THEME-I

SURFACE WATER HYDROLOGY

COMPLEXITY, UNCERTAINTY AND ERROR IN HYDROLOGIC MODELS

L.J. Lane & M.H. Nichols**

*Southwest Watershed Research Centre, Tucson, U.S.A.

Issues of complexity, parameter and input variable uncertainty, and resulting model errors are reviewed and assessed. Simple measures are derived to represent degree of complexity, degree of uncertainty, and degree of systematic error for a simple subset of hydrologic models. Model complexity is represented by a complexity number, Nc = nm + 1. The quantity n is the number of model parameters and input variables and m is the number of simulation runs (around a vector of base or nominal values) required to assess noninteractive model sensitivity. Model uncertainty is represented by a normalized coefficient of variation, Cv, computed from the sum of the individual coefficients of variations of the n parameters and input variables. Systematic error, Se, is a function of the number of the basic concepts of conservation of mass, momentum, and energy, and of the basic variables position, velocity, and acceleration included in each model component. Three infiltration models: Phi Index, SCS Runoff Curve Number, and the Green- Ampt Infiltration Equation; Two peak discharge estimation procedures: The Rational Formula and the Kinematic Cascade Model; and one continuous hydrologic simulation model are used as example illustrations. These examples are used to illustrate the highly interactive and important concepts of model complexity, uncertainty, and systematic error. The methodology and examples are used to formulate and partially test the hypothesis that simple measures can be formulated and used to objectively evaluate model complexity and its relationships with uncertainty and systematic error.

STRATIFIED MUSKINGUM ROUTING IN NATURAL CHANNELS

M.Karmegam

Anna University, Madras, India

Muskingum equation for flood routing is very popular for its simplicity and ease with which calculations can be done. The method receives a constant attention since its development. Consequently it is being improved in its application. Improved calculation of the parameters and introduction of variable parameters are the notable ones among the changes made in the parameter calculation originally proposed.

Following the above works, a procedure called "Stratified Muskingum Routing" was developed and tested with a set of hypothetical data by the author. This procedure improves the variable parameter calculation by using a set of historical flow data through optimization techniques resulting in simple relationships for the routing parameters as functions of the flow to be routed. Attempt is made here in this study to extend this theory to a real flood routing problem. It is found that natural floods can be routed with improved parameters leading to better results than obtained before.

SIMULATION OF STREAMFLOWS FOR A FORESTED CATCHMENT USING CONCEPTUAL MODELS

A.M. Kalra & S.K. Goyal

Punjab Engineering College, Chandigarh, India.

The Sacramento model and the Pitman model have been applied to simulate the mean daily flows for the river Ramganga, the catchment of which lies in the lower Himalayan ranges and has been under extensive afforestation. Both the models are deterministic, lumped input and lumped parameter conceptual hydrologic models.

The Sacramento model explicitly accounts for the soil moisture and involves a temporal distribution function for the conversion of channel flow into discharge hydrograph. Rainfall inputs are the volumes over six hour time steps. For the purpose of model calibration, first three years of data are selected and for the validation last three years of data are used. Mean daily flows are simulated for the whole catchment upto Kalagarh and for the subcatchment of Naula using this model.

The Pitman model involves fewer parameters and lesser runtime on the desktop computer and can be

used with limited length of data. the daily/monthly precipitation and monthly evaporation are the inputs. For days during which there is no rain, a one day time step is used. When a rainy day is encountered, the duration of the rainfall is estimated and distributed as hourly amounts in order that the water budget may be computed at one hour time interval. Calibration of the model carried out using the data from six raingauge stations and the daily runoff observations at Kalagarh for October 1969 to September 1971. The validation was done using the rainfall and runoff at the same station viz. Kalagarh. Mean daily flows are also for the Naula subcatchment using the Pitman simulated model. The simulated mean daily flows compare favourable with the observed flows.

A COMPARATIVE EVALUATION OF TWO RAINFALL-RUNOFF MODELS FOR SMALL WATERSHEDS

Pushpa Raj Onta & Kao Chia-Loong

Asian Institute of Technology, Bangkok, Thailand

This paper analyzes two common approaches of deterministic rainfall runoff modeling, viz, the black box type regression model and the conceptual lumped type NAM model, based on their applications on two small watersheds representing different hydrological and catchment characteristics. These are the Lan Yang catchment (area= 824 sq.km) in the subtropical Taiwan and the Khlong Si Yat catchment (area = 951 sq.km) in the tropical Thailand. The models are calibrated using daily streamflow and rainfall data for 7 years (1980-1986) and tested for their predictive capabilities during a 3 year period (1987-1989). For NAM model, evaporation data are also used. Several statistical criteria such as the mean, standard deviation, correlation coefficient, coefficient of efficiency and root mean square error are considered in evaluating the models for reproducing and prediciting annual flow volume, peak flow and time to peak, and base flow.

The regression models are found to be applicable in both the catchments, with the results in Lan Yang, which has better data availability, marginally better than in Khlong Si Yat. Due to steep mountainous topography with heavy rainfall, runoff is mostly associated with previous rainfall in Lan Yang whereas in the flatter forested Khlong SI Yat with average rainfall, previous discharge is found to be more important in the regression model. Although the NAM model is satisfactorily calibrated in both the catchments within the scope of available data, its predictive capability in simulating annual flow, especially in Khlong Si Yat, is not very good. However, the peak flow and time to peak are quite accurately predicted especially in Lan Yang. Relatively speaking, the simpler regression approach is found to perform better than the more data intensive conceptual approach in both the catchments.

COMPUTATIONAL ASPECTS IN KINEMATIC MODELLING

Bernhard H.Schmid & Wolfgang Summer

Technical University Vienna, Institute of Hydraulics, Hydrology and Water Resources Management, Vienna, Austria

In this paper mathematical and computational properties of kinematic wave models in hydrology are reviewed and discussed. Special attention is paid to questions relating to the formation and propagation of shocks as well as the presence of numerical diffusion in certain finite difference schemes. As shocks and shock structures (the latter obtained from higher order "parent" models) travel with the same celerity, locally increased error in the vicinity of a solution discontinuity does not invalidate the kinematic model. Care must be taken, however, in the evaluation of numerical results, as parasitic oscillations may develop. Numerical diffusion inherent in several numerical schemes should either be suppressed or matched to a previously determined amount of physical diffusion. The practical usefulness of kinematic models in hydrology is discussed, and so are certain recent modelling attempts aiming beyond the microcatchment scale. Finally, fields of future research are indicated.

FLOW RESISTANCE FOR LARGE SCALE ROUGHNESS

V.A. Copertino, B.De Bernardinis, F.A. Sciancalepore, A. Sole

Dipartimento di Ingegneria e Fisica dell' Ambiente, Universita della Basilicata, Via della Tecnica, Potenza, Italy.

Some uncertainties, either in knowledge of physical processes or in their quantitative interpretation, are still to be solved in channels where the size of roughness elements attains the same order of magnitude as the depth of the flow.

From this point of view, special care must be paid to analyse and estimate flow resistance, because of the simultaneous action of different dissipative forms and the difficulty of full quantification of morphological and geometrical characteristics of the bed.

The biggest grains, which are just covered up by the free surface or which overhang it, give rise to distorsions in the surface that strongly increase their profile drags, according to Froude number and relative submergence. They act as proper boundaries for the flows that are funnelled on the nearly flat parts of bed between the elements. In those regions a minor contribution to the total resistance should be produced by friction of the finest fraction of sediment.

In order to get a more correct evaluation of the dependence of some paramenters, such as wetted perimeter or flow cross sectional area, on funnelling, a simple model, able to represent the geometry of roughness in a cross section, is developed. A further improvement is made possible by the help of a digital elevation model of the bed.

Finally, the estimation of coefficient of resistance is carried out through the integration of a basic semilogarithmic velocity profile whose reference datum position is depending (on the grounds of hydrodynamic equivalence) on some parameters which can be easily measured.

The proposed method is subsequently tested using a collection of river data published by several authors. The method has given a very good performance.

A PC BASED COMPUTER PROGRAM FOR DETERMINING SCS CURVE NUMBER FOR AN UNGAUGED WATERSHED

A.K. Lohani & K.K.S. Bhatia

Ganga Plains Regional Centre, National Institute of Hydrology, Patna, India.

Much hydrologic research has been directed at understanding the hydrologic processes involved with a gauged watershed and applying this knowledge to predict the run-off values needed for efficient water resources development and management. Mathematical models are commonly used to estimate run-off values. A widely used hydrological model for calculating storm run-off, developed by the USDA Soil Conservation Service (SCS) uses storm rainfall and curve number. The Soil Conservation Service run-off curve number (CN) is a quantitative descriptor of the land use/ land cover/soil complex characteristics of a watershed and is commonly assigned based on information acquired from field surveys and/or interpretations of aerial photographs. Therefore, for the establishment of the curve number of a basin the information on hydrologic soil group, hydrologic condition, treatment or practices, and land use/cover are utilized.

The calculations of curve number require much manual work and time particularly when the gridwise information are available either by remotely sensed data or field surveys of the basin. Keeping in view the requirement of a speedy method for curve number establishment, a computer software using the Pascal language has been prepared. The software can be successfully used for the determination of curve number. It can also be used for the determination of curve number for Indian basins by utilizing the curve number values for different land use/land cover and treatment practices using the information given in Hand Book of Hydrology published by Ministry of Agriculture, Govt. of India. The Kolar sub-basin which comprises of an area of 820 sq. km, was selected to utilize the features of the software. Landuse/soil information available on 2 km x 2 km grids were considered as an input to the software and the curve number of the basin has been successfully established. The paper describes the computer programme, input requirement, expected

output, a sample example and explains the method to use the programme for other basins where landuse and soil types are available.

SHORT TERM DAILY FLOW PREDICTION FOR TROPICAL WATERSHEDS

M.V.Somasundaram & S.K. Srinivasan***

* Anna University, Madras, India

**Indian Institute of Technology, Madras, India

Short term daily flow prediction for tropical watersheds characterised by seasonal rain is carried out for Aliyabad watershed in Tamilnadu, India. Earlier data and analysis of daily rain and flow was for a period of 14 years from 1958 to 1971. Recent data and analysis is for a period of 17 years from 1972 to 1988. 'C' language programs have been developed for Fortran programs developed earlier. Modification, generalization and synthesis of programms have also been attempted. Both model representation and forecasting using Wiener multiple time series approach and Venkataraman autoregressive approach are also done. Statistical analysis of rainy and flow days and southwest monsoon seasonal analysis are done for the recent data which was not contemplated for the earlier data. On the other hand, stationarity, correlation and spectral analysis carried out for the earlier data is not contemplated in the recent data. The results revealed in confirmity with the earlier work that no significant improvement is achieved, by increasing the order of the model from 2 to 4 in the Venkatraman autoregressive approach. The confirmation of the better behaviour of the raw time series in contrast to the decomposed time series is as observed in the earlier data analysis. In autoregressive approach, it is observed that error variances for southwest monsoon are less as compared to those of northeast monsoon. The complexity of rainfall prediction is also observed as compared to flow prediction. In the Wiener multiple time series approach, the error variances for southwest monsoon are close for daily series than for weekly flow series. The result revealed Wiener multiple time series approach is better suited for prediction of daily flows. For prediction of weekly flow and daily rain, Venkatraman autoregressive appraoch is preferable. This finding is in confirmity with the earlier work. In 'C' language programming, the CPU time consumption was 96 seconds for both Wiener and Venkatraman approaches of prediction. Individually, Venkatraman autoregressive appraoch consumed 47 seconds and Wiener approach consumed 61 seconds, the total time being 108 seconds. For the earlier data analysis in Fortran IV programming, corresponding CPU time for Venkatraman approach was 62 seconds, for Wiener approach 75 seconds, the total time being 137 seconds.

BAYESIAN UNIT HYDROGRAPHS

A. Ramachandra Rao

Purdue University, W.Lafayette, USA

The unit hydrograph was introduced by Sherman. It is a direct runoff hydrograph resulting from a unit of effective rainfall distributed uniformly over a basin during a specified time duration. Unit hydrographs were derived by Sherman from observed hydrographs of isolated storms by first separating baseflow from total runoff to get direct runoff. The ordinates of resulting hydrographs are divided by the direct runoff volume to obtain the unit hydrograph.

