACH, A DYNAMIC METHOD OF REGIONAL FLOOD FREQUENCY ANALYSIS IN COMPLEX AND HIGHLY VARIABLE ENVIRONMENTS - EXPERIENCES FROM SWITZERLAND

M. Pfaundler and P. Burlando

Institute of Hydromechanics and Water Resources Management. Federal Institute of Technology Zurich; HIL G28.2, ETH-Hönggerberg, CH-8093 Zürich, Switzerland email: pfaundler@ihw.baum.ethz.ch

A common case in water resources management is that at the site-of-interest no data are available for estimating flood quantiles. In such cases the approach of Regional Flood Frequency Analysis (RFFA) may be a solution, where regions (sets of catchments) are identified, within which an information transfer from gauged sites to ungauged sites-of-interest may be carried out. In some countries this concept has been adopted in a way that the whole country is subdivided into a distinct number of regions or clusters, that were defined either subjectively, based on flood statistics or on some single basin characteristics.

However, in very complex and differentiated environments where the relevant hydrometeorological and physiographic characteristics show high variability in space (like e.g. in the Alps) and where many different processes are driving the flood generation, a more dynamic approach is necessary for the region identification process. In this respect the Region of Influence (ROI) approach - introduced some years ago - provides a flexible methodology. There are no a priori regions, rather every site-of-interest gets its own ROI. The set of gauging stations that constitutes a site's ROI is determined on the basis of similarity of relevant hydrometeorological and physiographic basin attributes, to which weights are assigned. The method is also flexible in the sense of it's capability in reflecting the fact that different attribute-sets and weight-sets are relevant in different parts of the country and for the individual site-of-interests since the dominant processes will not be the same anywhere.

This approach is tested for applicability in Switzerland. For this purpose, a number of basin characteristics have been derived that are deemed to be good indicators for relevant processes and can serve as attributes in defining similarity. The robustness of the ROI-site selection is investigated by performing a sensitivity analysis, changing the attribute- and weight-sets. Different tests on homogeneity, which is the main assumption of the flood regionalization approach, are carried out. Firstly statistical homogeneity tests. Secondly, investigation of the seasonal behaviour - that is believed to have a certain link to the processes - of the ROI site's annual maximum flood series (looking at mean time and variability of flood occurrences). Thirdly analyses of the scaling properties of the ROI (simple scaling versus multiple scaling). Furthermore the effect of different data aggregation rules on the resulting growth curve (regional dimensionless flood frequency distribution) is analysed. The many options the method offers produces a high degree of freedom to the user. This is why examining the robustness of the results is a main part of the analysis. A critical appraisal of the suitability of this approach for the Swiss environment and its performance in predicting flood quantiles will be given.

EXTREME CLIMATIC EVENTS ASSOCIATED WITH EL NIÑO/SOUTHERN OSCILLATION (ENSO): ANALYSIS (1500-1999) AND FORECAST (2000-2050).

J. Sánchez-Sesma

Instituto Mexicano de Tecnología del Agua; Paseo Cuauhnahuac 8532, Jiutepec, Morelos, CP 62550, México
e-mail: jsanchez@tajin.imta.mx

ENSO is considered the most important climatological phenomena during the last decades. The last two decades were marked by intense and frequent ENSO phenomena. The 1982-1983 and 1997-1998 ENSO events were the greatest registered in the century, while the 1991-1995 ENSO event was the longest in this century. Associated with these extreme climatic events are extreme hydrologic ones (floods and droughts) that have been occurring all around the globe.

ENSO is considered to be caused by the interaction of atmosphere and oceans. However, considering the coincidence of volcanic eruptions and micro-seismicity previous to ENSO occurrences, some authors have suggested that besides the atmosphere and hydrosphere, the lithosphere must be considered as a part of the climatic system. Although significant advances in forecasting short-term evolution of ENSO have been reached, many questions remain unanswered. Taking into account the possible existence of secular periodic oscillation for ENSO values, a simple periodic model based on spectral analysis is proposed. The model was first tested using *hindcasting* for the 1900-1999 period. In this *hindcasted* period the model explained more than 80% of the variance for ENSO, and shows its maximum during the 1990's, which coincides with the longest registered ENSO event. Using data from 1500 to 1999, a model with periodic functions was used to forecast a nearly 50 year period. The results for ENSO activity in the 1999-2050 period show several levels of activity. For ENSO the periods with activity above present values are 2000-2012, 2025-2028, and 2041-2050. The results suggest that anomalous ENSOs and their associated extreme hydrologic events (floods and droughts) can be expected for the next decade.

