RECENT TECHNICAL LITERATURE RELEVANT FOR THE HYDROLOGISTS OF THE COUNTRY

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CONTENTS

ABSTRACT

A sizable number of Journals in the field of hydrology and water resources are published. It is not a easy task to go through all of them by the scientists involved in different studies and projects. Also some hydrological institutes, NGO's, regional centres cannot have all journals in their library. So it will be convenient to have a compilation of hydrology related research papers and data published in a set of journal for dissemination by the concerned hydrologist.

It has been decided to review five National Journals and five International Journals to identify the relevant information/research papers of topical interest for the last two years i.e., 1996-1997. The abstract of the papers have been collected only for two national and four International journals because some journals have not been procured in this period. It can be a source of appropriate and useful source for ready reference for the present status of hydrological problems and their solutions in the emerging frontiers of hydrology relevant to the country.

Reviewed Journals are :

National	International
1. Mausam	3. Journal of Hydrology
2. Photonirvachak	4. Hydrological Sciences Journal (IAHS)
	5. Hydrological Processes J.
	6. American Water Resources Bulletin

Table 1: Referring Abstract Numbers of the Journals w.r.t their
topics.
(Covered Journals are J. of Hydrology, American Water
Research Bulletin, and IAHS)

Topics/Journ -als	J.of Hydrology (Abstract Nos.)	American Water Res. Bulletin (Abstract Nos.)	IAHS(Hyd.Sci) (Abstract Nos.)
Surface Water Hydrology	3,5,8,14,22,35 ,40,45,52,59,6 0,63,64,68	79, 82, 90,101	105, 111, 112 126, 128, 129 130, 149
Ground Water Hydrology	1,4,9,10,11,19 ,23,28,36,41,4 2,53,46,51,54, 56,57,67,69	74, 75, 76, 78, 85, 86, 88, 100, 102	104, 108, 110 119, 120, 122 135, 137, 142 147, 154
Land/soil erosion	7,20		153
Drought Management	73		136, 152
Sediment -ation in Reservoirs	7,62,65	89, 92	150
Flood Hydrology	24,68		109, 138, 141
Recycling & reuse of water/ water Harvesting	29,71	96	
Environmen -tal Hydrology.	48	78	139, 148
watershed management		81, 84, 93	103
Forest Hydrology			
Snow /Mountain Hydrology	6,21,26,27,32, 38,44,49,58,66	77	113, 118
Rem.sensing & data collection		89	108, 116, 117 118, 119, 120 122, 123, 124 125, 126, 127
Lake pollution/ Hydrology			121, 134

Flash flood & Dam safety			
Hydrological data networks	18,31,39,47	91	127, 140, 146
Water Policy/ Management	15,16		145
Reservoir routing	37	87	106, 138, 148
Potable water/ Water Quality	17,25,30,72	83, 93, 94, 95	121, 154
Climatology	2,12,34	80, 98	107, 131, 133 141, 151
Hydrologic Modelling/ Instrumentation	61	75, 81, 99	114, 123, 124 132, 137, 143
Nuclear Hydrology	13,33,50,53,55,70		
Neural Networking			115
Waterlogging / soil salinity			

Table 2: Referring Abstract Numbers of the Journals w.r.t their topics.
(Covered Journals are Hydrological Processes J., Photonirvachak and Mausam)

Topics/ Journals	Hydrological Processes J. (Abstract Nos.)	Mausam (Abstract Nos.)	Photonirva -chak (Absrtract Nos.)
Surface Water Hydrology	163, 166, 168, 179		210, 211, 216
Ground Water Hydrology	159, 167, 174, 178		204, 207, 215
Land/soil erosion	174		
Drought Management	170	187, 193	209
Sedimentation in reservoirs			
Flood Hydrology	160, 176, 182		
Recycling of water/water Harvesting			216
Environmental Hydrology			202, 206
Watershed management	171, 173, 179		203, 213
Forest Hydrology			205
Snow/Mountaio Hydrology	157, 164, 165, 181	200	
Rem.sensing & data collection	182, 183		201, 202, 203, 208, 210, 211, 212, 214, 215
Lake pollution Hydrology			201
Flash flood & Dam safety			

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Hydrologica-l data networks	177		
Water Policy/ Management			
Reservoir routing			
Potable water/Water quality	155		
Climatology	156, 167	185,186,188,189, 190,191,192,194, 195,196,197,198, 199,	
Hydrologic Modelling/ Instrumentati on	158, 161, 162, 169, 172, 175, 180, 184		
Nuclear Hydrology			
Waterlogging/ soil sailinity			212
Neural Networking			

JOURNAL OF
HYDROLOGY

GROUND WATER HYDROLOGY

1. Journal of Hydrology 174 (1996) 19-35

Multivariate geostatistical analysis of evapotranspiration and precipitation in mountanious terrain
A. Martinez-Cob

Abstract
    This paper reports the evaluation of three geostatistical interpolation methods (ordinary kriging, cokriging and modified residual kriging) to interpolate long-term mean total annual reference evapotranspiration (AETO) and long-term mean total annual precipitation (APRE) in a mountainous region, where the stationarity hypothesis probably do not hold for the whole region, but do hold locally. AETO and APRE estimates and estimation errors were evaluated at validation stations. Estimates and computed estimation error variances (used as indicators of estimation uncertainty) were also obtained at 19135 km grid points. In general, estimates at validation stations were in good agreement with observed values for all interpolation methods, although modified residual kriging estimates of APRE were slightly worse than those obtained by the other two methods. Based on mean absolute error (MAE) and mean squared error (MSE) at validation stations, no method ranked clearly above other for interpolation of AETO. At grid points, AETO estimation uncertainty was improved by cokriging by about 11.5% and 8.4% compared with ordinary kriging and modified residual kriging, respectively. Likewise, cokriging was superior for interpolation of APRE in terms of MAE and MSE obtained at validation stations. At grid points, cokriging reduced estimation uncertainty by 18.7% and 24.3% compared with ordinary kriging and modified residual kriging, respectively, whereas modified residual kriging in general did not improve ordinary kriging results. Computed estimation error variance values indicated that modified residual kriging would reduce estimation uncertainty in areas where very few weather stations are available for interpolation.

CLIMATOLOGY

2. J. of Hydrology 174(1996), 83 - 127

Global Warming and the Hydrological Cycle
Hugo A. Loaiciga, Juan B.Valdes, Richard Vogel et.al.

Abstract
    Starting with a review of the basic processes that govern greenhouse warming, we have demonstrated that the hydrologic cycle plays a key role in the heat balance of the Earth's surface-atmosphere system. Through the water and other climatic feedbacks, the hydrologic cycle is shown to be a key factor in

the climate's evolution as greenhouse gases continue to build up in the atmosphere. This paper examines the current predictive capability of general circulation models linked with macroscale and landscape-scale hydrologic models that simulate regional and local hydrologic regimes under global warming scenarios. Issues concerning hydrologic model calibration and validation in the context of climate change are addressed herein. It is shown that the natural uncertainty in hydrologic regimes in the present climate introduces a signal-to-noise interpretation problem for discerning greenhouse-induced variations in regional hydrologic regimes. Simulations of river basins by means of macroscale hydrologic models nested within general circulation models have been implemented in a few selected cases. From the perspective of water resources management. such simulations, carried out in detail under greenhouse-warming scenarios in midlatitudinal basins of the United States, predict shorter winter seasons, larger winter floods, drier and more frequent summer weather, and overall enhanced and protracted hydrologic variability.