Linearity and time invariance are the two fundamental principles of the unit hydrograph theory. Other assumptions are often made for practical convenience, but they are not essential from a fundamental and theoretical point of view. Although the unit hydrograph method is widely used, the strictly linear time invariant relationship between rainfall and runoff does not exist. The hydraulic equations which characterize the surface flows are nonlinear. However, comparative studies have shown that the combined effect of the nonlinearities is usually small. Consequently, unit hydrographs are still being widely used.

Various investigators have linked unit hydrograph characteristics with geomorphologic characteristics of basins. Some of these efforts are directed towards estimating geomorphologic unit hydrographs. Others are interested in the development of Topological Unit Hydrographs which are based on the theory of topologically random networks.

Different methods are developed to estimate unit hydrographs. The Bayesian and Ridge Regression methods of Unit Hydrograph estimation are investigated in this study. Both synthetic and observed rainfall-runoff data are used. The Bayesian Method is more general and gives non-oscillatory unit hydrographs with non- negative ordinates.

TRANSFER FUNCTION MODELS FOR HYDROLOGIC FLOOD ROUTING

M.P. Cherian & Prabhir Kumar Pal

Indian Institute of Technology, Bombay, India.

Transfer function (T-F) models of the type described in Box and Jenkins (1976) can be readily used for hydrologic flood routing because it is possible to determine a relationship between the time series of flows at a downstream location on a river and the time series of flows at an upstream point. T-F models of this type are all the more valid for flood routing since the physics of the flow phenomenon indicates that the flow at the u/s point "drives" the flow at the d/s point thus making a feedback relation highly unlikely.

In this particular study, T-F models are fitted to two different pairs of u/s and d/s flow time series, one of which is taken from the data given in V.P. Singh (1988). In the fitting procedure, a prewhitening model is first identified for the input series (u/s flows) by making the input series stationary, and then fitting an autoregressive moving average (ARMA) model to this time series. The same prewhitening operator is then applied to the output series (d/s flows) after which the residuals of the input and output series are cross-correlated to determine the transfer function weights. These weights are utilized to determine the final form of the T-F model which includes an appropriate model for the noise.

The T-F models are then used to generate the outflow series from the inflow series for the two cases considered herein. It is demonstrated that T-F models are more accurate than the traditional methods of flood routing such as the Muskingum method. It is shown that T-F models belong to the general category of linear hydrologic routing models relating the outflow to the inflow of a river reach, of which the Muskingum and Convex methods are but special cases. Finally, it is shown that the power of the procedure adopted in this study lies in its ability to identify precisely the most parsimonious structure of the general linear routing model which fits the given data.

COMPARATIVE STUDY OF STOCHASTIC MODELS FOR SEASONAL STREAMFLOW GENERATION

K. Srinivasan & M.C. Philipose

Indian Institute of Technology, Madras, India.

Generated synthetic flows add up to the hydrologic information available to evaluate reservoir designs and operating policies. Seasonal streamflow series can be generated using the following basic approaches namely: (i) Periodic models whose parameters change from season to season; (ii) Generate annual flows first and then disaggregate these into seasonal flows; (iii) Represent the periodicity in the parameters by the required number of significant harmonics in the respective parameters (functional method of modelling).

This paper deals with the comparative study of these three standard procedures through an example of univariate modeling of inflows into the Krishnarajasagara (KRS) reservoir in the upper reaches of Cauvery river basin in South India, in respect of:

(i) Preservation of basic statistics at the periodic (monthly) and the aggregated (annual) level and their spread.

(ii) Preservation of the over-year drought characteristics of the aggregated (annual) flows and their spread.

(iii) Model parsimony.

(iv) Preservation of the extremes (minimum and maximum flows) and their variation.

SPECTRAL ANALYSIS OF CAUVERY RIVER FLOWS

D.Nagesh Kumar & P.P. Mujumdar***

* National Remote Sensing Agency, Hyderabad, India.
** Indian Institute of Science, Bangalore, India.

Time series analysis plays an important role in hydrology. The methods of time series analysis have been extensively applied to the streamflow process for forecasting and synthetic generation. An important component of the time series studies is the Spectral Analysis, which provides valuable information about the structure of the given sequence. The periodicities, if any, present in the series are identified by spectral analysis.

In the present work, the spectral analysis of the Cauvery River flows at Krishna Raja Sagar (KRS) reservoir in Karnataka is carried out. Monthly streamflows for 40 years from June 1934 to May 1974 are used for the purpose. The mean monthly flows and their standard deviations are plotted to visualise the non stationarity present in the flow sequence. The correlogram is constructed to test the dependence present in the series. The structure of the correlogram indicates that the statistical dependence of the monthly streamflows from one year to another decays slowly with time. Two estimates of the power spectrum are used for spectral analysis. The first estimate results from expressing the time series (X_t) as a Fourier series, and the second expresses the estimate of the spectrum as a function of the correlations at different lags. The spectrum indicates that periodicities at 12 months, 6 months and 4 months are present in the streamflow sequence considered. The significance of these periodicities are tested by using an appropriate statistic. It is inferred that all these periodicities are statistically significant. The effect of standardising the series on the correlogram and the line spectrum is investigated. Correlations of only the first few lags are found to be significant in the standardised series. Also, no significant periodicity is indicated by the standardised series.

The analysis carried out in this study prepares for the development of models for forecasting and synthetic generation of the streamflows.

NONSTATIONARY TIME SERIES AND HYDRAULIC DESIGN

Witold G. Strupczewski

Institute of Geophysics, Polish Academy of Sciences, Warsaw, Poland

In view of weakness of an conclusive direct evidence of a global climate change and of an imperfection of theoretical background of the GCM's serving as a intermediary way to prove such changes, a common conviction on its existence and its significant influence on our life is intriguing and it calls for psychological, sociological, political and economical studies of its sources. Hydrology as a branch of environmental sciences benefits from this psychosis getting some funds for development and implementation of measurement techniques and methods of interpretation of measurement data adequate to model mass add energy exchange processes in a large spatial scale. To reciprocate this statistical hydrologists are trying to find an evidence of climate changes in "long" hydrological time series by means of various statistical tests, which may remind the KGB methods to force innocent people to plead guilty. It would be easier to analyze antropogenic influence on climate variability and change if the classic definitions of weather and climate were replaced by one which covers both physical and chemical properties of the atmosphere.

The scope of the paper is an impact of the climate change idea on the methodology of Water Resources systems planning. Obviously the assumption of stationarity of hydrological processes with annual periodicity only shall be abolished and replaced by the nonstationarity which adds new element of uncertainty to all uncertainties of WR planning. If nothing is known about a change of water balance in a catchment during the life time of the project except of a conviction that it will be no longer stationary process then all what can be done is sensitivity analysis of a planned WR system for changes of a hydrologic input. The use of scenarios generated by the GCM's assumes new stationary state why the process shall be considered at least as a transient one.

An emphasis is put in the paper on hydraulic design of high flow structures in changing environment. The probability that a flood exceeding certain magnitude

will occur during the life of a particular project is a crucial part of the analytical input for making decisions about that project. There are two broad categories of approach for estimating the probabilities of extreme floods from available data: those employing statistical analysis of at site or regional stream flow data, and those employing such analysis of meteorological data and a model to simulate the physical processes of runoff. Both of them implies the assumptions that

(a) the data to be analyzed describe random events;

(b) the natural processes involved are stationary with respect to time;

(c) the population parameters can be estimated from the sample.

In the parametric approach it is additionally assumed that PDF of maximum annual flow discharge belongs to some parametric family which is determined by respective regulations.

Two methods are commonly used to determine a hydraulic design value:

(1) return period (or its reciprocal, probability of exceedence) design;

(2) hydro-economic risk-based design.

In both of them there is the upper tail of PDF in use which in view of available stream flow records has neither a sound empirical basis nor a theoretical one. In spite of commonly shared criticism of such approach there is no constructive counter proposals.

However if the records are nonstationary, then statistical characteristics of the nonstationarity need to be modeled, estimated and extrapolated into the period of life of a particular project.

Nonstationarity in hydrologic time series is generally due to

(a) a slow change in hydrologic parameters caused by gradual changes in land use or climatic change in the global or local scale;

(b) a rapid change in the parameters caused by, for example, building of dam, earthquakes, landslide, which is out of scope of the paper.

UNIT HYDROGRAPHS FOR ASSESSMENT OF DESIGN FLOODS IN INDIAN TROPICAL REGION

P.R. Rao

Central Water Commission, New Delhi, India

Duration of high intensity spells in severe rainfall storms of Indian Tropical Region is around 6 hrs. Consequently, in design flood computations, change in Unit Hydrograph (UH) peak by ± 25 % affects the flood peak marginally (less than 10%) for catchments with basin lag of around 6 hrs or more, indicating that complex procedures and models for UH are not necessary. The need is to evolve simple procedure for sketching a unit hydrograph which is reasonable looking and accurate enough to meet the requirements of the project design. Attempts towards achieving this objective are presented in this paper.

Simple relationships to assess 1-hr UH parameters viz., peak (q_p) and time to peak (t_p) on the basis of easily known physiographic characteristics of the catchment are derived:

(i) $q_p = 1.2\ A^{-1/3}$ (ii) $t_p = 0.7\ (L/Seq)^{2/3}$

Where A is the catchment area is sq km, L is the length of the main stream in km and Seq is its equivalent slope in m/km.

It is shown that gamma function with n = 3 and $K = 0.2707/q_p$ can be used for sketching the peak segment of 1-hr UH. Knowing t_p, the starting point is located and joined to the peak segment with a smooth curve and the recession cut off keeping the base period, T_b = 3 to 4 times t_p and ensuring that the sum of the UH ordinates is equivalent to 1 cm/hr over the catchment area, A. If data of some flood events such as time of rise of flood, volume and peak of direct surface runoff hydrograph are available, the appropriateness of the UH synthesised could be checked and suitably adjusted, if considered necessary.

The simple procedure evolved is illustrated with a case study

SPREADSHEET APPLICATION TO UNIT HYDROGRAPH ANALYSIS

R.I. Patel

S.V.R. College of Engg. & Tech., Surat, Gujarat, India

Spreadsheet is a very convenient menu operated computational software for engineers and analysts in carrying out analysis and design. The software is capable of arranging data, carrying out mathematical and statistical analysis and graphics in relatively short span of time. It also provide facility of programming which is known as macros, to increase efficiency and speed of the work.

Since unit hydrograph relates rainfall and direct run-off over the catchment it is an important relationship to be developed for any basin. In practical applications, unit hydrograph of different duration are needed, the same can be best derived from field data. Lack of adequate data precludes development of unit hydrographs covering a wide range of durations for a given catchment. Under such condition, a unit hydrograph is used to develop unit graphs of different durations.

Present paper discusses the application of spreadsheet software to carry out computation of unit hydrograph of dfferent durations from a given streamflow hydrograph and other relevant data.

FRACTAL STRUCTURE, ENTROPY AND ENERGY DISSIPATION IN RIVER NETWORKS

P. Claps & G. Oliveto

Universita della Basilicata, Potenza, Italy

The entropy associated with a channel network is defined, according to the Shannon informational definition, as the expectation of (-log p_j), where p_j is the ratio of the existing paths at the bifurcation level j to the total number of paths. Here j and p_j are respectively proportional to the arrival time of water to the network outlet and to the number of water parcels arriving from the distance j. Then, the expression for the channel network entropy is well suited for hydrologic purposes. Fiorentino, Claps and Singh (Water Resor. Res., in press) showed that the network entropy is strictly related to basin characteristics such as average elevation, Horton order, and magnitude. Also they therotically explained, upon the use of the principle of maximum entropy, some very largely observed scaling properties of channel length and slope with the basin area. Fiorentino and Claps (23rd Italian Conference on Hydraulics and Hydraulic Structures, Firenze 1992, in Italian) derived the entropy function for fractal bi-dimensional tree, for which scaling properties can exactly be derived, and argued that river network structures and river networks growth tend to obey maximum entropy and minimum entropy production criteria respectively.

In this paper entropic properties of fractal networks are deeper investigated and it is shown that some dissipative phenomena which act at a basin scale obey, in average, the minimum and uniform energy dissipation criteria. Scaling properties with the drainage area, of channel slope and length, as well as of energy dissipation per unit length of the channel, are shown to depend upon the reciprocal of the branching network fractal dimension.

The results, which in the paper are shown with regard to a number of basins of Southern Italy, are very interesting and shed more light on the understanding of river network growth and runoff evolution.