It should be noted that both climatic and hydrologic extreme events must be analysed in a long-term perspective in order to consider their low frequency variations.

WEIGHTED LEAST SQUARES METHOD – THE IMPROVEMENTS ON ESTIMATES WHEN INDEX FLOOD METHOD IS USED WITH AM FLOODS

S. Senaratne and C. Cunnane

Dept. of Engineering Hydrology, National University of Ireland, Galway, Ireland
e-mail: savithri.senaratne@nuigalway.ie

Regression analysis is used in regional analysis in order to obtain the magnitude of the index flood at an ungauged site. The Ordinary Least Squares (OLS) method is commonly used to calibrate regression models. The OLS method requires a number of assumptions, one such assumption being that the error term in the calibrated model is homoscedastic. This means, that the variances of the individual error terms corresponding to each data point are equal. However, unequal record lengths used in obtaining the mean annual flood ($\overline{Q}$) and the measurement errors in annual maximum (AM) floods can result in unequal variances of the error terms. The Weighted Least Squares method is used (Draper & Smith, 1981) in such instances in calibrating a regression model.

This paper deals with issues arising from the presence of heteroscedasticity, in regression models for estimating $\overline{Q}$. The objective of this study is to obtain an optimum weight matrix to be used in the WLS method.

The benefits of the WLS method and the Generalised Least Squares (GLS) method over the OLS method were examined in a number of research studies (Tasker, 1980; Stedinger and Tasker, 1985; Stedinger and Tasker, 1986; Tasker and Stedinger, 1989) in which, the regression model used in the simulation experiment was hypothetical. This study differs from those in that the simulation strategy originally employed by Hebson and Cunnane (1987) is used. In that strategy, real annual maximum flood data are used in arriving at the parameters of the GEV distribution selected for generating the AM floods. Basing the generation of floods on real world data allows use of actual catchment characteristics in the simulation experiment.

Three data sets from Ireland, UK and the State of Arkansas in USA are used as three separate regions and the simulation experiment is run for them separately. Four types of weight matrices are used and for each data set the simulation experiment is performed with each data set. The best-fit regression model using indicators such as coefficient of determination (R^2) and efficiency of the coefficients are used in obtaining the best weight matrix. The Q_T values obtained using the different methods of flood estimation are compared using the indicators, bias, standard error and rmse.

The conclusions are as follows: (1) the best weight matrix to be used in the WLS method is that which uses 1/Cv as the elements. (2) the WLS method in regional only analysis is able to improve the estimates of Q_T obtained over that of OLS method in regional only analysis. The standard error is reduced by 50% in the WLS method from that of OLS method and the bias is reduced or unchanged.

SIMULATION OF DISCHARGE FIELDS

T. Skaugen

Norwegian Water Resources and Energy Directorate, University of Oslo,
Dept. of Geophysics, P.B. 5091, Maj, 0301 Oslo, Norway
e-mail: ths@nve.no

Operative flood forecasting in Norway is based upon the simulated results of the Swedish rainfall-runoff model HBV, which is driven by meteorological forecasts provided by the Norwegian Meteorological Institute. However, these results can only be considered as point estimates and it is difficult to extrapolate the results to areas where no such model is calibrated. In this project we aim to quantify and produce a stochastic model for the spatial variability of discharge in order to produce discharge simulation scenarios for an area.

The basis for this study has been the analysis of specific discharge values from several gauging points within a larger catchment with respect to spatial variability and the spatial coverage of discharge intensities. For each daily event, the spatial coverage of specific discharge intensities has been mapped and a stochastic model has been formulated. This exercise has been performed for two catchments of quite different physiographical characters and location in southern Norway, and it appears that a part of the parameters of the stochastic model are general. The remaining parameters of the stochastic model are estimated from the output of the HBV model, calibrated for the catchment in question. The output of the HBV model acts as a constraint in the simulation procedure. The output of the stochastic model is discharge scenarios presented as a mapping of the spatial coverage for different discharge intensities. This can be viewed as a disaggregation of the specific discharge forecasted by the HBV model and we are thus able to forecast for smaller areas than that of the HBV catchment.