All these predictions point to potentially worsening conditions for flood control, water storage, and water supply in areas of semiarid midlatitudinal climates currently dependent of spring snowmelt. Little information of this type is currently available for other areas of the world. Practice of sound water resources engineering principles ought to be adequate to cope with additional hydrologic uncertainty that might arise from global warming.

SURFACE WATER HYDROLOGY

3.   Journal of Hydrology 174 (1996) 235-241

Analytical verification of Muskingum-Cunge routing
V.M.Ponce, A.K.Lohani and C.Scheyhing

Abstract
      A verification of Muskingum-Cunge routing is accomplished by comparing theoretically calculated peak outflow and travel time with those generated using the constant-parameter Muskingum-Cunge method of flood routing. The close agreement between analytical and numerical results underscores the utility of Muskingum-Cunge routing as a viable and accurate method for routine applications in flood hydrology.

GROUND WATER HYDROLOGY

4.   Journal of Hydrology 174 (1996) 357- 374

Groundwater recharge in irrigated agriculture: the theory and practice of inverse modelling
J. Boonstra and M.N. Bhutta

Abstract

Quantifying the rate of natural groundwater recharge is a prerequisite for drainage design in waterlogged areas. The present study was aimed at determining the seasonal net recharge in the Schedule I-B area of the Fourth Drainage Project, Faisalabad, Pakistan. A numerical groundwater model was developed for the said area and was run in inverse mode to determine the seasonal net recharge. Net recharge values were determined for the period June 1985-June 1990, resulting in five monsoon and five non-monsoon estimates. The data used by the model were the geometry of the aquifer system, the aquifer parameters, and historical water table elevations. The methodology is unique in that it gives information on temporal and areal recharge variations, and requires fewer data than the traditional water-balance method. The maximum average net recharge to the aquifer was calculated as 0.6 mm day^{-1} during monsoon 1986; the corresponding monsoon rainfall had a return period of some 2.8 years.

SURFACE WATER HYDROLOGY

5.   Journal of Hydrology 175 (1996) 3-16

Modelling of rainfall, flow and mass transport in hydrological systems: an overview
P.E. O'Connell and E. Todini

Abstract
Contemporary themes and research directions in hydrological modelling are reviewed in brief, to provide a suitable backcloth against which the Special Issue can be viewed. Some leading modelling issues are discussed and future research directions contemplated.

SNOW MOUNTAIN

6.   Journal of Hydrology 175 (1996) 181-211

Use of the SHE hydrological modelling system to investigate basin response to snowmelt at Reynolds Creek, Idaho
J.C.Bathurst and K.R. Cooley

Abstract
The first test of the snowmelt component of the Systeme Hydrologique Europeen (SHE) hydrological modelling system is reported, in which the SHE is used to simulate a 12.5 day period of snowmelt runoff for a 40 ha subbasin of the Reynolds Creek rangeland research basin in Idaho. The results show the SHE to be capable of successfully simulating hydrograph responses caused by snowmelt generated by heat inputs, especially net

radiation and sensible heat transfer. The results also show how, in the absence of previous field studies of basin response, the SHE can be used to investigate different hypotheses of basin behaviour. In this case, four hypotheses of basin response are examined, based on different representations of the soil permeability and subsurface flow pathways: (1) impermeable (frozen) ground surface; (2) fully permeable soil profile throughout the basin; (3) reduced soil permeability away from the channel; (4) rapid, near-channel subsurface response. Comparison of the measured and simulated hydrographs supports Hypothesis 4, with a possible cause of the response being the rapid conversion of a near-surface, tension-saturated capillary fringe into a pressure-saturated zone by the infiltrating meltwater. In the absence of direct measurements of net radiation and wind gradient, indirectly derived values are used as input to the snowmelt component. The implications which the uncertainty attached to these values holds for the simulation results is investigated in sensitivity tests which show that, with sensible heat transfer forming the major heat flux to the snowpack, greater uncertainty is introduced into the simulation results by the uncertainty in the wind gradient than by the uncertainty in the net radiation. The snowmelt simulations are based on an energy-budget option: a test of a temperature-based (degree-day) option shows comparable accuracy but only through empirical fitting. Overall the study shows that a greater hydrological expertise is required in operating SHE-type models compared with simpler models.

SOIL EROSION / SEDIMENTATION IN RESERVOIRS

7.   Journal of Hydrology 175 (1996) 213-238

SHESED: a physically based, distributed erosion and sediment yield component for the SHE hydrological modelling system
J.M. Wicks & J.C Bathurst

Abstract
     SHESED is introduced as a physically based, spatially distributed erosion and sediment yield component for the existing SHE hydrological modelling system. for use at the catchment scale. For hillslopes (represented spatially by the SHE grid square network) SHESED simulates soil erosion by raindrop impact, leaf drip and sheet overland flow (without rilling), and the transport of the eroded material by overland flow. For channels the component simulates the erosion of bed material and the downstream transport of this material together with that supplied by overland flow. In the channel sediment routing procedure it is assumed that the flow can carry any available load of fine sediments (less than 0.062 mm in diameter) but for coarser sediments the load is limited by the calculated capacity transport rate of the flow. The channel component also allows for bed armouring. Application of SHESED to rainfall-induced sediment yield events at two agricultural catchments (areas 5.1 and 6.4 ha) in Iowa shows generally good reproduction of the

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observed temporal variations in sediment yield. Application to
a 3.3 km reach of the East Fork River, Wyoming, for a 37 day
period shows good reproduction of observed sediment discharge
magnitudes but some discrepancy in the timing of the simulated
sediment discharge peak.

SURFACE WATER HYDROLOGY

An analysis of the dynamic component of the geomorphologic instantaneous unit hydrograph

Marco Franchini, & P. Enda O'Connell

Abstract
     A geomorphologic instantaneous unit hydrograph (IUH)
consists of two components, one relevant to the geomorphology and
the other to the hydraulic aspect describing the movement of a
drop of water along a stream. Different formulations of the
geomorphologic IUH are reviewed, and a contrast is drawn between
the geomorphologic and hydraulic components of the geomorphologic
IUH (GIUH) proposed by Rodriguez-lturbe and Valdes (Water Resour.
Res., 15(6); 1409-1420,1979) and those of a width function based
IUH (WFIUH). In this paper a comparison has been carried out of
the original GIUH and a WFIUH which allows the effects of
different geomorphologic and hydraulic components to be
identified. The comparison, which is based on four sub-basins
of the River Tyne, UK, clearly shows that the GIUH velocity
parameter lacks physical interpretation in contrast to the
hydraulic parameters of the WFIUH, which are seen to be
physically consistent. For practical application of the GIUH,
an equation is then proposed to estimate the velocity parameter
through the basin concentration time, the Horton length ratio and
the length of the stream of the highest order of the channel
network.