THE MOST PROBABLE HYDROLOGIC RESPONSE OF FRACTAL RIVER NETWORKS

P. Claps, Mauro Fiorentino & Giuseppe Oliveto

Universita della Basilicata, Potenza, Italy

Fiorentino, Claps and Singh (Water Resour. Res., in press) defined the entropy S associated with a channel network as the informational entropy of its width function. According to the Shannon informational definition, S is given by the expectation of (-log p_j), where p_j is the ratio of the existing paths at the bifurcation level j to the total number of paths. In a hydrologic fashion j and p_j are respectively proportional to the arrival time of water to the network outlet and to the number of water parcels arriving

from the distance j. Furthermore, Fiorentino, Claps and Singh (see also Claps and Fiorentino, this Conference) showed that the river network entropy is stricly related to basin characteristics such as average elevation, Horton order, magnitude and fractal dimension.

The hydrologic response of a river basin is defined as the probability density function (pdf) of the arrival times, to the outlet, of water particles uniformly injected into the network nodes. Then, it is controlled by the structure of the network width function and by the hydrodynamic characteristics of flow in the channels. The Geomorphologic Instantaneous Unit Hydrograph (GIUH) provides an estimation for the hydrologic response of the river basin. Since the pioneering work of Rodriguez Iturbe and Valdes (Water Resour. Res., 1979), up to the recent work by Rinaldo (Water Resour. Res., 1990), a number of expressions have been proposed for the GIUH formulation. Some of them are well known pdfs, e.g., one of those proposed by Troutman and Karlinger (Water Resour. Res., 1985) which is the Weibull dstribution. On the other hand Singh (Water Resources, Bulletin, 1985) has derived the expression of the informational entropy, at its maxima, for several distribution functions.

In this paper a new method for estimating GIUH parameters, based upon the geomorphologic and informational meanings of the river network entropy, is proposed. The method has a great physical appeal and is simply applicable. The assessment of the proposed model is carried out using data from a number of basins of Southern Italy.

A NONPARAMETRIC APPROACH TO STATISTICAL HYDROLOGY : KERNEL METHODS

Upmanu Lall

Utah State University, Logan, USA.

Statistical methods are routinely used by hydrologists in a number of contexts to describe the uncertainty inherent in hydrologic processes. Typical applications include the estimation of return periods of extreme events (e.g., floods or rainfall), spatial interpolation of data (e.g., rainfall, or groundwater contaminant concentration), synthetic simulation of time series (e.g., daily rainfall, or monthly streamflow) and the functional dependence between different variables (e.g., net annual rainfall and basin water yield). Traditionally, a prescribed model (e.g., Lognormal probability density, or logarithmic regression, or a Linear Autoregressive model, or a Poisson process) is assumed to apply to the situation, and its parameters are estimated from the data using a criteria of best fit. While such an approach is often expedient, it tends to mask rather than expose the salient features of the data. Usually, there is no prior justification of the model selected; the "global" fit to the data is largely influenced by a few, extreme observations; a strong assumption that the behavior of the process follows the assumed form over its full range is made, leading to a largely misguided belief of its applicability outside the range of data; and it is difficult to choose between competing models using standard criteria.

Nonparametric function estimation has been a very active area in the statistical literature in the last decade. These methods work under weak assumptions as to the underlying structure (e.g., assume that the target function is twice differentiable), are "local" (only points in a neighborhood of the point of estimate contribute to the estimate), are robust with regard to model mis-specification, and to "outliers" in the data. Kernel estimators are conceptually the most general form of nonparametric estimator and are the easiest to understand. They are representable as moving weighted averages of the data, where the weight sequence and the span of the moving average is chosen under an optimality criterion appropriate for the function estimation situation. The utility, structure and motivation of kernel estimators is explored in a hydrologic context in this paper, with examples of applications to flood frequency estimation, lake volume forecasting, identification of climatic regimes, estimation of spatial surfaces of groundwater level, and daily rainfall modeling.

INFLUENCE OF RAINFALLS ON THE GEOMORPHOLOGICAL CRISIS OF MARCH APRIL 1973 IN BASILICATA (SOUTHERN ITALY).

Francesco Sdao & Vincenzo Simeone***

* Basilicata university, Potenza, Italy
** Politechnics of Bari, Italy

In the period March - April 1973 several landslides occurred in Basilicata (Southern Italy). Some were first time slides, others were partial or global remobilizations of previous landslides. Rainfalls occurred in that period have turned out not to be exceptional events, as shows by means of a statistical analysis. On the other side, a limited amount of landslides occurred in 1972, after rainfalls events with high recurrence times.

Some considerations on the meteorological aspects and the effective seepage of rainfalls can explain the above circumstances.

In this paper several remobilization phenomena of previous landslides occurred in 1973 are discussed, in connections with statistical evaluations of the rainfalls and some hydrological and phreatimetric data which allow to explain the different seepage characteristics of the rainfalls.

THE USE OF NON-PARAMETRIC PROBABILITY DISTRIBUTIONS IN STREAMFLOW MODELING

Ashish Sharma, David G Tarboton & Upmanu Lall

Utah State University, Logan, U.S.A.

This paper describes new approaches to stochastic simulation of streamflow based on non-parametric probability distributions. The probablity distributions of streamflow are often asymmetric or bimodal reflecting diverse physical causative processes. Serial correlation is sometimes state dependent. Despite these complexities and nonlinearities the conventional approach is to fit an appropriate marginal distribution and to transform the streamflows into a normally distributed variable space. The serial dependence between streamflow can then be reproduced by linear auto regressive moving average (ARMA) models. The normalizing transformation is capable of reproducing simple asymmetries, but is not capable of reproducing state dependent correlation or bimodality.

The present work is motivated by the need to generate synthetic sequences that reproduce the true multivariate dependence structure present in the data rather than focusing on moment matching in a transformed variable space. Variable bandwidth Kernel density estimates are used to develop a first order, state dependent, Markov streamflow simulation model. Kernel density estimates have the advantage that they are free of assumptions as to an appropriate distributional form and can reproduce many and mixed distributions. They are relatively robust and true to the data, letting the data speak for itself. The univariate kernel probability density estimate is defined as:

$$f(x)= \sum_{i=1}^{n} \frac{1}{nh} k\left(\frac{x-x_i}{h}\right) \qquad .....(1)$$

where K(.) is a kernel function centered at the observation x_i, and h (a scale parameter) is called its bandwidth. The kernel function is typically taken to be asymmetric density, with finite variance and vanishing higher moments. In general a kernel density estimate can be viewed as a smoothing of a histogram. The bandwidth h is allowed to vary with x_i, in a manner proportional to $\sqrt{f(x_i)}$. This reduces bias near the modes where the data is dense and reduces the variance in the tails where the data is sparse.

Hydrologic simulation and forecasting can be viewed as an exercise in conditional distributions. A first order model is then the following conditional distribution.

$$f(x_{t+1} \,1x_t) = \frac{f(x_{t+1}, x_t)}{f(x_t)} \qquad .....(2)$$

A generalization of equation (1) is used to estimate bivariat probability densities. Comparative results for conventional ARMA procedures and the proposed method are presented from applications to Colorado river streamflow.

DESIGN CRITERIA FOR THE IMPROVEMENT OF HYDROMETEOROLOGICAL DATA AQUISITION SYSTEMS. AUTOMATION OF SOME NETWORKS IN SICILY

G. Rossi, A. Ancarani ** & A. Jakomin ***

* Instituto di Idraulica, Idrologia e Gestione delle Acque, Universita di Catania, Italy

** Studio Associato G&A, Italy

The development of new technologies for collecting, transmitting, storaging and processing of hydrologic data has lead in the last decade to a modernization of the exisiting hyrometeorological networks in several countries. The replacement of manual gauging stations by automatic sensors combined with a line for automatic data transmission to a processing center requires an accurate design of the network lay-out and of the instruments and methods of observation. Moreover, a detailed prevision of the necessary changes in the organizational structure and of the related training of personnel has to be taken in account.

This paper presents a project for improvement and automation of the networks for hydrometeorological data acquisition developed within the Telematic Plan for the Sicily region in Southern Italy. Existing networks include about 230 precipitation gauges, 70 temperatures gauges and 55 streamflow stations operated by the Hydrographic Service since 1917.

Objectives of the project were:

- to make the acquisition and the first processing of data faster and more reliable;
- to set up the basis for new tasks to be developed in the next future such as the development of flood forecasting systems in main rivers, the systematic control of water quality in water courses and the development of a hydrologic support to an improved operation of water resources schemes.

The necessity of gradual changes in operation and the financial constraints imposed to restrict the number of stations to be automatized. The first step of the project was the selection of the meteorological stations and streamflow stations to be linked through the automatic transmission line: the existing stations, which were recognized as representative of a certain area or of the river characteristics while having long time serie, were chosen. Then the sites where new measurements of snow depth air humidity, wind movement, net radiation, and barometric pressure had to be done were identified, in order to improve the climate knowledge over the island.

The architecture of the system is presented. It includes 68 meteorological stations, 28 streamflow stations, 13 sea level stations, two central offices, and automatic transmission line by radio with 20 repeater equipments.

The main requisites for the measurement instruments of meteorological and hydrometric data are discussed. The characteristics of the hardware and software equipment needed for data transmission storage and processing in the center are also presented.

Guidances for the development of the systems and for the operation in the first years after their establishment in order to facilitate the success of the modernization of the service are outlined. The financial and economic evaluation of the investment was made through a benefit-cost analysis, which is presented in terms of cash-flow of costs and benefits during the 10-years considered period and of economic indices.

PRECIPITATION GAUGE DENSITY FOR A GANGA SUB-BASIN

Ramakar Jha & Rahul Jaiswal

Ganga Plains Regional Centre,
National Institute of Hydrology, Patna, India.

Precipitation is one of the basic data required for water resources studies. Estimation of the number and location of raingauge stations which will provide sufficient information regarding rainfall falling over the catchment is referred as network design. A network of rain gauges are intended to serve general as well as specific purposes such as water supply,

hydropower generation, flood forecasting, irrigation and flood control. During recent years, some network design studies have been carried out but inspite of its importance, studies for determining optimum density of hydrometic network in particular are not extensive in India.

In the present paper an attempt has been made to determine the precipation gauge density using Kagan's model to meet a specified error criteria under the assumption that the spatial variability of rainfall can be quantified through a spatial correlation function. The Punpun catchment (Area=8530 Sq.km.) which is an important right bank tributaries of the river Ganga was considered for the study. Seasonal (i.e. from June to September) rainfall data of 29 precipitation gauge stations located in the catchment for the period from 1974-86 were used to determine the cross-correlation of inter stations in Punpun catchment, the average distance and the average correlation for the stations falling within each interval, and then relative error. The result indicates that the relative error is decreasing as the number of raingauge stations are increasing, and the change in relative error are negligible after 25 stations. Therefore, the existing network may be utilised as input for rainfall-runoff models and other simulaton models.

OPERATIONAL HYDROLOGY ASPECTS OF DESERTIFICATION

Arie Ben-Zvi

Israel Hydrological Service, Jerusalem, Israel

Operational hydrology deals with the professional background required for preparation of predictions and forecasts. These are measurement networks design and operation; data collection, processing, storage, and dissemination; methods for preparation of predictions and forecasts, etc. These aspects are particularly important in dealing with desertification, which is a gradual transformation of an area from a semi-arid into an arid state. As the precipitation and flow values, for either state, are highly variable, distinction between them requires much data and delicate analysis.

Networks providing data on desertification ought to extend over both arid and arid prone areas. As operation of stations is difficult in these areas, the processing of data cannot reach, in many cases, the accuracy and completeness levels which are usually reached in more humid area. Therefore, detection and assessment of desertification process is a difficult task. Analysis of variables should not be restricted to volumes r depths of precipitation and runoff. Valuable conclusions about desertification can be derived from analyses of other variables, such as occurrence frequency of flow events, magnitudes of peak discharges (rise with aridity), coefficient of variation of volumes of events (rises with aridity), rate of abstractions along channels, sediment load, etc.

Owing to the deep economic and social consequences of desertification, detection and assessment of its process might often be requested before sufficient data for baisng reliable conclusions are available. under these circumstances, obtaining of dependable detections and assessments requires the talents of highly skilled professionals. Owing to the wide-range fluctuations in the hydrologic variables, successive assessments, prepared at different times, might reach dfferent, and in some cases even contradicting, results. the hydrologists, and other professionals, on the one hand, and the managers and politicians, on the other hand, should tolerate the fluctuations in the results, because the alternative approach requires deferment of the assessment, and consequently of any reasonable action, untill enough data are available. Deferment of actions untill a desertificaton process is clearly evident might result in too high loses for the society.