Some preliminary results are obtained, and are encouraging, but many questions and problems remains to be addressed before we have an operational forecasting tool.

FLOOD FORECASTING FOR THE RIVER RHINE IN THE NETHERLANDS

E. Sprokkereef

Institute for Inland Water Management and Waste Water Treatment (RIZA),
P.O. Box 9072, 6800 ED Arnhem, The Netherlands
e-mail: e.sprokkereef@riza.rws.minvenw.nl

The hydrological years 1994 and 1995 were characterised by two extraordinary extreme floods in the basins of the rivers Rhine and Meuse. At the beginning of this period, in December 1993, and in the months of January and February 1995, floods occurred in the northern part of the Rhine and in the Meuse basin, which were partly floods with a return period of more than 100 years. The water levels that were measured in January 1995 on the Rhine at the German Dutch border are the second highest since the beginning of measurements in the 19th century. Along the Dutch part of the Rhine critical water levels were exceeded and over 200.000 people had to be evacuated as a precaution. The total costs funded by the Dutch government came to 166 million Euro.

Both flood events showed again the importance of reliable forecasts with a sufficient forecast period. In the Netherlands the potential damage for the part of the country endangered by rivers is roughly estimated at 1200 billion Euro. For every hour the forecasting period can be prolonged, the possibilities for realising measurements are extended and therefore the potential damage will be reduced.

During the floods of 1993 and 1995 forecasts for the gauging station Lobith on the Rhine near the German Dutch border were carried out with a fairly simple multiple linear regression (MLR) model that allows relatively reliable forecasts up till 48 hours ahead. The model uses measured water levels in the German part of the Rhine basin as well as measured and forecasted precipitation for the upstream catchment.

After the floods of 1993 and 1995 it was decided that it was necessary to extend the forecasting period for the Rhine to 3 days by the year 2000 and to 4 days by the year 2005. To meet these goals the existing model for the Rhine had to be abandoned and a new model had to be constructed. Therefore 250 km of the German Rhine upstream from Lobith were modelled with a one-dimensional hydro-dynamic model. The modelling was carried out as a joint project between the German and the Dutch national water authorities. The new model also consists of two rather simple provisional rainfall runoff models for the main tributaries of the northern Rhine. The first operational use of the new model during some minor floods in the beginning of 1999 showed reliable results for the 3 days forecast and considerable improvement for the 4 day forecast. To further improve the 4 day forecast, and maybe even prolong it to 5 or 6 days, an extension of the hydro-dynamic model is foreseen, first upstream to the gauging station of Maxau (an extension of 250 km) and possibly later to Lake Constance. The main tributaries in the middle and the southern part of the German Rhine will be modelled with more sophisticated rainfall runoff models.

HYDROLOGIC FREQUENCY ANALYSIS MODELS WITH UPPER AND LOWER BOUNDS

K. Takara and K. Tosa

Disaster Prevention Research Institute, Kyoto University, Uji, Kyoto 611-0011, Japan
e-mail: takara@rdp.dpri.kyoto-u.ac.jp

Conventional frequency analysis has been using the probability distribution functions (PDFs) with an infinite upper bound and/or an infinite lower bound. From the viewpoint of physical rationality, negative values for rainfall and discharge are not justified. Likewise, rainfall and discharge should have a finite maximum limit under the hydro-meteorological and geographical conditions considered. The author incorporates the finite lower and upper bounds into the PDFs used in hydrologic frequency analysis (Takara et al., 1996; Takara & Joesron, 1996; Takara & Tosa, 1999). The probable maximum precipitation (PMP) should be the upper bound for storm frequency analysis, while the probable maximum flood (PMF) for flood frequency analysis.

Two PDFs with upper and lower bounds are considered: the four-parameter log-normal distribution using the Slade transformation and the extreme-value distribution with lower and upper bounds (EVLUB distribution) proposed by Kanda in 1981. The goodness of fit and stability of these models are evaluated in terms of the four goodness-of-fit criteria and the jackknife and bootstrap methods (Takara & Stedinger, 1994).

The significance of this incorporation of the lower and upper bounds is:

(1) It stimulates interdisciplinary research on probable maximum or minimum hydrological variables among meteorologists, hydrologists, statisticians and so forth.

(2) It essentially has scientific (physical) rationality.

(3) It has a practical advantage in estimating quantiles for smaller samples.