GROUND WATER HYDROLOGY

An extended formulation of the integrated finite difference method for groundwater flow and transport

Massimo Ferraresi & Alberto Marinelli

Abstract
     An extension to the integrated finite difference method,
applied to two-dimensional problems, has been developed that
permits a more accurate approximation of the governing equations
for groundwater flow and mass transport in heterogeneous
anisotropic media. The method adopts a linear two-dimensional
interpolation over triangular elements for the numerical

evaluation of gradients at any point of the spatial domain. Applications of the method are presented for various test cases. A comparison is also made between the results obtained by applying both the extended method and the finite element method to the same test problems. This comparison illustrates the utility of the extended integrated finite difference method for simulating flow in anisotropic media. The application of an automatic calibration procedure, based on Kalman filtering, to several test problems and the validation of the resulting models further confirms the advantages of the new formulation. The sources of error introduced by ignoring anisotropy in the integrated finite difference method are found to be significant in the cases presented.

GROUND WATER HYDROLOGY

A solution to the Inverse problem in groundwater hydrology based on Kalman filtering

M. Ferraresi, E. Todini and R. Vignoli

Abstract
The paper introduces a new method for the solution of the inverse problem, that is, the estimation of parameters characterizing the hydrodynamic behaviour of aquifers given their geometrical description, the piezometric field, the net infiltration (infiltration minus abstractions) and the boundary conditions. The method, which falls in the class of Bayesian estimators, is based upon a Kalman filtering formulation which optimally combines a priori parameter values with the information contained in the observations to obtain the a posteriors parameter estimates. In that respect it can also be viewed as an extension of the subjective weighting method proposed by Neuman and Yakowitz (Water Resour. Res., 15(4), 1979). An example of the application of the proposed method to two Libyan aquifers is presented, showing the statistical adequacy of the resulting permeability estimates when compared with the permeabilities obtained at a number of points by means of pump tests.

GROUND WATER HYDROLOGY

^{18}O studies on recharge of phreatic aquifers and groundwater flow-paths of mixing in the Delhi area

P.S. Datta , S.K. Bhattacharya, and S.K. Tyagi

Abstract
Widespread decline in the groundwater level and growth of salinization are the critical factors controlling future groundwater quality and availability in the Delhi area. δ^{18}O and

salinity data have been integrated for studying recharge conditions of phreatic aquifers and tracing the flowpaths of groundwater mixing. Wide range (-2.8%. to -8.6%.) and spatial inhomogeneity of $\delta^{18}O$ in groundwater indicate that the aquifer is characterized by a slow process of natural mixing of groundwater in its lateral extent. There is infiltration of river water to the groundwater, in addition to the recharge from rainfall. Groundwater recharge in the area also occurs through stagnant water pools in low elevation areas where water surface run-off collects. Chloride concentration in groundwater has a wide range from 15 ppm to 5070 ppm with a log-normal frequency distribution indicating that the salt deposits in the area are not homogeneously distributed. The $\delta^{18}O$-Cl relationship clearly suggests mixing of multiple sources of high salinity groundwater with low salinity groundwater or river water along specific pathways. The data also indicates leaching of salts present in the soil during vertical recharge from rainfall and irrigation. Large lateral variation in chloride concentration indicates changes in evapotranspiration rate during recharge. Detailed investigations on identifying the potential recharging zones, flow-paths of mixing and recharge conditions will be useful to protect the groundwater resources from depletion and salinization.

CLIMATOLOGY

12.   Journal of Hydrology 176 (1996) 219-225

The runoff coefficient as the key to moisture recycling
Hubert H.G. Savenije

Abstract
    Moisture recycling by evapotranspiration from vegetation is probably the most important mechanism sustaining rainfall on continental catchments, particularly in semiarid areas. A very simple and very useful parameter to evaluate moisture recycling is the annual runoff coefficient C_R. On continents, the proportion of rainfall recycled equals $1 - C_R$, whereas the average number of times that a moisture particle returns as rainfall equals $1/C_R$. Since the runoff coefficient is widely mapped, it is a very handy indicator to evaluate the importance of landuse practices in rainfall recycling. It is further stated that the idea of some water resources that a high runoff coefficient is an asset for water resources development is a misconception. For the water resources management of continental areas, the most efficient use of Water is made by minimizing runoff.

NUCLEAR HYDROLOGY

13.   J. of Hydrology 177(1996) 77-97

Environmental and injected tracers methodology to estimate direct precipitation

recharge to a confined aquifer

B.S.Sukhija, D.V. Reddy, P.Nagabhushanam et.al.

Abstract

Direct precipitation recharge to a confined aquifer is a vital parameter for groundwater budgeting, management, and modelling. We describe the conjunctive use of environmental isotopes and geochemical tracer technique, and injected tracer method to estimate direct precipitation recharge to an important coastal aquifer undergoing large withdrawal stress. The methodology evolved delineates the intake area of the confined aquifer based on environmental isotope and geochemical data and then utilises the recharge rates of the intake area only, as determined using injected tracer and geochemical data, to estimate the amount of recharge by direct precipitation to the confined aquifer.

SURFACE WATER HYDROLOGY

Analysis of rainfall-recharge relationships

Jinquan Wu, Renduo Zhang, Jinzhong Yang

Abstract

Understanding the recharge process and its relationship with rainfall is of critical importance to the management of groundwater systems and enormous effort has been made to estimate the amount and process of recharge by infiltration using precipitation data. In the present research, in-situ lysimeter experiments and numerical simulations were used to study the relationships between rainfall and recharge by infiltration at different groundwater depths. Four lysimeters, 1.5, 3, 4.5, and 5 m deep, were installed in the field to measure the infiltration recharge rates under conditions of fixed water tables at the bottoms of the soil columns. Annual infiltration recharges at different groundwater depths were obtained through the lysimeter measurements. The effect of rainfall pattern and annual rainfall distribution on infiltration recharge was simulated at various groundwater depths using a numerical model based on soil-water dynamics, and comparisons of the simulated and observed recharges showed very good agreement. Relationships between rainfall and infiltration recharge at different groundwater depths were investigated using the lysimeter measurements and computer simulations. Groundwater systems were classified into three categories, i.e. shallow water table, intermediate water table, and deep water table, based on the relationship between rainfall and infiltration recharge at different groundwater depths.

WATER MANAGEMENT

AQUATOOL, a generalized decision-support system for water-resources planning and operational management

J. Andreu, J. Capilla, E. Sanchis

Abstract

This paper describes a generic decision-support system (DSS) which was originally designed for the planning stage of decision-making associated with complex river basins. Subsequently, it was expanded to incorporate modules relating to the operational stage of decision-making. Computer-assisted design modules allow any complex water-resource system to be represented in graphical form, giving access to geographically referenced databases and knowledge bases. The modelling capability includes basin simulation and optimization modules, an aquifer flow modelling module and two modules for risk assessment. The Segura and Tagus river basins have been used as case studies in the development and validation phases. The value of this DSS is demonstrated by the fact that both River Basin Agencies currently use a version for the efficient management of their water resources.