DEVELOPMENT OF A DATA ACQUISITION SYSTEM FOR HYDROLOGICAL MEASUREMENTS

V.C. Goyal & B.W.G. Block***

* National Institute of Hydrology, Roorkee, India

** Delft Hydraulics, Delft, The Netherlands

The need for collection of reliable hydro-meteorological data like precipitation, evaporation, temperature, humidity, wind speed and direction, sunshine hours, water-level and gauge/discharge, soil moisture etc. at predefined time intervals in any systematic hydrological study is obvious. These parameters are required for use in flood and weather forecasting, and efficient water management.

With conventional manual observations,there is often inadequate information, especially from remote areas, and where observers are not readily available. With the use of automated data-collection systems, most of the hydro-meteorological parameters can be measured reliably, and continually. Moreover, the automation of data collection systems may reduce or eliminate the human observational errors.

Recent advances in electronic technology have accelerated the development of data logging devices that are both compact and capable of monitoring many transducer channels. The cost of such modern systems is comparable to that of multi-channel devices of earlier decades but the reduced power requirements and flexibility brought about by software control of logging operations has led to a revolution in the way hydrologic data can be collected and stored, especially at field sites. These systems are highly reliable in both laboratory and field environments.

The paper reports development of an automated system for collection of hydro-meteorological data, which is especially useful for application in remote areas. The system described is developed for continuous measurement and recording of varied hyro-meteorological parameters through its 12 analogue, 2 pulse, and 8 digital I/O channels. The system uses commercially available components, namely data-logger, portable computer, and telemetry device. Presently, few sensors are interfaced with the system to monitor rainfall, soil sunction at different depths, soil temperature, and air temperature. The instrument is programmable using a series of application-specific instructions to perform measurement of sensor outputs, some mathematical computations, logical control, data storage, and data output to peripheral devices. The data retrieval is possible on a portable computer either by direct connection to the data-logger, or through telemetry. A solar panel is provided for charging of the batteries.

SENSORS AND SYSTEMS FOR MEASUREMENTS ON HYDROLOGY AND WATER RESOURCES

T.K. Sivadas

Central Institute of Fisheries Technology, Cochin, India

The success of the hydrological investigations depends on the data required directly from the relevant sites and the reliability of the measurement system, particularly the sensors which are exposed to the hostile environment and subjected to the operational constraints. Research methodologies and investigations are influenced by the nature and scope of the instruments made available from time to time. The author describes a series of sensors and measurement systems developed by him for acquisition of data on hydrology and water resources directly from the sites. The advantageous features of the instruments and particularly the sensors with remote operation facility through long cable enable to carry out several new investigations. Some of the hydrological and related parameters for which sensors and instruments have been developed with advantageous features are; water level of different ranges, water temperature, salinity, water turbidity, sedimentation, soil temperature, soil moisture, water current, bulk flow rate and discharge, relative humidity, air temperature, solar radiation, underwater radiation and water evaporation. The technology developed includes more than 2 dozens of sensors, instruments and data acquisition systems with fully indigenous technology. A set of noval field experiments are mentioned using the special features of the sensors to assess and estimate the mutual influence of various hyrometeorological parameters inview of their applications in agriculture, soil science, irrigation and water management.

RECENT DEVELOPMENTS IN ESTIMATION OF DESIGN DISCHARGE-THEIR APPLICATION IN INDIAN RAILWAYS

G.P. Garg, D.K. Saini & P.B. Sinha
Research Designs & Standards Organization, Lucknow, India

One of the most important parameter for design of any hydrological structure is the design discharge. With the Standard Bridge Sub-Structures and Foundations Code for the purpose of estimation of design discharge for bridge waterways, it became imperative to evolve rational methodology for estimation of design discharge of desired return period.

Indian Railways in co-ordination with Central Water Commission, Ministry of Surface Transport and India Meteorological deprtment has farmulated ratonal methodologies and the procedure for estimtion of design discharge. These methodologies are duly approved by Flood Estimation Planning and Co-ordination Committee (FEPCC) for their adoption by users. This paper describes the development of procedure for estimation of design discharge for ungauged medium catchments, (area ranging from 25 to 5000 Sq. Km) and small catchments (area less than 25 Sq. Km) in conformity with the codal provision for Indian Railways. These methodologies cover almost 90% of the total existing bridges as well as bridges proposed in future.

EEFECT OF VEDERNIKOV NUMBER ON OVERLAND FLOW DYNAMICS

Victor M. Ponce & Kelly T. Dillenberger
San Diego State University, San Diego, USA

The effect of the dynamic hydraulic diffusivity in kinematic-with-diffusion overland flow modeling has been tested. Unlike the kinematic hydraulic diffusivity, the dynamic hydraulic diffusivity is a function of the Vedernikov number. The results of numerical experiments showed a small lag in the rising limb when comparing two equilibrium rising hydrographs using kinematic and dynamic hydraulic diffusivities. The existence of the lag is attributed to the error of the solution that specifically excludes inertia. The error was quantified by integrating the absolute value of the difference between the two rising hydrographs, dividing this difference by the total runoff volume and expressing it as a percentage. The error is small and likely to be within 0.35 percent for a wide range of realistic flow conditions. Since the dynamic effect is shown to be small throughout a wide range of bottom slopes, a diffusion wave model with inertia may be all that is required to model the overland flow dynamics.

SENSITIVITY OF ENERGY AND MOISTURE BALANCE COMPONENTS TO SUBGRID SCALE PRECIPITATION VARIABILITY

Divya & J A Ramirez***
* National Institute of Hydrology, Roorkee, India
** Colorado State University, USA

The information on expected changes in hydrological cycle and its components due to future climatic changes is greatly needed for water resource development and management, the prerequisite for which is the knowledge of reliable future climatic change scenarios. In order to obtain reliable climate change scenarios from climatic models, land surface parameterization has to be realistically incorporated in the models including the subgrid scale heterogeneity in precipitation input and soil and vegetation parameters, as the interaction and feedbacks between land surface/biospheric and atomspheric processes play an important role in providing informations regarding climatic change scenarios. However, our present understanding of land surface-atmospheric interactions and the processes and fluxes that define these interactions is limited.

In order to develop increased understanding on land surface — atmosphere interactions, which is necessary to obtain reliable climate change scenarios, this paper aims at the study of surface energy and moisture balance components for Central India using biosphere Atmosphere Transfer Scheme (BATS) — a land surface parameterization scheme and its modified version, that allows for the simulation of spatially inhomogeneous conditions in precipitation input. The land surface parameterization scheme accounts for vegetative and soil control on evapotranspiration and runoff efficiencies and for effects of seasonally varying canopy cover.

The sensitivity analysis of energy and moisture balance components to subgrid scale variability in precipitation has been made. The results highlight the importance of accounting for the subgrid scale heterogenity and shows the large sensitivity of energy and moisture balance components to precipitation variability in space.

PALEOHYDROLOGY OF QUATERNARY RIVER SYSTEMS OF NORTH BIHAR PLAINS, INDIA

Rajiv Sinha

National Institute of Hydrology, Roorkee, India

The surface impressions on the satellite images, combined with field investigations and subsurfce data, have been used to infer the paleohydrologic conditions in parts of the world's largest tract of Quaternary sedimentation. The present-day set-up in the north Bihar plains, eastern India consists of fan and interfan rivers and it appears likely that their relative positions have kept changing, as evidenced from the borehole data. The paleochannel traces seen on the satellite images as well as in the field bear testimony to the paleohydrologic conditions of the region. From a sedimentologist's point of view, the fluvial deposits provide information about the morphology and hydraulic regime of the rivers that transported them. Variations in the grain size of the sediments may therefore be indicative of fluctuations of speed, and/or strength in the transporting flows. The present study attempts to draw important inferences about the channel pattern changes, channel belt migration trends, paleoflow conditions and depositional history of the Quaternary sediments in the north Bihar plains and to investigate if they are related to any environmental change in the Quaternary era. The study presented in this paper will be a significant contribution towards understanding the paleohydrologic system of the region and will be of use in water resources management.

TIDAL FLOW MEASUREMENT AND ANALYSIS IN THE RIVERS OF SOUTH WEST REGION OF BANGLADESH

M. Shahjahan, M. Fazlul Bari* & M. Jhangir Kabir***

* Bangladesh University of Engineering & Technology, Dhaka

** Water Resources Planning Organization, Dhaka, Bangladesh

Tidal flow and water level data are collected by several organizations. Among them Bangladesh Water Development Board (BWDB) collects both flow and water level whereas Bangladesh Inland and Water Transport Authority and the Port Authorities measure tidal water level data only. In addition to these routine measurement programmes, project specific measurements are also undertaken.

Measurement of flow in tidal channels poses problems additional to those encountered in unidirectional streams. Measurement and computation of discharges in non-tidal rivers are straightforward and methods and well-established in the country. The topic on tidal channels has not been presented in detail. The purpose of this paper is to feel this need. First, various methods of tidal flow measurement and computation are, critically examined including equipment used, data processing and storage, consistency checking, and errors in tidal flow measurement. Statistical analyses are performed to assess the uncertainties involved in measurement.

The rivers in the southern part of the country are influenced by tides from the Bay of Bengal. During last three decades many embankments have been constructed along the banks of rivers to control tidal inundation and saline water intrusion on agricultural lands. As a result of such confinement of rivers, tidal prism has been curtailed and spill areas have been reduced. Consequently, river beds as well as outfall channels of drainage sluices have been silted up over the years. So the second objective of this paper is to analyze tidal flow in this region by one-dimensional hydrodynamic model. Tidal events are simulated and the effects of man-made alterations on the flow regime are investigated by the numerical model. The results of analyses provide an insight of the tidal flow regime and the probable changes that might have occurred due to reduction in tidal volume as well as prism caused by various engineering works and development schemes in the region.

PREDICTING RUNOFF USING ARTIFICIAL NEURAL NETWORKS

Allen T. Hjelmfelt, Jr. & Menghua Wang

University of Missouri, Colombia, USA

Estimation of the runoff hydrograph due to a rainfall event is a fundamental problem in hydrology. Numerous linear and nonlinear methods have been proposed and are in use. In most cases calibration, or fitting, of the model is a problem. Each rainfall-runoff event, however,

gives a different set of fitting parameters, so it is necessary to estimate a best average. The complications arise due to noise in the data, effects of nonlinearity, and limited knowledge of the phenomena at hand. artificial neural networks may alleviate some of the problems because they provide a method which includes a fitting, or training scheme, as a fundamental part of the model. In this paper, a simple artificial neural network is shown to have the same structure as application of a unit hydrograph. The neural network was constructed as a computer program and applied to a small watershed located in central Missouri with satisfying results. Based upon these results, a more general network was constructed and trained to test the value of the nonlinear capability of neural networks.

An artificial neural network was constructed that has the same structure as application of a unit hydrograph. This network was trained using eight rainfall-runoff events simultaneously, and the trained network verified using sixteen events observed on a 12.2 km^2 watershed located in north central Missouri. The results were quite good.

One advantage of neural networks is their ability to learn nonlinear situations. A traditional three-layer, feed-forward artificial neural network was also constructed to test the nonlinear approach. Results were good, but a traditional unit hydrograph was not obtained.

STREAMFLOW ANALYSIS AND SYNTHESIS BY PATTERN RECOGNITION TECHNIQUES

U.S. Panu

Lakehead University, Ontario, Canada

Analysis and synthesis of streamflows is required for a variety of purposes, such as streamflow forecasting, reservoir operations and management, and general water resources planning and control. among other methods of streamflow analysis and synthesis, the pattern recognition based method is the focus of this presentation. A pattern, in general terms, is a shape representation of physical objects. In streamflows, objects can be conceived as groups of high or low flows. The pattern analysis includes collection of data on patterns and procedures used in inferring the deterministic and probabilistic structures that are present in data on patterns. The pattern synthesis generally involves procedures and techniques capable of utilizing the information obtained in pattern analysis phase to generate patterns likely to occur in the future.

In this paper, such procedures and techniques are utilized in analysis and synthesis of monthly streamflows of five rivers Northwest Ontario. The correlogram and periodogram analyses of monthly streamflows these rivers indicate the presence of two seasons, each comprising of six months. The segmentation of streamflows in a year into two types of objects is achieved by using the peak valley method. In other words, two types of streamflows objects, each corresponding to a season, are considered. Each streamflow objects (or pattern) is numerically represented in a vector format by using the streamflows values corresponding to the object. The vectors thus obtained are analyzed using pattern recognition techniques for obtaining the deterministic and stochastic structures defining the relationships (i.e., intra-pattern-structure) within the vectors of one type and the relationships (inter-pattern-structure) among various types of vectors. The deterministic and stochastic structure in this paper is obtained by using the pattern recognition system (PRS).