REFERENCES

Takara, K. T. and J. R. Stedinger (1994): Recent Japanese Contributions to Frequency Analysis and Quantile Lower Bound Estimators. Stochastic and Statistical Methods in Hydrology and Environmental Engineering, (ed.) K.W. Hipel, Kluwer Academic Publishers, Vol. 1, 217-234.

Takara, K. and Joesron Loebis (1996): Frequency analysis introducing probable maximum hydrologic events ---Preliminary studies in Japan and in Indonesia---.
Proc. of International Symposium on Comparative Research on Hydrology and Water Resources in Southeast Asia and the Pacific, Yogyakarta, Indonesia, November 18-22, 1996, Indonesian National Committee for International Hydrological Programme, pp. 67-76.

Takara, K., T. Takasao and K. Tomosugi (1996): Possibility and necessity of paradigm shift in hydrologic frequency analysis. Proceedings of International Conference on Water Resources and Environment Research: Towards the 21st Century, Kyoto, Japan, October 29-31, Vol. 1, 1996, pp. 435-442.

Takara, K. and K. Tosa (1999): Storm and flood frequency analysis using PMP/PMF estimates, Proc. of the International Symposium on Floods and Droughts, Nanjing, China, 18-21 October 1999, IHP-V, Technical Documents in Hydrology, No. 4, UNESCO Jakarta Office, Hohai University Press, 1999, pp. 7-17.

SESSION 8-9

PREDICTABILITY AND ABATEMENT OF FLOODS: CLOSURE

AVALANCHE EVENTS IN THE WINTER OF 1999 IN SWITZERLAND

P. Baumgartner

Environmental protection agency, Gürtelstrasse 89, CH-7000 Chur, Switzerland
e-mail: Peter.Baumgartner@afu.gr.ch

In the winter of 1999 the most dramatic avalanche events since 1951 occurred in Switzerland. The weather situation was extreme adding 4 meters of fresh snowfalls in Davos and 7 meters on the peak of Säntis during ten days, on top of the existing layer. The meteorological situation and the snow morphology leading to the extraordinary situation are documented. In some ski resorts up to 45,000 holiday guests were grounded because of closed roads and railways. Several hundred avalanches descended and several of them barred roads, a few led to casualties and many resulted in damages to buildings.

The emergency organisation was in operation for ten days resolving the tasks of:

* Guaranteeing the safety of the local population and the holidaymakers by opening/closing the commute by road, train and helicopters
* Advising the local authorities
* Securing the logistics and supply
* Informing the involved people, especially the temporarily grounded tourists

The consequences compared to the last winter with big avalanche damages, in 1951, were reduced for the following reasons:

* Investments in the construction of avalanche prevention devices for several hundred millions of Swiss francs
* Re-cultivation of alpine protective forests
* Identifying and respecting of areas banning the construction of housing in areas with the possibility of avalanche hazards
* Optimal functioning of a pretrained emergency management

Some experiences can be derived for future events:

* Criteria for the decision for early artificial tripping of avalanches with explosives, versus waiting for their natural release, must be improved
* The information of the touched but not directly involved (relatives, press, tourists) must be professionalized

Impressive visualisation is available both as pictures and on video.

The author has personal experience with avalanche accidents in his career as a mountaineer, was a staff-member of the crisis management in winter 1999 and has professional knowledge in the risk assessment in context with natural hazards.

THE WORLD'S MAXIMUM OBSERVED FLOODS

R. Herschy

Scientific & Engineering Services, 5 Alderney Court, Montague Street,
Reading RG1 4JW, United Kingdom
e-mail: newsome@cns.org.uk (fax: 0118 958 7666)

Knowledge of exceptional large floods is essential in solving many problems in water resources management and to assess the susceptibility to flooding of structures in the vicinity of rivers. The study, initiated by IAHS, UNESCO and WMO, addresses the collection and analyses of flood data from questionnaires sent out to 166 countries. For each country on the list, details are presented giving the maximum flood, method of estimation, rainfall if available (many historical floods are recorded where this was not available), hydrological information, and a selection of long-term series of annual maxima. Finally, an envelope curve of maximum floods is presented. The present study updates the work of Rodier and Roche (1) and others (2).