WATER MANAGEMENT

Simulation of the Kenyan longest dry and wet spells and the largest rain-sums using a Markov model

T.C. Sharma

Abstract

In general, the dry and wet spells during a rainy season tend to persist and can be modelled using a Markov (order 1) process. The stochastic behaviour of the longest dry and wet spells can be predicted using the theory of runs, Poisson probability density function of the occurrence of spells, geometric distribution of the length of spells and the Weibull distribution of total rain over a wet spell (designated as rain-sum). The entire analysis can be carried out using only five parameters, namely, the probability of any day being a dry day (q), the probability of a dry day followed by the previous dry day (qq), the probability of a wet day followed by the previous wet day (pp), the mean (μ) and variance (σ^2) of the daily rainfall sequences during a rainy season. The aforesaid modelling technique adequately simulated the length of the longest dry and wet spells, and the largest rain-sums for Kabete (semihumid) and Kibwezi (semiarid) in Kenya, East Africa. Rainfall in Kenya is generally characterized by a bimodal distribution with the short rains during November-December and long rains in March-May. A major application of the longest dry

spell analysis is to predict extended drought durations during the growing season which forms a basis for planning the crop production strategies. The largest rain-sum analysis forms one criterion of designing rainwater catchment systems. The graphical comparison of cumulative distribution function of the simulated longest dry and wet spells with observed ones provides a powerful way of affirming the Markov persistence as against a customary chi-square test involving transitional probability matrices.

WATER QUALITY

Ecoregions for describing water quality patterns in Tamiraparani basin, South India

S. Ravichandran , R. Ramanibai , N.V. Pundarikanthan

Abstract
    A regional approach which was developed for managing environmental resources, known as an 'ecoregional concept', was found useful for describing spatial water-quality patterns. Eco-regions, when defined within the framework of a river basin concept, provided a satisfactory explanation of water-quality variations occurring in the Tamiraparani basin, South India. The methodology consists of principal component analysis (PCA) of 23 features of the geological, geomorphological, basin morphometry and land-use aspects of the Tamiraparani basin defined in terms of 63 micro-basins. The PCA scores calculated on five components were used to cluster the micro-basins into groups based on a similarity measure. The groups identified in the analysis were traced on the drainage map to delineate nine ecoregions. A water-quality survey of the identified ecoregions was carried out. The pH, EC, DO, TDS, major ions and nutrients were estimated in 278 water samples. A PCA of the water-quality data revealed that three processes appear to be particularly important for water quality in this basin: the geological origin of ionic richness variables, nutrient leaching from agricultural operations, and the carbonate system. The spatial ability of ecoregions to account for regional variations in water quality was compared using two existing classification methods (hydrological and limnological). Water samples were grouped in terms of ecoregional, hydrological and limnological classifications, based on their location in the basin. Visual examination of the box plots of water-quality variables showed that ecoregions have less within-region variation with statist-ically significant differences between the group means than either hydrological or limnological classification. Discriminant analysis displayed the relatively better ability of ecoregions to account for spatial water-quality variations than the other groups in the space defined by the first two discriminant functions representing the ionic richness and nutrient variability of the water samples.

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HYDROLOGICAL DATA NETWORK

Monthly hydrologic data generation by disaggregation

S. Maheepala, B.J.C. Perera

Abstract

Stochastically generated hydrologic data have been used in the past by water authorities world-wide for long-term planning of water resources development projects. These data are also currently being used in short- and medium-term planning and operation of water resource systems. For valid and realistic results, it is necessary that the generated data sequences preserve all statistical properties of historical data. This paper presents an improved disaggregation method for generation of alternative sequences of monthly hydrologic data. The method is designed explicitly to preserve the over-year monthly serial and cross correlations, in addition to other monthly and annual parameters of the historic sequence. The method is applied to both single-site and multi-site cases, and compared with two other disaggregation models that are used in Australia. The comparison of results shows that the developed method satisfactorily preserves both monthly and annual statistical parameters of the historic data sequences including the over-year monthly correlations.

GROUND WATER HYDROLOGY

Use of Green-Ampt model for analysing one-dimensional convective transport in unsaturated soils

R.S. Govindaraju , M.L. Kavvas , S.E. Jones, D.E. Rolston

Abstract

A general analytical solution to the equation describing purely convective vertical transport of a conservative solute under transient water flow conditions is presented. Richards equation does not yield analytical solutions for the flow field, except under restrictive choices of hydraulic properties relating water content, hydraulic conductivity and the soil matric potential. The utility of the Green-Ampt model for homogeneous unsaturated soils is investigated as an alternative to Richards equation. This model, though approximate, provides analytical solutions to the flow field. It is found that the flow quantities required for the analytical solution of convective transport (specifically the soil water storage) are predicted accurately by the Green-Ampt model. Comparisons of numerical and analytical solutions of solute concentration profiles suggest that the Green-Ampt water flow model is adequate for convective solute transport predictions, and that the flow field need not

be computed by the more numerically expensive Richards equation for this problem.

SOIL EROSION

20.   Journal of Hydrology 178 (1996) 351-367

Unsteady soil erosion model, analytical solutions and comparison with experimental results
G.C. Sander, P.B. Hairsine, C.W. Rose, D. Cassidy et.al.

Abstract
     Hairsine and Rose developed a soil erosion model which described the erosion transport of the multiparticle sizes in sediment for rain-impacted flows in the absence of entrainment in overland flow. In this paper we extend their steady-state solutions to account for the time variation of suspended sediment concentration during an erosion event. A very simple approximate analytical solution is found which agrees extremely well with experimental data obtained from nine experiments. We are able to reproduce the rapid initial increase to a peak in the total sediment concentration, which occurs about 3-5 min after the commencement of rainfall, as well as the subsequent declining exponential tail towards steady-state conditions. We are also able to show that the fraction of shielding of the original soil bed resulting from depositing sediment reaches its equilibrium value on about the same time-scale as the total peak suspended sediment concentration. Interestingly, we find that the masses of the individual particles which form this deposited layer are far from equilibrium, and that there is a great deal of continuous reworking and sorting of this material during the erosion event. Finally, our solution shows that the initial peak in the total sediment concentration is due to the enrichment of this sediment by the finer size classes and that as the event continues their percentage contribution diminishes.

SNOW / MOUNTAIN HYDROLOGY

21.   Journal of Hydrology 179 (1996) 23-36

The determination of the snowmelt rate and the meltwater outflow from a snowpack for modelling river runoff generation
L.S. Kuchment, A.N. Gelfan

Abstract
     Two procedures to estimate the area-averaged snowmelt and meltwater outflow from a snowpack were compared for a river basin in the south part of European Russia. Both methods are based on the same model of melting snow but use two different methods for computing the snowmelt rate at the surface of the snowpack, the degree-day method and the Kuzmin method. For averaging, the

spatial change in the meteorological inputs and the statistical distribution of the premelting snow water equivalent before melt are taken into account. The calculated basin averaged meltwater outflow is checked against the snowmelt input obtained from the measured runoff hydrograph by solving the inverse problem for a runoff generation model. It also gives opportunities to calibrate the basin-averaged degree-day factor, coefficients of the heat component dependences, or dependences for parameters of spatial statistical distribution of snow characteristics. The procedure based on the Kuzmin method gave better results than that based on the degree-day method, both in the case of a priori assigned parameters and in the case of parameter calibration.