Sixty realizations, each of 30 years long, have been synthesized for each river. Separate statistical tests have been conducted to examine whether the synthesized streamflow patterns are embedded with same characteristics as observed in historical streamflow patterns. All such statistical tests indicate that synthesized streamflow patterns in each river are satisfactory for various hydrologic purposes.

Based on our results, it is concluded that pattern recognition based techniques provide an alternative to present philosophy of streamflow analysis and synthesis. It is noted that the pattern recognition based methodology inherently embeds the correlation structure, and streamflow data analysis and synthesis is conducted in groups of data rather than as single data values. Pattern based analysis and synthesis can easily be extended for analysis and synthesis of other hydrologic data, such as rainfall, sediment, water quality etc.

MODELING SURFACE RUNOFF WITH KINEMATIC, DIFFUSION, AND DYNAMIC WAVES

V.M. Ponce

San Diego State University, San Diego, California, USA

Surface runoff can be modeled deterministically with Kinematic, diffusion, or dynamic waves. Kinetic waves convect runoff, but do not diffuse it. Diffusion waves convect runoff under a small but perceptible amount of diffusion. Dynamic waves convect runoff and strongly diffuse it. Kinematic and dynamic waves are well established in hyrologic engineering research and practice. Diffusion wave, however, have only recently been accepted in practice, as shown by their inclusion in Version 4.0 of HEC-1: Flood Hydrograph Package (Hydrologic Engineering Center, 1990). Given the current emphasis on coputational modeling of surface runoff, a review of these three models is warranted at this time. This paper focuses on the following: (1) definition and properties of kinematic, diffusion, and dynamic waves, (2) role of numerical diffusion in kinematic wave modeling, (3) nature of kinematic shock, and (4) role of Vedernikov number in surface runoff modeling.

HYDROLOGIC SAFETY AND REHABILITATION OF OLD DAMS

Manju, P. Sharma & A. Prakash***

* Metropolitan Water Reclamation, District of Greater Chicago,Chicago, Illinois, USA

* Dames & Moore, Rolling Meadows, Illinois, USA

Several plausible options are presented to rehabilitate, downgrade, or remove an old earthen dam so as to meet current guidelines for hyrologic safety of dams. The dam served as a source of water supply for a local establishment. This establishment has to cease operations within two years and has no further use for the dam. The dam was designed for a flood lower than 0.4 PMF. Its removal or failure is likely to result in significant flood damages to a community located within 2.5 km downstream. Results of PMF routing with and without dam failure are presented to indicate the anticipated risks. Major criteria for comparative evaluation of rehabilitation/disposition options for the dam are described.

This paper describes potential rehabilitation options for an old earthen dam built in 1930 to provide water supply for an establishment which has to cease operations within two years or so. Since the construction of the dam 63 years ago, a pre-existing township in the river valley has expanded into a modern urban community approximately 2.5 km downstream from the dam.

MODELING THE EFFECTS OF CLIMATE CHANGE ON THE HYDROLOGIC RESPONSE OF MOUNTAIN WATERSHEDS

Alok K Sikka, Ashutosh S Limaye & J P Riley

Utah State University, Lagon, USA

Coarse resolution and simplified hydrologic parameterization in the general circulation models (GCMs) make the direct use of an on-line approach for hydrologic interpretation a risky proposition at the watershed scale. The off-line approach uses hydrometeorological data from GCMs output to drive watershed hydrologic models for determining the effects of climate change on hydrology. One of the important concern in hydrologic modeling of climate change is the effects of expected changes in vegetation on water yield. This issue raises the question as to how well existing water balance and watershed hydrologic models reflect climate-vegetation-evaportranspiration (ET) and hydrologic interactions.

Most of the watershed models compute potential evapotranspiration (PET) and then scale it to actual evapotranspiration (AET) using some kind of crop coefficient or transpiration coefficient. Such coefficients cannot be used to simulate the effects of vegetation changes on ET because these are not defined as the function of vegetation parameters such as leaf area index, and stomatal resistance which might change due to enhanced level of carbon di-oxide in the atmosphere.

The paper presents application of a distributed parameter modeling approach to better reflect the effects of climate and vegetation changes on the hydrologic response of a watershed. A distributed parameter watershed evapotranspiration model for natural vegetated mountain watershed with explicit representation of vegetation is used. Leaf area index (LAI) is used as a measure of forest

structure to quantify energy and mass exchange. The concept of hydrologic response unit (HRU) is used to partition the watershed into distributed units. Results of sensitivity analysis by assuming changes in climate and plant variables over credible ranges of change based on the GCMs output and current literature are discussed in the paper for watersheds in Utah.

WARNING OF APPLICATION OF THE CHEZY-MANNING FORMULA REGARDLESS OF CHANNEL SHAPE

Witold G. Strupczewski

Polish Academy of Sciences, Warsaw, Poland

The way of the Chezy formula derivation implies a straight uniform channel with an identical velocity distribution along cross-section, i.e. a wide uniform rectangular channel with uniform lining. However to apply it for natural river channels this restriction are relaxed. The reasons for that is the lack of alternative for stage-discharge rating curve derivation applicable for any channel shape in case of small number of flow discharge measurements and an encouragement from authors of hydrologic books stating lack of definite evidence about the shape of a channel as an important factor affecting the value of n Manning coefficient. However the influence of shape may be overshadow by other factors usually existing in natural channels like irregularities along their length, nonuniform lining,...

From human knowledge got during the ages of irrigation practice comes that for steady state in a channel with uniform lining and without flow obstruction:

(1) any increase of water level is related with increase of flow discharge;

(2) an increase of channel width above any level causes an increase in flow capacity for any other level above it.

The author working with the Manning formula on deep, narrow channels of Liberian (West Africa) rivers with few measurements below a mean level only has found that neither of two axioms was fulfilled by the formula with constant slope-friction factor in case of encountered irregular cross-section shapes. In fact it may have been anticipated since a violation of the first axiom is widely known in case of the direct use of the Manning formula for a compound channel and it is width/depth ratio which controls this paradox, i.e. it is more likely in a deep and narrow channel than in a wide compound one. Artificially division into subsections gives results conformable with both axioms but not necessary closer to the true values.

The scope of the paper is a mathematical analysis of the Chezy formula for steady flow in an uniform symmetric channel with constant slope-friction factor focused on investigation of both paradoxes. A channel is assumed to be filled up to a certain level called an initial level and the analysis is made above this level with corresponding initial shape defined by flow area, wetted perimeter and width of water surface. Dependence of the paradoxes upon the geometrical parameters of an initial shape is demonstrated. The problem of determination of the channel shape above initial level for given rating curve of stage-flow discharge or flow area-flow discharge, i.e. an inverse solution of the Chezy formula, is posed and then solved for selected forms of rating curves and of initial shapes. It is shown that there is a double solution in both cases. Obviously the double solution in the case of the stage-discharge rating curve is not conformable with reality.

The paper is addressed as a warning of unlimited in channel shape use of the Chezy formula and it may explain one of the reasons of difficulties faced in an interpretation of the roughness coefficient n - gauge height relationship in natural river channels.

INVESTIGATION OF POTENTIAL FLASH FLOODS FOR UNGAUGED REGION USING THE KRIGING METHOD

Tiao J. Chang & Hongyong Sun

Ohio University, Athens, USA

The 1990 Shadyside flash flood in Ohio raised the question of flood protection in an ungaged small watershed, especially those areas that do not have flood protective structures. For a small rural community situated on a flood plain, it is not economically justified

for any flood protective structure. Therefore, they are extremely vulnerable to a flash flood. A community warning system by the use of existing precipitation gage stations could be an alternative. This paper investigated the regional distribution of potential flash floods based on several existing precipitation gages in the studied area. Truncation levels of 80%, 90%, 95%, 99%, and 99.9% were used to define flash floods, where a 90% flash flood means that 90% of daily precipitation are larger than or equal to the truncated value. The higher the truncation level, the more severe the potential flash flood. Daily precipitation records from twenty-one gages in the Scioto River Basin were selected for the study. The kriging method based on the minimum unbiased estimation was used to compute spatial interpolation for the ungaged area. These estimations will form the regional distribution of flash floods at various truncation levels. Contour lines of potential flash floods at each truncation level were constructed and associated errors were estimated. The result shows that estimation errors associated with constructed contour lines were reasonably small.

MODELLING EVAPOTRANSPIRATION OF DUNE VEGETATION

P.J.M de Laat

IHE, Delft, The Netherlands

Dune areas in The Netherlands have been used since the middle of the last century for the extraction of groundwater to supply the densely populated Western part of the country with drinking water. The importance of the dunes for the water supply has stimulated hydrogeo logical research in the dune area from the very onset of the extractions. However, an important component of the water balance, the areal evapotranspiration, remains difficult to assess.

The method for the estimation of evapotranspiration is based on the equation of Penman as adapted by Monteith (1965) and Rijtema (1965) for cropped surfaces. In the past this method has been successfully applied to many agricultural crops for which the crop dependent parameters were calibrated. In this study the relation between the leaf water pressure and the canopy resistance for dune vegetation is established. Other parameters that have been determined include the albedo, the plant resistance for liquid flow and the interception reservoir capacity.

The simulations are carried out with the Model for Unsaturated flow above a Shallow water table, MUST. This model simulates vertical transport of water in the unsaturated part of the soil by a succession of steady flow situations. MUST includes modules for the simulation of actual evapotranspiration and drainage. The model is verified for various field situations.

In the dune area four lysimeters were installed in the early nineteen forties. Each lysimeter has a depth of 2.25 m and a surface area of 25x25 m^2. One lysimeter is bare, two are covered with coniferous and deciduous forest respectively, and one with dune vegetation. The outflow from the drainage system at the bottom of each lysimeter was measured weekly. The meteorological data of a nearby station and the outflow data of the lysimeters with dune vegetation and bare soil were used for this study. The data cover a period of 5 years (1984-1988).

The bare soil lysimeter was used to calibrate the drainage resistance and to verify the soil physical parameters. The simulated outflow compared excellently with measured drainage from the lysimeter. The total actual evapotranspiration as obtained from the water balance for the lysimeter with dune vegetation was very well simulated by the model. Simulated and observed outflow compared favourably, although the simulated outflow tends to arrive too early at the outlet. This phenomenon can be explained as resulting from the solution method.

SPATIAL ESTIMATION TECHNIQUES FOR PRECIPITATION ANALYSIS - APPLICATION TO A REGION IN INDIA

Balaji Rajagopalan, Ashutosh S. Limaye & Alok K. Sikka

Utah State University, Logan, USA

Spatial estimation of precipitation over a region from point observations is a vital input for modelling the hydrologic and ecologic processes. This task becomes more challenging with the data sampled at sparse number of points in heterogenous regions. With the

advancement of remote sensing and geographic information systems (GIS), application of distributed parameter hydrologic and ecologic models are gaining importance. Spatially distributed estimates of precipitation are crucial for driving such hydrologic and ecologic models.

Simple spatial techniques such as Thiessen polygons, polynomial trend surfaces, and inverse distance methods for precipitation data are commonly used. The weights assigned to each supporting data point in these methods are necessarily not optimal. In view of this, robust, powerful and optimal techniques are needed for spatial estimation of precipitation.

Kriging, a parametric regression procedure is widely used for spatial estimation problems. The estimates suffer from second order stationarity assumptions and subjective way of fitting the variogram. This is often unrealized in common practice. Nonparametric techniques such as Splines, LOWESS (Locally Weighted Regression), and Kernel regressions are capable of addressing the above problems. These techniques do not assume second order stationarity of the underlying function and are objective in nature.

In this paper, precipitation data from a region in India is analyzed using the above mentioned techniques. The estimation capabilities of these techniques are compared and discussed.