A MAP OF EUROPEAN FLOOD RISK

R.Muir-Wood, A.Beger and H.J.E. Rodda

[1]Risk Management Solutions Ltd., 10 Eastcheap, London EC3M 1AJ, UK
e-mail (H. J. E. Rodda): hrodda@riskinc.com
[2]Department of Geography, Downing Place, Cambridge, CB2 3EN, UK

A wall map of flood risk in Europe has been created, which represents the risk associated with five types of flood hazard: storm surge, tsunami, river floods, flash floods, and dam bursts. It also includes an analysis of the risk of flooding for the principal urban areas. The map has been generated using data from a variety of sources. The river network, digital elevation model and the extent of urban areas were all obtained from USGS published datasets. The risk from a particular type of flooding has been assessed from a detailed analysis of historical events, often on a country by country basis. Documentary evidence for these events provided information on the depth of water, area inundated, number of persons killed and the degree of damage. Indications of the extent of historical coastal floods have also been included as a feature on the main map. This presentation will provide detail on the methods, which have been used, for determining and illustrating flood risk. The map is at a scale of 1 to 5,000,000 and covers the area of Europe west from the former USSR.

(1) Rodier, J.A. and Roche, M. 1984. World Catalogue of Maximum Observed Floods IAHS Publication No. 143.

(2) Herschy, R.W. and Fairbridge, R.W. 1998. Encyclopedia of Hydrology and Water Resources, Kluwer.

SOME EXTREME FLOODS OF THE LAST DECADE IN TURKEY AND LESSONS LEARNED

Ü. Kiliçer[1], Z. Kulga[2] and H. Özgüler[3]

[1]Investigation and Planning Department, General Directorate of State Hydraulic Works, Ankara, Turkey
[2]Hydrologist-Meteorological Engineer, Ministry of Energy and Natural Resources, Ankara, Turkey
[3]Hydrologist-Meteorological Engineer, General Directorate of State Hydraulic Works, Ankara, Turkey
e-mail: hamza.ozguler@dsi.gov.tr

In recent years especially, a number of devastating flood events have occurred in the various river basins of Turkey. In many cases floods caused deaths, suffering and extensive damages to both public and private properties, and costly social and economic disruption for a time after the disaster. After almost each flooding event, the government has paid a large proportion of the damage in addition to losing significant revenues due to the consequences of economic disruption.

Both the two flood cases presented in this paper and other flooding experiences gained elsewhere in Turkey in the last decade have shown that almost all essential infrastructure might be at risk of costly damage. On the other hand, irregularly uncontrolled human activities ongoing at the river basins scale have a major role in the rising cost of floods, as well as other factors such as meteorological and hydrological magnitudes of the occurrences. Two flooding cases presented in this paper are typical samples of the assessments noted above. In the first flooding case only, which occurred in the Western Black Sea region of the country in May, 1998, more than 80 settlement areas including five province centres were significantly affected, and as a result 13 people lost their lives.

The last decade's flooding events with their costly results have brought Turkey to a new viewpoint to reduce and control the susceptibility to flood damages, namely the "Hazard Mitigation Approach". It is nowadays well known that, owing to the complex nature of the Hazard Mitigation, specific measures for the flooding hazards cannot be implemented or evaluated independently. In this regard, it can be concluded that building a flood control structure is neither the best solution nor the only solution to a flood problem. Structural flood protection projects may be considered as one of the basic strategies that can reduce flood damages, and in this context flood protection planning should consider the full range of the hazard mitigation activities.

In this paper, some ongoing efforts in Turkey included in the comprehensive flood hazard mitigation concept, Turkey Flood Inventory prepared by the General Directorate of the State Hydraulic Works (*), and two case studies related to two extreme flood events of the last decade in Turkey are presented respectively.

(*) Giving special importance to projects to eliminate or mitigate the adverse effects of flooding conditions, the General Directorate of State Hydraulic Works (DSI) is the primary executive state water agency which has been charged by law to develop all of water resources in the country.

FLOOD PROTECTION IN THE CONTEXT OF SUSTAINABLE DEVELOPMENT

Z. W. Kundzewicz

Research Centre of Agricultural and Forest Environment, Polish Academy of Sciences, Bukowska 19, 60-809 Poznan, Poland
e-mail: zkundze@man.poznan.pl

There has been much recent emphasis on sustainable development and management of water resources. Even if there is no such thing as a precise and commonly accepted definition of sustainable development, it is typically understood as a development where the needs of the present generation are fulfilled without compromising the ability of future generations to meet their needs, or as a development where the quality of human life does not decline with time.