SURFACE WATER HYDROLOGY

22. Journal of Hydrology 179 (1996) 197-205

Field evaluation of unsaturated hydraulic conductivity models and parameter estimation from retention data

Lakshman Nandagiri , Rama Prasad

Abstract

Predictions of two popular closed-form models for unsaturated hydraulic conductivity (K) are compared with in situ measurements made in a sandy loam field soil. Whereas the Van Genuchten model estimates were very close to field measured values, the Brooks-Corey model predictions were higher by about one order of magnitude in the wetter range. Estimation of parameters of the Van Genuchten soil moisture characteristic (SMC) equation, however, involves the use of non-linear regression techniques. The Brooks-Corey SMC equation has the advantage of being amenable to application of linear regression techniques for estimation of its parameters from retention data. A conversion technique, whereby known BrooksCorey model parameters may be converted into Van Genuchten model parameters, is formulated. The proposed conversion algorithm may be used to obtain the parameters of the preferred Van Genuchten model from in situ retention data, without the use of non-linear regression techniques.

GROUND WATER HYDROLOGY

23. Journal of Hydrology 179 (1996) 321-351

On the stochastic theory Of solute transport by unsteady and steady groundwater flow in heterogeneous aquifers

M.L. Kavvas , A. Karakas

Abstract

In this study the exact and approximate deterministic partial differential equations of the time- space evolution Of mean solute concentration, of solute concentration two-point moment and of solute concentration n-point moment for conservative Solute transport by unsteady and steady groundwater flow in a heterogeneous aquifer were developed in the real time-space domain under second-order cumulant expansion. These derivations were performed by means of the cumulant expansion method, combined with the calculus for the time-ordered exponential and with the calculus for Lie operator. The mean solute transport equations which describe the time-space evolution of mean conservative solute concentration under transport by unsteady and steady groundwater flows in a heterogeneous aquifer have convective-dispersive forms whose convective and dispersive coefficients are defined precisely in terms of the mean and covariance functions of the Pore flow velocity random field. However, owing to the spatial nonuniformity of groundwater flow in heterogeneous porous media a new convective coefficient, besides the standard mean velocity vector. appeared in the derived mean solute transport equations in the case of steady flows. In the case of transport by unsteady groundwater flow in a heterogeneous aquifer. the new convective coefficient (besides the standard mean velocity vector) is due to the non-zero divergence of the pore flow velocity. The fundamental reason for the convective-dispersive form of the mean transport equations is the second-order truncation of the formal cumulant expansion. In the derived mean solute transport equations the macroscopic dispersion coefficient emerges as the time integral of the covariance function of the Pore flcw velocity. However, both in the case of transport by unsteady groundwater flow and in the case of transport by steady spatially nonstationary-nonuniform groundwater flow the macroscopic dispersion coefficients and convective coefficients vary with spatial locations within the porous medium. Only in the case of transport by steady spatially stationary-nonuniform flow are both the macroscopic dispersion coefficient and the convective coefficient constant with respect to spatial location within the heterogenous aquifer. Therefore, only in the case of conservative solute transport by steady spatially stationary-nonuniform groundwater flow in a heterogeneous aquifer does the mean transport equation apply to all spatial locations within the aquifer with the same parameter values at each time instant.

FLOOD HYDROLOGY

A nearest neighbour linear perturbation model for river flow forecasting
Asaad Y. Shamseldin, and Kieran M. O'Connor

Abstract

The non-parametric nearest neighbour method (NNM) for river flow forecasting is explored and developed further as the nearest

neighbour linear perturbation model (NNLPM), which combines the nearest neighbour concept with the concept of perturbations from a mean value, as used in the linear perturbation model (LPM). The NNLPM model is tested on six catchments and its results are compared with those of the simple linear model (SLM) and the linear perturbation model (LPM). The results indicate that the NNLPM is a more reliable indicator of the discharge forecast than either the SLM or the LPM in the case of non-seasonal catchments.

WATER QUALITY

25. Journal of Hydrology 180 (1996) 361-371

Simulation of acid water movement in canals
To Van Truong, Nguyen Tat Dac & Huynh Ngoc Phien

Abstract
   An attempt to tackle the problem of the propagation of acid water in canals is described, and a mathematical model to simulate the acid water movement is developed, in which the jurbanite equilibrium is found to prevail. The processes of settling owing to sedimentation, precipitation and redissolution have been considered in the modelling. Data available from Tan Thanh, in the Plain of Reeds of the Mekong Delta in Viet Nam, are used as a case study.

SNOW \ MOUNTAIN HYDROLOGY

26. Journal of Hydrology 181 (1996) 49-62

Factors controlling suspended sediment transport in   Himalayan glacier meltwaters
Syed I. Hasnain

Abstract
   Suspended sediment concentration was determined both on the rising and falling limbs of the flow hydrograph between 28 August and 21 September 1992 and 23 October to 17 November 1993 within a 600-m reach of the Dokriani Glacier portal, Ganga basin, Garhwal Himalaya. In the Ganga basin proglacial stream patterns of sediment flux first follow the spring rise in discharge between April and June, then the frequency of occurrence of monsoonal rainstorms has an impact, increasing the discharges with high sediment flux between July and mid-September, and after the cessation of rainfall the discharges are mainly controlled by outflows from subglacial waters. Coupling sediment with runoff suggests that glacially controlled sediment exhaustion is offset between July and the middle of September by the monsoonal regime and later maintained sediment transfer by the subglacial linked cavity or distributed system.

SNOW / MOUNTAIN HYDROLOGY

Snowmelt modelling by combining air temperature and a distributed radiation index

F. Cazorzi, G. Dalla Fontana

Abstract

High spatial variability in snowmelt phenomena was observed in the experimental watershed of the upper Cordevole (7 km^2), in the Dolomites. Snowmelt depends, at a point scale, on available energy, which in turn is heavily affected by slope, aspect and shading effects of the site. A distributed hourly model of snowmelt was set up as a geographical information system (GIS) module. The model accumulates snowfall for each raster element (20 m x 20 m) using a temperature threshold. It simulates snowmelt using air temperature and a radiation index consisting of daily average values of clear sky radiation that have cumulated at selected dates since 21 December. It should be underlined that the only relevant calibration parameter of the model is the combined snowmelt factor, which is unique for the whole basin. The clear sky radiation maps were computed for a selected period of the year, based on the watershed digital terrain model and the solar path sampled at very short intervals. When run for a season, the model produces snow water equivalent maps at given dates. The model was validated, with satisfactory results, by comparing these maps with 60 snow covered area surveys and related water equivalent measures collected in six snowmelt seasons from 1986 to 1991. The classical temperature index approach to snowmelt modelling does not allow the full variability over the basin to be taken into account. Besides, it seems important to point out that this fully distributed approach allows us to avoid the use of snow covered area (SCA) depletion curves, the definition of which still proves a troublesome task.