EXPERIENCE WITH SNOW PILLOW

Virender Kumar, M.B. Ganeshan & Bir Singh Negi

Snow & Avalanche Study Establishment, Manali, H.P., India

Snow and Avalanche Study Establishment is working on development of automatic weather stations for acquisition of snow and meteorological data from inaccessible Avalanche formation zones. Precipitation, temperature and wind are main parameters for avalanche forecasting and snow-melt runoff computations. Various types of sensors have been used to evaluate their performance in Himalayan conditions. Nucleonic snow gauge, heated tipping bucket rain gauge, weighing precipitation gauge and snow pillows are used for precipitation measurement. Nucleonic snow gauge and snow pillow are best suited for unattended measurement. Our observation on performance of nucleonic snow gauge are reported elsewhere (1). US soil conservation service after extensive evaluation (2) preferred snow pillows over nucleonic snow gauge. Snow pillow have been reported to have problems of diurnal variation, delayed response and bridging. The study is aimed to evaluate performance of snow pillows, and to assess magnitude of error due to the above problems and to ascertain their cause and possible remedies.

The paper presents the result of performance evaluation of snow pillow. Snow pillow measures water equivalent of snow cover and monitors its build up during snow storm with an accuracy of +10% of manual measurement. During snow storm snow pillow under measures by about 15% but continues to show increase in output for about 6-12 hours after ceasation of snow fall. In early spring, when snow cover under goes melt-freeze cycle, snow pillow under measures in the morning hours but returns to normal by 1200 Hrs. Diurnal variations are also observed. Possible causes are analysed but no definite conclusion could be made. Amount of undermeasure due to delayed response is proportional to water equivalent of snow cover before snow storm and amount of precipitation during the storm. Snow pillow is judged best among available precipitation sensors for unattended measurement.

MODEL STUDY RESULTS ON FLOOD CONTROL ASPECTS OF BRAHMANI RIVER SYSTEM — AN ANALYSIS

L.K. Mirsa & B. Mahakul

Univ. College of Engineering, Burla, Orissa, India

River Brahmani, the second largest river of Orissa, contributed large floods in the districts of Dhenkanal and deltaic tracts of 2211 Sq. Km in Cuttack almost every year before it was dammed at Rengali. For the primary purpose of flood control Rengali Dam Project was planned. It is functioning since five years. After the functioning of Rengali Dam Project the river flow pattern is expected to change in its regime in the down stream. Before the construction of the Rengali Dam, the maximum observed flood was of the order of 25000 cumec at Jenapur, the delta head of this river. The dam

will moderate the flood to 11,320 cumec. Even after the moderation of this flood, the regime pattern of this river will be changed and new areas may be proned to flood. So mainly to observe this change in behaviour of the river flow in delta area of this river system, a model study of the river system was included in the master plan for flood control. In the delta of this river Brahmani, the contribution of Mahanadi system by the branch river Birupa, a quantity of 792 cumec is being added. Also Baitarani river system contribute to Brahmani delta about 3428 cumec through the river Burha. Brahmani itself branches as Kharsuan river which ordinarily carries 49.5 percent discharge. There are mainly four escapes from the Kharsuan river which do not find access to the sea.

So it is of utmost importance to see the water levels and discharges in various branches of Brahmani, considering the tidal and storm effects and in conjunction with closure or otherwise of some or all escapes. Also it is required to see the safe spacing of embankments that are generally a part of the flood control measure in this delta, to the right of the branch rivers. With these objectives in view the physical model study of the river system in the delta has been taken up at SNERI Laboratory at Burla for the non-tidal portion of the river. The results have been analysed and it has also been seen that they tallied well with those obtained by Electronic analogue test results taken up by Calcutta Port Trust Hydraulic Laboratory.

APPLICATION OF LINEAR SYSTEM MODELS FOR WASH LOAD ESTIMATION

N.S. Raghuwanshi, R.A. Rastogi** & Santosh Kumar****

* Univ. of California, Davis, California, USA

** G.B. Pant Univ. of Ag. & Tech., Pantnagar, UP, India

*** Department of Agriculture, Morena M.P. India

The surface runoff - sediment yield process is generally recognised as a non-linear, time - variant process, and is governed by large number of unknown climatic and physiographic factors which may vary both in time and space. In describing the sediment response of a watershed, the use of linear system model has spurred criticism. It is only recently that the application of linear system theory for prediction of sediment yield (wash load) has recognised as one of the tools for solving certain non - linear problems. A few conceptual linear models have been used by some researchers in oder to develop sediment graphs for gauged and ungauged watersheds. However, these studies require further testing and extension of application of linear system theory in sedimentation engineering both with regard to their underlying assumptions and their accuracy in prediction of wash load. On the other hand, most of the sediment yield prediction models predict only average annual sediment yield. These models consider watershed characteristics, land use pattern, soil characteristics, conservation practices, but do not consider individual storm characteristics, which is primarily responsible for wash load production from a watershed. Therefore, a method of predicting sediment yield (wash load) based on individual storm can be more accurate than annual prediction procedure.

Keeping in view, the above problems and limitations in the use of linear system models for prediction of wash load from catchment, an attempt has been made to demonstrate the applicability of linear models (unit sediment graph and series graph) for prediction of wash load from Chaukhutia catchment of Ramganga reservoir. The sediment graphs generated by unit sediment graph method and series graph method in all cases resulted in better agreement with the measured sediment graph. The measured and predicted peak sediment flow rates were also correlated with the sediment mobilised. The result of study reported herein can be served as guidelines for furthering use of linear system model for prediction of wash load.

EFFECT OF CROSS-SECTIONAL SHAPE ON FREE-SURFACE INSTABILITY

Victor M. Ponce & Pedro J. Porras

San Diego State University, San Diego, California, USA

The effect of cross sectional shape on free-surface hydrodynamic instability has been analyzed. The characterizing parameter is the dimensionless relative kinematic wave celerity $C_{drk} = \beta - 1$, in which β is the exponent of the normal discharge-flow area rating. Two generic types of cross-sectional shapes are identified: (1) those of constant C_{drk}, and (2) those of variable C_{drk}. Three cross-sectional shapes of constant C_{drk} are: (1)

hydraulically wide, with $C_{drkM} = 2/3$, (2) triangular, with $C_{drkM} = 1/3$, and (3) inherently stable, with $C_{drk} = 0$ (Manning or Chezy). (The subscript M refers to Manning friction). Cross-sectional shapes of variable C_{drk} include trapezoidal, rectangular, and circular shapes. Two asymptotic cross-sectional shapes are identified: (1) hydraulically wide, and (2) hydraulically narrow. These theoretical cross-sections set limits to the range of variation of C_{drk} for trapezoidal and rectangular shapes. The hydraulically wide channel sets the upper limits, with $C_{drkM} — 2.3$; the hydraulically narrow channel sets the lower limit, with $C_{drk} — 0$. Two types of stable channels are identified: (1) inherently stable, and (2) stable. An inherently stable cross section is such that the Vedernikov number V is identically zero for all Froude numbers. A stable cross section is such that $V \leq 1$ for Froude numbers in the range $F \leq F_{ns,}$ in which F_{ns} is a design neutral-stability Froude number. A stable cross-sectional shape is designed by setting C_{drk} and the related cross-sectional parameter δ to match a certain choice of $F_{ns.}$ The resulting stable cross-sectional shape is much narrower than the comparable inherently stable shape.

DAM BREAK MODEL, AN IMPORTANT TOOL IN HYDROLOGY - REFERENCE TO DAMBRK PROGRAMME OF NATIONAL WEATHER SERVICE, USA

B.P. Roy & J.N. Nanda***

* National Institute of Hydrology, Roorkee, U.P., India

** Planning Commission, New Delhi, India

Protection of the public from the consequences of dam failures has taken on increasing importance as population have concentrated in areas vulnerable to dam break disasters. This has created general interest in the dam safety analysis in recent years. The organisations which are responsible for the safety of dams should plan for preventive measures so that in the eventuality of dam failures the disaster will not struck the lives of the population living downstream.

Planning and design requirements for a wide range of projects, such as emergency preparedness and location of nuclear power plants, have generated widespread interest in dam break floods analysis.

IS - 11223 - 1985 : Guidelines for Fixing Spillway Capacity, has recommended dam break studies as aid to visualise potential flood hazard downstream of dam and to plan appropriate flood plain zoning and disaster mitigation measures. This calls for adopting routine procedure for dambreak studies.

In this paper, the application of DAMBRK Programme has been narrated. DAMBRK is a dynamic flood routing programme. It has the capability of simulating a total of 12 different cases corresponding to a combination of various reservoir routing techniques and channel flood routing techniques in the presence of a single or multiple dams in river reaches. Some of these options take into consideration the routing of dam break flood wave through the downstream structures, like major bridges, with special internal boundary conditions. These are helpful in hydrological studies for flood hydrograph using multi basin concept, reservoir operation, flood level, flood warning time and navigation etc.

USE OF DIGITAL ELEVATION MODEL IN RUNOFF MODELLING

P.K. Garg

University of Roorkee, Roorkee, India

Both rainfall and runoff detach and transport the soil particles from the ground surface, and provide the basic energy input to derive the erosion processes in the catchment. Runoff from a catchment is influenced by three major factors i.e. climate, geomorphology and physiography; the dominant factors being the geomorphology and climatic region in which the catchment is situated.

In semi-arid environments, runoff is difficult to observe and measure where flow is ephemeral, rainfall events are irregular and unpredictable, and the terrain is very rough. However, such areas with restricted vegetation cover and thin soils on hillslope, generate an enormous quantity of runoff. Under semi-arid conditions, Hortonian concept can be used for runoff modelling, which requires data on storm intensity and duration, infiltration and topography. Runoff is also a function of slope length, steepness and shape, all of which modify the energy of the hydrologic inputs. To route the flow to

the bottom of the catchment, slope of the ground is required to be known.

In this study, the Digital Elevation Model (DEM) has been used extensively for the assessment of runoff within a catchment and at the outlet of the catchment. The study area covers a small catchment (20 km^2) in semi-arid region of south-east Spain. The DEM was generated from the topographic maps to compute slope and catchment area which were subsequently used to generate the flow direction, network flow pattern, and drainage network in the catchment. These information alongwith the infiltration and rainfall data were used for runoff modelling, employing Hortorian type relationship.

The results have been computed on storm events basis, which could be used further for the assessment of erosion and sediment yield in a catchment. Thus the study demonstrates the utility of DEM alongwith other field data for the assessment of runoff in a semi-arid catchment.

SNOWMELT RUNOFF ESTIMATION FROM GORIGANGA CATCHMENT USING SRM MODEL

B.P. Parida & A.K. Dash***

* Indian Institute of Technology, New Delhi, India

** National Hydropower Corporation, New Delhi, India

In attempts to augment India's power generation potential, the Central Electricity Authority, India, has identified the middle Himalayan region together with North-East and North-Western part of the country for implementation of new hydro-power generation projects. But, general feature of middle Himalayan region is that, major portion of the catchments located in this region are above 4200 m elevation and permanently snow covered and areas falling below the elevation of 4200 m experience seasonal variation of snow cover. As a result of this, during periods of hot weather and rainfall, large quantities of additional flows take place in the mountainous streams. Therefore, proper planning and design of hydraulic structures across such streams would need reliable estimation of snow melt runoff.

From amongst several available models in literature, an attempt has been made to use a simple concept such that reliable flow estimation together with easy implementation of the model can be achieved. The SRM model of NASA, USA is one such model and is primarily based on use of degree-day index concept.

The model has been used for snow melt runoff estimation from a middle Himalayan catchment namely the Goriganga catchment which originates from Milam glacier at an elevation 3600 m. Snow depletion rate estimation which is heart of the problem has been carried out using 1987 snow cover data from ITBP organisation and imageries from LANDSAT-I. This along with other data such as stream flow, rainfall, maximum and minimum air temperature has been used to calibrate the model parameters, which in turn have been used to estimate snowmelt runoff values for the year 1988.

A comparison of observed and simulated flows in general showed a good agreement, with Nash-Sutcliffe goodness of fit index at 0.76. Based on the results, the model can be implemented for other snow-bound catchments too for reliable snowmelt runoff estimation. However, as the SRM model is very sensitive to lapse rate and degree-day factor, these should be determined carefully. Even the snow cover depletion curves used in the model be established based on large number of satellite imageries for improvement of result.

ESTIMATION OF HYDROLOGICAL SOIL PROPERTIES FOR DESIGN OF DRAINAGE SYSTEM IN BULANDSHAHAR AREA, U.P.

M K Shukla, B Soni & S L Srivastava

National Institute of Hydrology, Roorkee, U.P., India

High irrigation intensities or excess precipitation may cause drainage congestion on the surface of the soil or in the root zone of crops. If the top soil of such area is less permeable than the situation becomes alarmingly worse. Such a situation is found in the Bulandshahar district situated in the western part of Uttar Pradesh. The gross area of Bulandshahar district is 4568 sq. km. It has been reported that the area is suffering from waterlogging problem and drainage congestion. This study deals with the estimation of hyrological soil parameters needed for design of drainage system.