Flood protection can be seen in the sustainable development context from at least two points of view. On the one hand, floods killing people and destroying human heritage and breaking continuity of progress are enemies of the sustainable development. On the other hand, systems of preparedness to hydrological extremes, including systems of flood protection and management, are being increasingly reviewed with the question asked - how well different options for flood defence fare in regard to sustainable development?

Global change, including increasing anthropopressure and human encroachment into flood-prone areas aggravates flood risk. The issue of climate variability and change and the possibility of their adverse impacts on the severity and frequency of flooding, introduce an additional uncertainty to difficult sustainability issues.

There are a number of examples of technical infrastructure related to flood protection, which are being criticised in the context of sustainable development because they close options for future generations and introduce unacceptable disturbances in ecosystems. Large structural flood defences like dams, storage reservoirs and embankments are often listed in this category. However, structural means are indispensable to safeguard existing high-value developments, in particular in urban areas.

"Soft", non-structural approaches, such as capacity building (improving flood awareness, understanding and preparedness), flood forecasting and warning systems can be rated as closer to the spirit of sustainable development than "hard" (structural and largely irreversible) measures.

Source control, promoting infiltration and augmenting storage, catching water where it falls raise increasing interest and approval.

Where adequate flood protection cannot be provided, moving out of the harm's way is a viable option, in the spirit of sustainable development.

On a global scale, an essential self-sustaining option is a benign population growth management, attainable by family planning and fertility reduction through improving living standards. If the demographic pressure weakened, informal floodplain settlements around cities would not grow so fast.

As a flood protection system guaranteeing complete safety is an illusion, it is necessary to be aware of the possibility of floods, that is the attitude: "living with floods" seems more sustainable than a hopeless striving to "eliminate floods".

WHAT IS AN EXTREME FLOOD, AND FOR WHOM?

D. Lundquist

Glommens og Laagens Brukseierforening, Postb. 2903, 0230 Oslo, Norway
e-mail: dan.lundquist@glb.no

Media reports frequently on extreme floods from all over the world. Some of these regularly cause large economical damages to society, and even loss of lives, while others can be very rare and pose no severe threats to economical values. Some cover large areas with the gradual inundation of land being the main issue, while others cover only small areas, where intensities can be extremely high and erosion is the main problem. In other words, the meaning of extremes is related to economical damage potential, probability and scale. In the article these issues are further discussed based on examples from Norwegian floods during the last 200 years.

EXTREMENESS OF EXTREME FLOODS

F. Papp

H-1114 Budapest, Eszék u. 9-11, Hungary
e-mail: papp.vizinter@elender.hu

When dealing with extreme floods, the terms used by hydrologists tend to include peak stages, large flows and/or flood waves of long duration and they classify extremeness according to the **probability of occurrence** estimated from these parameters. On the other hand, the decision makers, who are responsible for allocating the funds needed to prevent or to localise inundation and to restore the damages caused, are much more interested in the hazard of inundation, in the losses which can be prevented, or in the cost effectiveness of flood control development, so that they attempt to classify extremeness in terms of the **risk of consequences**. Although attempts at similar estimations have been undertaken in a growing number of countries, no internationally accepted and applied method of flood risk analysis has emerged yet.

A proposal is suggested in the paper at a uniform method of **flood risk** estimation, and at a complex interpretation of **flood extremeness**. The measure of **flood risk** should be suited to assess flood hazard relative to other natural or anthropogenic threats together with the impacts of the contemplated control measures. Underlying the estimation the basic mathematical equation of risk analysis can be used:

$$r = p \, . \, I$$

where r is the magnitude of risk,
p is the probability of a loss event, and
i is a rate characterising the impacts of this loss event.

For a uniform application of the equation, it is essential to develop a method for estimating the probability of a loss event and the impact-rate. The former differs evidently from the flood risk used in hydrology, save for flood plains, where no structural defences exist and no emergency responses are contemplated. The impacts of a loss event are preferably expressed, rather than in terms of the magnitude of losses, by the ratio thereof to a relevant value.

As an illustrative example the risk of inundation is shown for a few typical past floods in Hungary and compared with similar data of other countries and with the risk of other natural disasters. Since in Hungary and in several other countries no monetary value is assigned to human life, two kinds of risk are analysed, viz. the risk to human life and to economy. In the former case the magnitude of loss is the ratio of fatalities to the population of the exposed area, whereas in the latter it is the total loss expressed in monetary terms related to the annual GDP of the particular country.