GROUND WATER HYDROLOGY

Identification of hydraulic parameters in layered soils based on a quasi-Newton method

Jan Zijlstra , and J.H. Dane

Abstract

In models for one-dimensional unsaturated flow in layered soils based on the general flow equation, non-linear coefficient functions appear. The inverse problem consists of the identification of parameters in models for these coefficients. In this study, parameters are identified for layered soils. The general flow equation is solved iteratively, adjusting the values

of the parameters until the solution matches a set of in situ water content data. The optimization method is based on a quasi-Newton method with Richardson extrapolation. Data sets of different size and with various degrees of perturbation are used to investigate existence, uniqueness and accuracy of parameter estimates. To stabilize parameter estimates, a weighting procedure is proposed based on the values of the water content data. The correspondence of parameter estimates, based on relatively small sets of unperturbed data, to the true parameter values indicates a high degree of numerical accuracy of the method. Parameter estimates based on perturbed data sets suggest that ill-posedness of the estimation problem is a matter of data insufficiency and modelling errors, rather than of data error alone.

WATER HARVESTING

Water recovery from dew

V.S. Nikolayev, D. Beysens , A. Gioda , I. Milimouk, E. Katiushin , and J.P. Morel

Abstract
The recovery of clean water from dew has remained a longstanding challenge in many places all around the world. It is currently believed that the ancient Greeks succeeded in recovering atmospheric water vapour on a scale large enough to supply water to the city of Theodosia (presently Feodosia, Crimea, Ukraine). Several attempts were made in the early 20th century to build artificial dew-catching constructions which were subsequently abandoned because of their low yield. The idea of dew collection is revised in the light of recent investigations of the basic physical phenomena involved in the formation of dew. A model for calculating condensation rates on real dew condensers is proposed. Some suggestions for the 'ideal' condenser are formulated.

WATER QUALITY

Application of chemical mass balance to upstream/downstream river monitoring data

C.K. Jain

Abstract
The river Kali in western Uttar Pradesh (India) has been heavily influenced by the discharge of untreated municipal, agricultural, and industrial effluents. In the main channel of the river, the metal contamination was found to be three to four times the background level. The concentration of iron, zinc, and

copper was 0.41, 0.04, and 0.015 mgl⁻¹, respectively, in the upstream section during October. The same were 0.56, 0.07, and 0.016 mgl⁻¹, during December.

Comparisons between upstream and downstream monitoring sites reveal changes in the concentration and/or load to the river and can be used to discriminate between point and non-point sources of pollution for these elements in the river. The resulting differential loadings, if adjusted for uncharacterized non-point contribution to the load, may represent the total point source load to the river minus any losses due to volatilization, settling, and/or degradation. Mass balance calculations conducted for iron, zinc, and copper indicated that additional inputs are needed to account for the observed differences in load along the river. The sources may include non-point sources of pollution due to agricultural activities, sediment remobilization or entrainment, groundwater intrusion or from a combination of these sources. The difference may also be attributed to some point sources of pollution which could not be identified in the course of investigations.

DATA NETWORKS HYDROLOGICAL

Residual maximum likelihood (REML) methods for analysing hydrological data series
Robin T. Clarke

Abstract
Much hydrological data can be displayed as two-way tables with observations classified (for example) by years (rows) and sites (columns), commonly with many missing entries; data classified by three factors or more (e.g. gauge sites within drainage basins; drainage basins., years) can also be put in this form. On an appropriate scale, the observations in such tables can frequently be represented by linear, additive models of components, some of which can be considered as random variables. Residual maximum likelihood (REML) is a technique for fitting models in which each observation is expressed additively in terms of fixed and random effects. When the model contains only one such random effect, the linear model reduces to a restricted form of multiple regression; REML can be regarded as an extension of multiple regression to the case where there are several error terms with different statistical characteristics. Models of this kind are appropriate in the hydrological context where the effects of the years (or other periods) of observation can be regarded as a sample from a hypothetical population of years (periods), or where sites can be regarded as random.
The paper discusses two examples where REML was used: one in estimating mean areal monthly rainfall in Amazonia, using incomplete records from 48 raingauge sites, and the other using incomplete records of annual floods from 19 gauging stations on the Rio Itajai-Acu, in southern Brazil. In both cases, the

assumptions of the REML model were satisfied and the objectives of the analysis achieved. Given the prevalence of incomplete hydrological records, the REML method may well have wider application.

SNOW HYDROLOGY

32.   Journal of Hydrology 183 (1996) 205-225

An approach to annual water balance for small mountainous catchments with wide spatial distributions of rainfall and snow water equivalent
Makoto Tani

Abstract
    One of the major problems in understanding the hydrological cycle in high mountainous regions with much snow is evaluating the spatial and temporal distribution of precipitation. This study evaluates the water balance in two small neighbouring catchments, namely Honryu (HN) and Shozawa (SH) in the Takaragawa Forest Watershed Experiment Station, Japan, by analysing records of precipitation in rainfall seasons and snow water equivalent (SWE) in snowfall seasons. Because both records were satisfactorily correlated with the filtered elevation, the distributed values of precipitation and SWE for each grid point of the digital elevation map were evaluated based on this correlation in each of the seasons. Total precipitation during the snowfall seasons was estimated from the SWE records using a relation of the mean catchment SWE to the cumulative precipitation monitored continuously at the observation station. An annual water balance in the two catchments averaged over several years was calculated from the total mean catchment precipitation in rainfall and snowfall seasons. The catchment evapotranspiration derived from the water balance was compared with Hamon's potential evapotranspiration. Although a large difference between the two catchments in evapotranspiration was calculated from the water balance, several probable causes could be suggested for this difference, and it is concluded that the annual water balance could be estimated with an acceptable accuracy.

NUECLEAR HYDROLOGY

33.   Journal of Hydrology 183 (1996) 263-275

A Laplace transform solution for tracer tests in a radially convergent flow field with upstream dispersion
Jui-Sheng Chen, Chen-Wuing Liu, Chia-Shyun Chen, and Hun-Der Yeh

Abstract

When tracers are introduced into an injection borehole, noticeable concentration gradients at the injection well may cause a backward spreading of the initial plume during radially convergent tracer tests. Based on this concept a non-rigorous mathematical model is developed to estimate the effect of backward spreading. The injection well with an instantaneous slug input is treated as a mathematical source and the initial plume at the injection well is allowed to move upstream. The model assumes that advection and longitudinal dispersion are the transport mechanisms in a radially converging flow field. The Laplace transform solution for solute concentration in an infinite porous medium is obtained using the method of Green's function. Breakthrough curves are computed by numerically inverting the Laplace transform solution. As compared with the solution of Moench, it is concluded that the presence of backward movement of initial plume yields a decrease of peak concentration and spreading out of breakthrough curve tails. This effect is significant for small Peclet numbers and can be neglected for large Peclet numbers. A field tracer test is carried out to demonstrate the applicability of the model. The experimental data are fitted with the type curves of this study, and those of Moench's study, to determine dispersivity and aquifer porosity. The results show that dispersivity values estimated by matching the two type curves are different. Because it neglects backward dispersion, Moench's solution overestimates the dispersivity and effective aquifer porosity.