The eastern part of the Bulandshahar was selected as pilot area. The soil samples were collected from different locations and were analysed for textural classification. It was observed that the soil of the area is mostly sandy loam with sand content varying from 35 to 60%, silt content from 30 to 55% and clay content from 5 to 25%. The in situ measurement of saturated hydraulic conductivity was also carried out by Guelph Permeameter at different locations. It was observed that saturated hydraulic conductivity varies from place to place. It was found that saturated hydraulic conductivity values at few locations were quite low as compared to saturated hydraulic conductivity of sandy loam soil. This was mainly due to the presence of carbonate in the soil layers. The carbonate was removed from the sample using HCL and percentage of carbonate present in the soil sample was worked out.

The groundwater table data of the area was also analysed and it was found that in general the watertable of the area was fairly deep and as such there was no problem of high watertable. Although at some places adjacent to canal system watertable was present within the root zone depth.

Thus in general from the study it could be ascertained that the Bulandshahar area is suffering from the problem of surface drainage. This is mainly because of the presence of carbonate in the soil which reduces the hydraulic conductivity of the soil. Thus the excess precipitation and/or irrigation results in the stagnation of water causing damage to the crops of the area. Suitable Surface drainage system must be designed, and provided in the area so that crop yield losses can be minimised.

HYDROLOGICAL FORECASTING

A.W. Jayawardena

University of Hong Kong, Hong Kong

Forecasting plays an important role in the prevention and mitigation of natural disasters. It has become particularly important in this decade in view of the fact that the United Nations General Assembly has declared the 1990's as the International Decade For Natural Disaster Reduction (IDNDR). Water related disasters such as floods and droughts have resulted in the loss of many thousands of lives, caused immense economic damage and brought misery to millions of people all over the world. The scale of such disasters could be reduced substantially if advance warning of impending disasters is available. Hydrological forecasting aims at making such advance warning realizable.

The objective of this paper is to present an overview of the recent developments in hydrological forecasting. Various approaches to the problem will be critically reviewed but emphasis will be on the stochastic approach in which continuous forecasting can be made.

In the stochastic approach, the hydrological information is viewed simply as data series with no consideration for the processes that generate the data. The time series of data is analysed for uncovering possible patterns of behaviour which can then be used for making forecasts for the future. In the deterministic approach, the physical processes that generate the hydrological information is considered and a constitutive relationship between various input and output components of the processes is established. This relationship is then quantified mathematically and solved numerically under a given set of input functions and a known set of process parameters.

The developments in the 'time series' type forecasting include the simplest 'mean model', traditional ARMA models, Transfer Function models, ARMA-Transfer Function models and their variations. Techniques such as Kalman Filtering have been used to address problems arising from measurement and model uncertainties. More recently, the theory of non-linear dynamic systems associated with the concept of strange attractors for the description of deterministic chaos has drawn the attention of a number of researchers in the area of weather and climatic data time series analysis. In this approach, the time series is viewed as a dynamic system with a low dimensional attractor which can be re-constructed using the time delay embedding method. Certain parameters calculated from the series are used to diagnose whether the series is chaotic or not. Although long term predictability for chaotic systems is not guaranteed, short term forecasts are still feasible.

In non-linear modelling, several approaches could be adopted. The global approximation technique in which

the least squares fitting of polynomials is used leads to insurmountable computational difficulties for higher order polynomials. A local approximation technique which uses only nearby states to make predictions offers a promising alternative. Attempts will be made to illustrate the application of this technique to rainfall and streamflow forecasts.

Other recent techniques that have been used include the application of artificial neural network theory where the learning process plays a role for estimating the optimal parameters of the system and the use of parallel processes in hydrological systems. Their developments will also be followed in the paper. Some thoughts about the future directions in hydrological forecasting and the key problems that have to be addressed in order to make more accurate forecasts are also highlighted.

DAILY FLOW FORECASTING FOR NEGARA RIVER BASIN, INDONESIA

R.D. Singh, Ranveer Singh**, & Permana Hendrawangsa***

* National Institute of Hydrology, Roorkee, U.P. India

** University of Roorkee, Roorkee, U.P. India.

An accurate forecasting of flow is one of the most complex problems being faced by the water resources engineers and hydrologists. Mathematical modelling of hydrological processes has been attempted by many investigators for issuing the flow forecast considering the different time intervals. However, due to the difficulties being faced in giving a generally correct account of the physical process through the mathematical models because of scarcity of data and lack of good computational facilities, the scope of the application of mathematical models for flow forecasting is somewhat limited.

In this paper a simple rainfall — runoff model for daily flow forecasting is described. The model considers a general linear relationship between the perturbations of the daily rainfall and runoff from their seasonal daily means with a specified memory length. The seasonal values of the daily rainfall and runoff are obtained by averaging their respective values for each date over the years during the calibration period. The model is applied for forecasting the daily flows at Amuntai gauging site on river Negara in Indonesia. The daily rainfall — runoff data from the year 1978 to 1984 for the Amuntai sub-basin are utilised for the study. The model is calibrated from the records of the daily rainfall-runoff for the years 1978 to 1981 using the least square approach. Subsequently, the residual errors are analysed to identify the persistence structure for one day lead period which is used for updating the daily flow forecast. In order to judge the performance of the model during validation period i.e. from the year 1982 to 1984, the model variance and model efficiency are computed using the calibrated model. It is observed from the study that the model has performed very well for fitting the daily flows in calibration as well as in validation phase. It indicates that the models of this kind might be useful particularly for large catchments exhibiting marked seasonal behaviour.

DIRECT RUNOFF PREDICTION FROM RURAL CATCHMENTS IN KENYA, EAST AFRICA

J.O. Onyando & T.C. Sharma***

* Egerton University, Njoro, Kenya

** University of Nairobi, Nairobi, Kenya.

The important elements of direct runoff viz. storm runoff volume and peak rates of runoff were studied. The study was carried out in small catchments in the headwaters of lake Victoria drainage basin in Kenya, East Africa. The catchments namely Sambret (7.02 km^2) and Lagan (5.44 km^2) were selected for model calibration and testing on the basis of availability of hydrometeorological data. Both catchments were under the former East African Agricultural and Forestry Research Organisation(EAAFRO) which conducted research on water balance of these catchments and a data base from 1957 to 1980 exists. The major land use of Sambret catchment is tea crop beautifully laid on terraces. Lagan is an adjoining catchment still under virgin forest. From Sambret catchment, 41 rainfall-runoff events were acquired, out of these, 25 were used for model calibration while 16 events were used for testing the suitability of the models. Further test was carried out in the neighboring Lagan catchment using 18 events.

Storm runoff volumes were estimated by antecedent precipitation index (API) model (Fedora and Beschta, 1989) which gave satisfactory results. However, the model performed better in Sambret than in Lagan and

this was attributed to the fact that the model was calibrated in the former one. Its success in Lagan indicates the possibility of transposing it in different catchments with similar soils and hydrologic conditions. The parameters of the model were determined from multiple linear regression and hence its application depends on the availability of some data base for model calibration.

The direct runoff hydrographs were generated by Nash gamma function and kinematic wave models. The parameters of Nash model namely the number of linear reservoirs in cascade (n) and the storage constant (k) were determined by the method of moments (Sambret) and geographic relationships (Lagan). The values of n and k were found as 5 and 1.66 h for Sambret and 3 and 1.7 h for Lagan. Direct runoff hydrographs were generated by the analytical solution of the convolution integral. This analytical solution was performed by employing the theorem of integration by parts. Times to peak and peak runoff rates were adequately predicted by the model in both Sambret and Lagan catchments. The base times were also adequately estimated.

Kinematic wave routing equation was based on a linear numerical algorithm and as a distributed flow model, routing was accomplished through a space time grid of intervals denoted by Δx and Δt. These parameters were found as 500 m and 480 s through optimisation. The Manning's roughness coefficient for overland flow was optimized as 0.1 and for channel flow as 0.04. The optimized values fall within the range of values tabulated in hydrologic literature. The model satisfactorily predicted the peak runoff rates and duration of flow in Sambret catchment. In Lagan catchment, the model adequately estimated the time to peak while the peak discharge was under predicted. The poor performance of the model in Lagan was attributed to the high drainage density which implied higher percentage of channel flow whereas a high level of soil conservation measures minimised channel flow in Sambret and encouraged sheet flow with low overland flow velocity.

On comparison of the results by visual and statistical indices, Nash model performed consistently better than kinematic wave. It therefore has a higher potential for use in both gauged and ungauged catchments for generating direct runoff hydrographs in Kenyan catchments than the kinematic wave model.

HYDROLOGIC DESIGN OF CROSS DRAINAGE WORKS OF KANDI CANAL

Ram Chand, R B Lal & Sanjeev Suri

Kandi Area Development Project, Chandigarh, India

For providing irrigation facilities to the sub-mountainous Kandi area in Punjab-India, rockfill/earthfill dams are being constructed in the upper reaches and beyond the command of these dams; a canal called Kandi Canal is being constructed. In a length of 59.5 km of the canal, 96 rivulets (hill torrents) cross the canal for which cross drainage works are being provided.

The design flood discharge for rivulets has been worked out empirically using Rational Formula (Q=CIA) and Dicken's formula ($Q=CM^{3/4}$) (for catchments area more than 4.0 Sq. Km). the discharge works out corresponding to 50 years flood inflow peak comparable with inflow studies of various Kandi watersheds by unit hydrograph method. The unit hydrograph method can not be adopted due to non-availability of rainfall data in all the crossing sites.

Further, to keep minimum head loss in the canal, canal syphoning has been avoided and aqueduct with fall type works have been preferred even by raising the canal bed locally by providing hump as per model studies. Syphon aqueduct type of works have not been adopted keeping in view the possibility of their choking up by debris/ silt. Open cut drains on the down stream of the crossing have been provided so as to join the NSL/choe bed in a suitable length so as to avoid syphoning of aqueducts. For energy dissipation, cisterns have been replaced by the provision of baffle piers and staggered blocks as per model studies and this system is functioning satisfactorily in the field for the last 5-6 years.

The above approach of design is discussed in detail in this paper.

FLOOD PREDICTION BY USE OF PARTIAL DURATION SERIES

Arie Ben-Zvi

Israel Hyrological Service, Jerusalem, Israel

Flood prediction is an assignment of recurrence intervals to magnitudes of floods which might occur. The assign-

ment for a gauged site is made through probability distribution function which is fitted to magnitudes of recorded events. As the interest is concentrated on floods, which are extremely high flow events, it is preferred to select, for the fit, magnitudes of high events only. Two methods are practiced for this selection, one is of the maximal value recorded during every hydrological year, and the other is of all the values which exceeded a pre-selected threshold value. Series obtained by the second method are called partial duration series.

Predictions made by use of partial duration series apply the mean number of events per year for transforming exceedance probabilities in the series into recurrence intervals. The temporal distribution of occurrence of high events is almost always assumed as following the Poisson distribution. Yet, the negative binomial distribution is found, in some cases, as fitting the observed frequency better than the Poisson distribution does.

The distribution of magnitudes is assumed, in most uses of partial duration series, as following the negative exponential distribution. Other distributions, found in the literature, are the Lognormal, Log-Pearson 3, and Generalized Pareto ones. The criteria for selection of a distribution are the goodness-of-fit to recorded data, regional consistency, and mathematical convenience in coupling with the Poisson distribution. Recently, an additional criterion about the thickness of upper tail of the data, is being considered. This is reasoned by the need for prediction of values which are considerably higher than the recorded ones. Application of a distribution which follows the trend observed for the upper tail of recorded data seems more credible than that of other distributions.

A partial duration series is determined with respect to a given threshold value. The higher the value, the lower is the correlation between the series' members, the fewer are the data to which the probability distributions are fitted, and the heavier is the weight, in the fit, of the higher events. Selection of threshold value is made with respect to one of the following criteria a relationship between the size of associated series and the number of years on record, physical properties of the site and its neighborhood, or regionally consistent consideration of statistical properties of the series. A recent suggestion is of best fit of the selected distribution to magnitudes in the associated partial duration series.

Having selected the threshold value and fitted the probability distributions to occurrences and magnitudes in the associated series (i.e. obtained the most suitable values for the parameters of selected distributions) one can estimate the time intervals between occurrences exceeding given magnitudes, and magnitudes of events to which given recurrence intervals are assigned. Most of these estimates are made for the peak discharge of the flood, which is the maximal momentary discharge during the occurrence of a flood. Other predictions, by use of partial duration series, are made for flood volume. A recent example is on flood volumes beyond threshold discharges. This variable describes innundations upstream from river constrictions such as bridges and culverts.