The proposed measure of **flood extremeness** is one, which takes account of both the familiar hydrologic and the aforementioned risk parameters. The approach is illustrated by the comparison of river floods, where four aspects are analysed to derive two hydrologic and two risk parameters, which are then combined into a complex term.

The parameter derived by comparing the catchment size and the probable maximum flow shows how extreme the given flow is on streams draining a catchment of similar size.

The high-water probability of the flood wave considered characterises the occurrence of the peak stage and the duration relative to former flood waves at the particular gauging station.

The impact of loss in human life is represented by the ratio of fatalities to the population living in the inundated area.

The impact of economic losses is represented by ratio of the losses expressed in monetary terms relative to the GDP in the particular country, in the particular year.

The parameters thus obtained can be assessed separately, but for characterising the **extremeness of flood** a complex parameter is suggested, which includes the impact of each.

COPING WITH EXTREME FLOODS: FORECASTING, WARNING AND RESPONSE

E. Penning-Rowsell and C. Green

Middlesex University Flood Hazard Research Centre, Queensway, Enfield, Middlesex, UK
e-mail: E.Penning-Rowsell@mdx.ac.uk

Coping with extreme floods means reducing their damage impacts. This in turn means that we need to understand the impacts of flood warnings on flood damages, so that we can manage the total forecasting, warning and response system.

The residential flood damage data published by Penning-Rowsell and Chatterton (1,2,3) and other data given by Parker *et al* (6) represent the maximum potential damage, ignoring the damage-reducing effects of action taken after flood warnings (see also (4) and (5)).

Research has continued over the last two decades on flood warnings and their effects, summarised by Parker (8). Particularly important has been surveys of those to whom flood warnings have been issued, designed to determine the actions that they were able to take, the damage that was thereby averted, and the factors that affect this (including flood warning lead time, the availability of assistance with moving vulnerable household goods, etc). A total of over 1200 interviews has been undertaken (e.g. (5,7)).

The following equation has been developed and calibrated in this research (8):

FDA = PFA x R x PRA x PHR x PHE.......................... Equation 1

where:

FDA	=	estimated actual flood damage avoided owing to the flood warning
PFA	=	potential flood damages avoided (property plus road vehicle damages avoided)
R	=	the reliability of the flood warning process (i.e. the proportion of the population at risk which is warned with sufficient lead time to take action)
PRA	=	the proportion of residents available to respond to a warning
PHR	=	the proportion of residents able to respond to a warning
PHE	=	the proportion of households who respond effectively.

An important assumption in the 1977 research was an aggregate response rate of 70% to warnings (a combination of PRA, PHR and PHE), and subsequent research was designed to refine that estimate. Parker (8) reports conclusions of 0.55, 0.75 and 0.70 for these three factors, respectively, leading to a combined value of 0.29 to compare with the value of 0.70 published in 1977.

The research over the last two decades therefore has yielded an aggregate response rate of less than 30 per cent rather than 70 per cent. The conclusion to be drawn from this is that project appraisals should use the moderated flood damage values arising from this research, rather than the maximum potential damage data as given by the FLAIR data archive (3).

This is even more important given that our most recent assessment of R is 0.45 (both residential and commercial) such that only 45 per cent of the population at risk is warned with sufficient lead time to take the action to produce our estimated damage savings (9,10,12). This means that FDA is approximately 0.13, so the estimated actual flood damage avoided owing to the flood warning is only some 13 per cent of potential damage (cf. c. 20% recorded by Smith (11)).

Thus flood warnings, for a variety of reasons, do not yield the level of damage saving at first estimated (13), so that while their benefits can still be considerable, these only begin to be realised when the total forecasting, warning and response system is operating effectively, and usually this is not the case (14).

IDF ZONING CURVES FOR ECUADOR AND ITS APPLICATION IN THE CIVIL BUILDING SITE DESIGN

L. Rodríguez

Instituto Nacional de Meteorología e Hidrología, INAMHI
Iñaquito 700 y Corea. Quito Ecuador
e-mail: inamhi@gov.ec

Design and construction of drainage systems, both urban and rural, is becoming a complex problem due to the expansion of urban areas, industry and consequently wastewater amounts. The increase in impervious areas has reduced the infiltration capacity of soils, consequently using adequate drainage systems properly designed should drain off the volume of surface runoff. In order to accomplish this it's necessary to examine the relationship among four main factors: intensity, duration, frequency and distribution. Surface distribution of rainfall can be found from spatial analysis of data registered at various gauging stations. Given the high cost of drainage systems, the importance of I D F analysis of rainfall using the longest series possible in order to have reliable statistics is evident.