CLIMATOLOGY

The effects of climate change due to global warming on river flows in Great Britain

N.W. Arnell, N.S. Reynard

Abstract

Global warming due to an increasing concentration of greenhouse gases in the atmosphere will affect temperature and rainfall, and hence river flows and water resources. This paper presents results from an investigation into potential changes in river flows in 21 catchments in Great Britain, using a daily rainfall-runoff model and both equilibrium and transient climate change scenarios. Annual runoff was simulated to increase by 2050 by over 20% in the wettest scenarios and decline by over 20% in the driest scenarios - and different catchments respond differently to the same change scenario. Monthly flows change by a greater percentage than annual flows, and under all the scenarios considered there would be a greater concentration of flow in winter. Snowfall, and hence snowmelt, would be almost entirely eliminated. Progressive changes in river flows over the next few decades would be small compared with year-to-year

variability, but would be noticeable on a decade-to-decade basis.

SURFACE WATER HYDROLOGY

A decision support system for the analysis and use of stage-discharge rating curves

Mark P.J. DeGagne, Glen G. Douglas, Henry R. Hudson et.al.

Abstract
    A decision support system for fitting stage-discharge relations is being developed by the University of Manitoba, Facility for Intelligent Decision Support, for Environment Canada's hydrometric program. The process of developing and applying stage-discharge relationships has been documented, the decision support system framework established, and a number of expert 'rules' developed and evaluated for stable and non-stable channels. The system categorizes stage-discharge rating curves as stable if they deviate within a predetermined accuracy (e.g. ± 5% of discharge), or if one of a suite of curves can be applied within the predetermined accuracy specifications for given changes in the energy slope caused by weed growth, channel ice and other conditions affecting backwater. Non-stable channels are defined as channels that experience evolution or abrupt changes in stage-discharge relationships resulting from changes in channel form. Rating curve stability is determined based on deviations in the stage-discharge relationship, utilizing specific gauge, absolute differences between sequential streamflow measurements and an analysis of residuals. Periods of instability, such as a meander cut-off changing the hydraulic control, are often repetitive in hydraulic response, such that a pattern of instability is recognizable as events occur. In addition, periods of instability are interspersed with periods of stability. The repetition in pattern allows knowledge of correctly identified historic events to be applied to contemporary hydraulic conditions. A suite of rating curves can be developed for specific periods (e.g. summer weed growth) and stages. These curves can be automatically applied based on changing streamflow conditions such that streamflow estimates can be generated in a rigorous and accurate manner with minimal hydrographer intervention.

GROUND WATER HYDROLOGY

Application of an empirical infiltration equation in the SMAR conceptual model

B.Q. Tan, and K.M. O'Connor

Abstract

An empirical equation, which relates the infiltration rate to the actual soil moisture content, is proposed and incorporated in the Soil Moisture Accounting and Routing (SMAR) model to demonstrate one application of that equation. A modified SMAR model (SMARY) is developed and tested on four catchments with different climatic conditions. The results show that the SMARY model performs better than the SMAR model in terms of R^2, mean square error and relative error. The modified model provides a more rational interpretation of the physical process of infiltration and also provides a tool for determining the actual infiltration rate under specific soil moisture conditions.

RESERVOIR ROUTING

Criteria for the choice of flood-routing methods in natural channels

Roger Moussa and Claude Bocquillon

Abstract

The Saint-Venant equations are used to describe river waves. Generally, for flood routing in rivers, the Saint-Venant system is reduced to the diffusive wave equation which can be resolved using finite-difference algorithms. The choice of a numerical method, and of the space and time steps to be retained, depends essentially on the form of flood hydrographs and the hydraulic properties of the river. This paper investigates these areas; two sets of criteria are proposed, the first to define parameter ranges representing each wave type and then, in the particular case of the diffusive wave model, to define criteria for the choice of numerical algorithm and appropriate space and time steps. The first analysis was based on the concept that river wave behaviour is determined by the balance between friction and inertia. The conclusions relate to the magnitude of temporal characteristics of flood waves, expressed as a function of the Froude number of the steady uniform flow and a dimensionless wave number of the unsteady component of the motion. The second part discussed questions related to the diffusive wave problem and to numerical instabilities. A technique is proposed to guide the user in the choice of the computational algorithm and specifies the error introduced by numerical methods. The technique was applied to flood-routing simulation for the Loire river in France. In this case, two finite-difference algorithms were compared to the exact solution given by the analytical method. Comparisons between results show the efficiency of the technique to optimise the choice of the finite-difference method and the adequate space and time steps.

SNOW HYDROLOGY

Suspended sediment discharge from snowmelt: Ikushunbetsu River, Hokkaido, Japan

Kazuhisa A. Chikita

Abstract

Sediment discharge generated from snowmelt was observed in the Ikushunbetsu River, Hokkaido, Japan (drainage basin area: 60 kM^2) in April-May 1992 and April 1993. Continuous records of water discharge Q and suspended sediment concentration C_s, indicated synchronous temporal variations at a station on the riverbank and a downstream increase in sediment discharge $Q_s (=Q.C_s)$ between two stations along a river channel. The sediment suspended over 90% of water depth consisted of more than 95 wt.% of silt (3.91 < d ≤ 62.5 μm) and clay (d ≤ 3.91μm). Sources of the fine suspended sediment were identified by comparing grain size distributions of riverbed and side gorge slope sediment samples, being supplemented by mineralogical analysis. It is concluded that the sediment discharge is generated by the fluvial erosion of weathered soils which are accumulated on side gorge slopes from the collapse of the top soil, and the amount of sediment eroded per unit area per unit time is approximately proportional to the fluvial shear stress.

HYDROLOGICAL DATA NETWORK

An overview of HAPEX-Sahel: a study in climate and desertification

J.P. Goutorbe, T. Lebel ,A.J Dolman, J.H.C. Gash P. Kabat et.al.

Abstract

HAPEX-Sahel was an international experiment designed to provide the field data needed to model the climate of the Sahel and its dependence on land surface conditions. The design of the experiment was based on the study of a 1° square experimental domain in which there were three observational supersites. At each of these supersites detailed hydro-meteorological studies were made at subsites for each of the three principal vegetation types: millet, fallow savannah and tiger bush. Remote sensing from satellite and aircraft was used to scale up from the local to the regional scale. Hydrological monitoring, from 1991 to 1993, was combined with an 8-week intensive observation period that covered the end of the wet season and the beginning of the dry season in 1992. The structure and content of the HAPEX-Sahel Special Issue are described and an introduction is given to the HMEX-Sahel information system where the data are stored.