Predictions for ungauged sites are based on regionalization of estimates for gauge sites. These are made either for the threshold and parameter values of the selected distributions, or for magnitudes to which given recurrence intervals are assigned. The regionalization is made through regression, or regression-like models, with respect to measurable, or clearly definable, properties of the gauging sites' watersheds. Once this relationship is established, a model is available for prediction of flood magnitude and frequency at any site in the defined region.

A VERSATILE METHOD FOR FLOOD QUANTILE ESTIMATION USING LOG-PEARSON TYPE-III DISTRIBUTION WITH PWM ESTIMATORS

*B.P. Parida**, *Rema Devi*** & *Arun Kumar***

* Indian Institute of Technology, New Delhi, India

** Delhi College of Engineering, Delhi, India

One of the widely used distribution in this and many other countries of the world for carrying out flood frequency analysis is the Pearson Type-III (PI-III/log-Pearson Type-III (LP-III) distribution. Although, this distribution has a good descriptive ability in terms of giving moderate fit to the observed floods can yield flood quantile estimates with large bias. It has generally been

agreed that, if the method of Probability Weighted Moment (PWM) is used for parameter estimation, not only can the above problems be overcome but also parameters as efficient as the method of Maximum Likelihood can be obtained even with small sample sizes. Because of the fact that, use of method of PWM is limited to distributions having inverse form, a procedure needs to be evolved such that the method can be used with PI-III/LP-III distribution to obtain reliable flood quantile estimates.

Some of the recent attempts made in this direction have been of limited success primarily because of the limitation of asymptotic expansion form of Incomplete Gamma Function used in the development which are insensitive at skew values more than 2.0. In addition to this, the procedures are not amenable to samples having negative skewness (which is often encountered with LP-III distributions).

In this paper recognizing relationship between Incomplete Gamma and Beta Functions, a versatile procedure has been suggested which is able to overcome the earlier limitations. Even, behavioural analyses carried out using the suggested procedure resulted in least blased estimates. The procedure has been applied on real life data R. Yamuna as an illustration.

APPLICATION OF HEC - 2 MODEL FOR PALAEOFLOOD STUDIES ON NARMADA

S.K. Mishra & K.S. Ramasastri

National Institute of Hydrology, Roorkee, India

Palaeoflood hydrology is the study of past or ancient flood events that occurred prior to measurements by modern hydrologic procedures. The technique involves the analysis of slack water deposits and palaeo-stage indicators (SWD-PSI). An important component of the palaeoflood analysis is the transformation of stage information into accurate discharge estimates which in turn would decide the design magnitude of water resources projects. A stretch of river Narmada where Indira Sagar Dam is proposed has potential sites of slack water deposits. The hydrological information for the Dam site at Narmada Nagar was derived on the basis of observations available at Mortekka site which is downstream of the Dam site. A volumetric analysis for the lateral inflow contribution from the catchment between these two sites has been made. It is shown that the lateral inflow affects the accuracy of discharge estimates derived for the Dam site. The use of HEC-2 based rating curve is recommended for more reliable estimates.

STUDY OF FLOOD VARIOGRAMS

U.C. Chaube & R.P. Samayar

University of Roorkee, Roorkee, India

Theory of variogram is based on assumption that difference in values of a variable between two locations depends only on the instance between them and their relative orientation in a two dimensional place. This theory has been applied equally well to variables which are spatially or temporally distributed. It can be used whenever a continuous measure is made of sample at a particular location in space (or time). The application of the variogram theory to the annual flow data series such as for annual floods may help to predict values of flows forward in the future or to fill in gaps in the records caused by measurement mistakes.

The variogram theory has been applied to the annual flood series in two possible ways in order to explore whether it could be used for prediction of extreme flood events.

(i) considering a future point in time as the direction.

(ii) considering ascending/descending order as a conceptual direction.

A function has been developed which expresses variogram as a function of length of data sample (m) and rank difference (L) of the values. The expression was tested for its goodness of fit and was found to be satisfactory. The interpretation given for the direction of L in terms of rank is significant. Since differences of annual flood values are used in the model, the total number of variates is much larger than the number of actual annual floods peaks which are considered in flood frequently analysis. The proposed expression becomes

particularly useful when semivariogram corresponding to the largest difference in annual flood peaks is being studied. The largest difference in annual peaks would occur only when the largest annual flood peak and the smallest annual flood peak are considered. The expression could be used to establish a relationship between an extreme flood (which is unknown) of a particular rank in terms of other known parameters.

INFLUENCE OF GEOGRAPHIC FACTORS ON SATELLITE SNOW COVERED AREA VS. SNOWMELT RUNOFF RELATIONSHIP IN THE PUNJAB HIMALAYAS

R.P. Gupta, R. Sinha & M.S. Roohani

University of Roorkee, Roorkee, India

Snowmelt runoff comprises the dominant part of the total annual stream flow in many mountainous areas of the world. Early prediction of the amount of runoff to be derived from the snow pack allows more efficient utilization of the limited and precious water resources for power generation, irrigation flood control, domestic and industrial water supplies, recreation and navigation purposes. Satellite remote sensing techniques have proved to be quite efficient for monitoring snow-cover area. Various empirical relationships have been developed for different catchments by different workers to relate the snow covered area and the snowmelt runoff. The present paper is a comparison of the snowmelt runoff behaviour in the Beas, Ravi and Chenab catchments, thus covering the entire Punjab Himalayas. It is shown that similar log-linear relationships exist in different catchments but with different regression parameters. It is also established that geomorphic parameters of the catchments have a systematic influence on the relationship between snow covered area and subsequent snowmelt runoff.

PHYSICALLY BASED LINEAR FLOOD ROUTING MODELING

Witold G. Strupczewski

Polish Academy of Sciences, Warsaw, Poland

The papers starts from recalling the St. Venant equation, its assumptions and problems of numerical solution of differential equations. Then outline of work on linerization of the St. Venant equation and on its application is given. The reasons why the linerized St. Venant model has not driven out the conceptual flood routing linear models are discussed.

In order to get the linerized equation valid for a large number of choices for the dependent variable, the perturbation potential is introduced. Problems in the linear theory of open channel flow are listed and their solutions either are presented or references to literature are given. Those of them still waiting for solution are also included.

The major part of the paper is given to search for a physical reason to a great practical popularity of the linear conceptual flood routng model in the form of a series of linear reservoirs with pure delay, known as Lag Kalinin–Miliukov model (LKM). It is used as an opportunity to presentation of solutions of some upstream control problems. Impulse response of the LKM model was compared with that of the linerized St. Venant model with upstream input (LCR) together with its limiting case of Froude number equal to one (RF). A comparison of LKM and RF models has shown that in spite of a certain structural similarity, the LKM model is not suitable for a step river channel. However for certain flow conditions, frequently met during floods, the LKM model shows amazingly good agreement with the LCR measured by the differences of higher order cumulants and a satisfactory one for differences of lags. That is why, taking additionaally into account the poor observability of a river system, the model is suggested to be accepted as a third, besides RF and Lag Diffusion Analogy (LDA) models, particular case of LCR.

The introduced coefficient a_R (R=4, 5,6,...) being a function of three cumulants has served to find a useful property of LCR and to classify the particular cases solutions. Regions of applicability of the particular cases models were defined by the criterion of an error of fourth cumulant simulation.

In view of presented results LKM model may have been derived by the oreticians working on fluid mechanics and then recommended for practice. However it has happened contrarywise.

MONTHLY STREAM FLOW GENERATION USING CONDENSED DISAGGREGATION MODEL

R. Mehrotra, N.K. Goel** & Ranvir Singh***

* National Institute of Hydrology Roorkee, India.

** University of Roorkee, U.P. India.

For monthly stream flow generation a number of models have been proposed in the past. The formal development of stochastic modelling started with the introduction and application of Autoregressive models (1963) and Thomas Fering models (1962), for monthly stream flow generation. Since then, a number of models have been developed. Each of the model has its own merits and demerits and some of them can be successfully applied in operational hydrology.

Disaggregation models being very versatile have become a major technique for modeling of hydrologic time series because of their capability to preserve the statistical properties at more than one level. Basic disaggregation model was proposed by Valencia and Schaake (1973) and later modified by Mejia and Rousselle (1976) and Lane (1979). Modified disaggregation model as developed by Lane is popularly known as condensed disaggregation model, which essentially sets to zero several parameters of the extended model (Mejia and Rousselle, 1976), which are not important. Approach uses the extended model form but on one-season-at-a-time basis and with only one lagged season.

In the present paper condensed disaggregation model is applied to four streams of India (Mahanadi at Hirakud, Sabarmati at Dharoi, Mahanadi at Naraj, and flows at Gandhisagar reservoir). In the study 25 replicates of monthly flow series (of length equal to the historical one) are generated and the average of the statistical proprieties of these 25 replicates is compared with corresponding historical statistical properties on the basis of, i) sum of squares of error, ii) sum of relative error and, iii) sum of absolute error. Confidence bands at 95% level for mean and standard deviation are also calculated and parameters are compared. Reproduction of mean, standard deviation, lag one serial correlation and, cross correlation properties in generated series is compared with historical parameters. Overall performance of condensed disaggregation model is also compared with Thomas Firing model. The results are quite encouraging and condensed disaggregation model preserves the monthly as well as annual statistical parameters satisfactorily.

THE GROWING NEED FOR SPECIALIZED COURSES IN REGIONAL HYDROLOGY

Mamdouh Shahin

International Institute for Infrastructural Hydraulic and Environmental Engineering, Delft, The Netherlands

The paper briefly reviews the formation and development of the UNESCO-sponsored international courses in hydrology and water resources. After a short description some remarks are given about the long-duration as well as the short-duration courses. These remarks highlight the general character of the current international courses. Hydrology and water resources in a certain region are the products of the geography, climate, geology, physiography and land use in that region. This state of affairs calls upon having rather specialized courses, where topics of regional interest can be dealt with. A few such courses are indeed organized here and there, though not on a regular basis and ad-hoc. The paper describes, in short, a few hydrologic situations of regional interest. It brings up the issue of intensifying the regional training courses, if any, and having them spread among the different regions of the world, especially in the developing countries. In every continent there are regional offices for UNESCO and other organizations, as well as specialized institutions. These institutions comprise a wealth of experts and expertise, which make their participation in the regional training programmes strongly recommendable.

HYDROLOGY TECHNICIAN TRAINING - NEED OF THE DAY

A.K. Sinha & Manohar Arora***

* State Hydrology Cell Patna, Bihar, India

** National Institute of Hydrology, GRC, Patna, Bihar, India

The training of hydrology technicians has been recognised as one of the major requirements for the development of water resources specially in the developing countries. The deficiencies in collection, compilation and dissemination of data have often become apparent which hampers the application of hydrology to water resources development. Without data as well as the training of technicians working in the area of hydrology, the research efforts are also lagging behind. The existing

piecemeal training at observers and technician level is mainly devoid of field work. The research institutes, universities and other agencies which can provide the training at this level are also not fully equipped with field expertise, regular courses & financial resources. The role of persons collecting hydrologic and related data becomes very important when the relationship between hydrology & water related development is considered.

The objectives of such training's should be to acquaint hydrology technicians with the basic concept of hydrology and related disciplines, to familarise them with the techniques involved in practical field work, and for collection, processing and analysis of hydrological data and to acquaint them with the use of modern techniques and equipment. It is also important that such training should make participants understand the role of hydrology in the development of water resources, with a clear perception of socio-economic implications. Such technicians/observers should feel their responsibility and hold themselves responsible for collecting such data.

In this paper an attempt has been made to outline the importance and need for the training of hydrolgy technicians. As any form of hydrological data collection or design must be dependent upon measurements. The importance of measurement and types of measurements are discussed in details. The data collected by different agencies differ in data transmission system, techniques, their suitability, quality control, storage, cataloging and publication. A brief description of various agencies involved in collection and publication of data in India is also given. Depending on the level of training relevant for average hydrology technicians, the course content should be in conjunction with basic text books. The paper brings out an ideal or model course contents in details and the various efforts made in India for developing hydrology technician training has also been enumerated. It has been stressed that in India there is a strong need for formal regular courses and the standardisation of course contents. The aspects relating to providing incentives to such technicians has also been stressed.