In the present work I D F analysis is given for all the country. The methodology used is described. Frequency analysis was carried out using FLOOD and SAFARHY packages developed by the U. of Chihuahua and the ORSTOM respectively. In this study 64 gauges with continuous records and 113 pluviometers were used for various durations.

SOCIAL AND ECONOMIC DIMENSIONS OF THE 1998 EXTREME FLOODS IN COASTAL CHIAPAS, MEXICO

Á. Sánchez-Crispín

Instituto de Geografia, UNAM, CP 04510 Mexico City, MEXICO
e-mail: ascrispin@yahoo.com

From a geographical point of view, and based on empirical research, this paper examines the social and economic consequences of the extreme floods that affected the pacific seaboard of Chiapas, Mexico, in September 1998. A tropical area of roughly ten thousand km^2 was the scene of extraordinary floods originated by the overflow of some twenty rivers, affecting more than 800 thousand people distributed in sparsely-populated rural areas and a handful of small and medium-size cities.

This questionnaire-based research was done in the early months of 1999. Several field-works were necessary to complete more than 1000 interviews, distributed all over the coast of Chiapas, and particularly concentrated in places worse affected by the floods. The questionnaire was made up of eighteen general entries. The aim of this instrument was to explore three basic situations disrupted by the extraordinary floods:

1. The quality of life in the region

2. The local population's sense of belonging to this part of Mexico

3. The perception of regional problems by locals

Since these key issues were tackled after the floods were over, we believe that the questionnaire-survey gathered significant information on the influence of this natural disaster on the continuity of the regional economy and livelihood.

Our research results were compiled on 45 maps, some of which accompany this paper, showing people's feelings and opinions about the aftermath of the floods. This material is a useful platform to draw action lines that should guide State efforts to alleviate and prevent some of the problems caused by floods in this area of the Mexico, already poor and socially marginal.

EXTRAORDINARY FLOODS IN HUNGARY

L. Szlavik

Water Resources Research Centre (VITUKI), Hungary
e-mail: szlavik@vituki.hu

Under the particular physico-geographic conditions of Hungary, important and steadily growing interests have for centuries been attached to flood control. The fundamental cause of the grave flood hazard is that the overwhelming plain country is situated in the deepest part of the Carpathian Basin. There the flood waves rushing down from the surrounding Carpathian and Alpine headwater catchments are slowed down and they overtake and coincide with each other, often resulting in high river stages of extended duration. Owing to the climate and the geographical situation floods are liable to occur virtually on any Hungarian river in any season of the year. Torrential floods are frequent. Drainage basins of rivers and smaller streams flowing to Hungary cover 290,000 km^2, i.e. more than three times the area of the country, which underlines the importance of boundary transit flow.

Flood plains make up 22,8 % (21,248 km^2) of the total 93,000 km^2 large area of the country. A system of 3-8 m high flood protection embankments and floodwalls was created, starting in the mid-19th century and nowadays 97 % of the flood plain is protected. About 2.5 million people in around 700 communities in the protected flood plains are exposed to flood hazard. Some 25 % of the gross domestic product is generated in this area.

Rainfall, snowmelt induced and mixed floods all are frequent. Most of the rivers inherit the possibility of the formation of ice jams and related flooding. Ice jam induced catastrophic floods appeared on the River Danube in 1838 and 1956, while on the River Tisza, a relatively recent icy flood of 1985 was remarkable.

Recent events have again focused public attention on flood safety in the country. The most recent floods occurred in November 1998 on Upper-Tisza and Bodrog rivers with disastrous consequences in the part of the catchment beyond the national boundary, just followed by another season of extreme historical floods on Bodrog and the middle current Tisza in March-April 1999. Although several of the floods in the streams in Hungary rose to record stages, the defences along them have withstood these flood waves without failure virtually since 1980. The last flood to claim lives was the ice-jam flood in the winter of 1955-56 in the Danube. The reason for this success with flood defences is not due to luck or any fortunate situations, but rather to carefully planned, methodical development and organising efforts.