SURFACE WATER HYDROLOGY

Rainfall climatology of the HAPEX-Sahel region during the years 1950-1990

L. Le Barba,T. Lebel

Abstract

In the Sahel, rainfall is the single most important factor conditioning the hydrology and the climate, but comprehensive statistical analyses of the rainfall climatology in the region are rare. Yet, even though in the Sahel rainfall data are scarce by the standards of the temperate countries, it is shown here that it is possible to obtain a reasonably good idea of what the rainfall has been over Sahelian Niger for the past 40 years, both in terms of interannual variability and spatial distribution. To that aim a statistical model is used, which decomposes the space-time fluctuations of long-term rainfall averages into the fluctuations of the mean event rainfall on the one hand, and of the mean number of rainfall events over any period of accumulation, on the other hand. This model is first applied to the analysis of monthly rainfall data over the whole of Niger. It is shown that the lasting drought which has affected Niger for more than 20 years is associated with a decrease in the number of rainy events, rather than to a decrease of the mean event rainfall, and that this decrease is more pronounced for the core of the rainy season. Because these fluctuations are not homogeneous over Niger, a $5°$ x $4°$ zone centred on the HAPEX-Sahel $1°$ x $1°$ square is selected in order to characterise more accurately the rainfall climatology of the HAPEX-Sahel area between 1950 and 1990. In comparison with what it was between 1950 and 1970, the average length of the rainy season has not changed significantly during the dry period 1970-1990. Rather, it is the decrease of rainfall in July and August that explains most of the diminution of the total annual rainfall over this part of the Sahel since 1970. The average number of rainy events in August was reduced by about 30%, while the mean event rainfall remained roughly constant. Finally, the analysis of the daily rainfall series for Niamey (which constitutes the longest record available in Niger, starting in 1905) enables the comparison of four periods of 20 years between 1910 and 1990. The period 1970-1989 appears to be by far the longest and most severe dry spell of the past century. Almost 90% of the annual rainfall decrease over this period is explained by the decrease of the mean number of rainfall events during July and August, while both the length of the rainy season and the mean event rainfall remained stable.

GROUND WATER HYDROLOGY

Water table fluctuation and recharge in semi-arid climate: some results of the

HAPEX-Sahel hydrodynamic survey (Niger)
Christian Leduc,John Bromley, Pierre Schroeter

Abstract
Groundwater level measurements taken over a 4-year period from an extensive network of wells and boreholes within the HAPEX-Sahel (Hydrologic Atmospheric Pilot Experiment in the Sahel) degree square (south Niger), together with existing data, have provided an insight into infiltration and recharge processes taking place in the porous phreatic aquifer of the Continental Terminal formation. Despite high spatial and temporal variability of aquifer response to rainfall (rises of between 0 and 9 m are recorded), a pattern of recharge can be recognised. Aquifer responses vary from site to site, but the type of response at any single point tends to be consistent from year to year. Recharge is dominated by infiltration from temporary drainage networks (pools and streams) and aquifer response depends to a large extent on aquifer hydraulic characteristics and distance from the nearest infiltrating zone. In many wells, for which data extending back to 1987 is available, water levels show a consistent year by year rise. This is interpreted as a process of aquifer recovery following the severe drought of the 1970s and early 1980s, though part may also be attributable to changing patterns of land management (e.g. woodland clearance). Initial estimates of regional recharge are from 50-60 mm year^{-1}, or in other words about 10% of annual rainfall. The figure is supported by other methods of investigation (hydrochemical analyses; water budgets of pools).

GROUND WATER HYDROLOGY

42.   Journal of Hydrology 188-189 (1997) 203-223

Estimating hydraulic conductivity of crusted soils using disc infiltrometers and minitensiometers
J.P. Vandervaere a, C. Peugeot, M. Vauclin, R. Angulo Jaramillo, T. Lebel

Abstract
Although soil crusting has long been recognized as a crucial runoff factor in the Sahel, very few field methods have been developed for the measurement of the crust hydraulic conductivity, which is difficult to achieve because of the small thickness of most surface crusts. A field method, based on the simultaneous use of disc infiltrometers and minitensiometers is proposed for determining the crust hydraulic conductivity and sorptivity near saturation. On crusted soils, the classical analysis of the steady state water flow was found to be inadequate. The proposed method is based on sorptivity measurements performed at different water supply potentials and uses recent developments of transient flow analysis. A minitensiometer, placed horizontally at the crust-subsoil interface, facilitated the analysis of the infiltration regime for the crust solely.

Results are shown for representative soil units of the East Central Super Site of the HAPEX-Sahel experiment: fallow grasslands, millet fields and tiger bush. Non-crusted soils were also considered and validated the transient method as demonstrated by comparison with Wooding's steady state solution. This validation was obtained in the case of fallow grasslands soil but not for the millet fields. In this latter case, the persistent effects of localized working of the soil to remove weeds caused large variations in infiltration fluxes between the sampling points, which tended to dominate over effects of differences in applied potential. For the tiger bush crusted soils, the ratio of the saturated hydraulic conductivity of the crust to that of the underlying soil ranges from 1/3 to 1/6, depending on whether the crust is of a structural (ST) or sedimentation (SED) type. The method also allows the estimation of a functional mean pore size, consistent with laboratory measurements, and 40% less for the crusts in comparison with the underlying soil.

The results obtained here will be used in hydrological models to predict the partition of rainfall between infiltration and runoff.

GROUND WATER HYDROLOGY

Soil evaporation from sparse natural vegetation estimated from Sherwood numbers

Adrie F.G. Jacobs, Anne Verhoef

Abstract

For various purposes and applications it is convenient to have a simple technique available that produces reliable estimates about the contribution of the soil sensible and latent heat of a crop canopy or natural vegetation to the total fluxes. This is especially of importance in the case of a sparse vegetation where the bare soil is the major component.

Under low wind conditions a free convective state often occurs which offers an opportunity to make a simple assessment of the soil sensible heat contribution to the total sensible heat flux. In this case there exists a unique relation between the surface Rayleigh number and the surface Nusselt number. The same technique can be applied to the vapour flux by using a unique relation between the surface Rayleigh number and the surface Sherwood number, if the soil surface is wet. The last condition occurs after a rainy period. Mostly, however, the upper soil layer is dry and the soil evaporation will be limited by the surface resistance to evaporation. If the relation between soil moisture and the so-called 'soil Bowen ratio coefficient' $**c_w$, as proposed by Massman (1992) is known, a simple correction to the potential soil evaporation can be applied. During the HAPEX-Sahel experiment the above-mentioned technique has been applied to a natural vegetation under semi-arid

conditions. Moreover, the modelled soil evaporation has been verified by micro-lysimeter data. It appeared that the proposed technique is promising and is in agreement with the measurement results.

SNOW HYDROLOGY

44.   Journal of Hydrology 190 (1997) 42-59

Spatial modeling of snow water equivalent using covariances estimated from spatial and geomorphic attributes

Steven S. Carroll, Noel Cressie

Abstract

As the demand for water in the USA rapidly approaches the total available water supply, it is essential that water resources be accurately monitored. Consequently, the National Weather Service (NWS) maintains a set of conceptual, continuous, hydrologic simulation models used to generate extended streamflow predictions, water supply outlooks, and flood forecasts. To obtain accurate predictions and forecasts, it is necessary, periodically throughout the snow season, to estimate the snow water equivalent in river basins throughout the USA. The estimates are obtained using a geostatistical model and snow course, SNOTEL, and airborne snow data. In this research, we develop a positive-definite spatial covariance function that allows researchers to incorporate geomorphic site attributes when snow water equivalent estimates are obtained. We illustrate our approach using snow course and SNOTEL data collected in the North Fork Clearwater River basin. Our results indicate that by incorporating elevation into the covariance model used for the North Fork Clearwater River basin we are able to improve substantially the accuracy of the snow water equivalent estimates.

SURFACE WATER HYDROLOGY

45.   Journal of Hydrology 190 (1997) 60-74

Streamflow recession in basins with multiple water storages

George A. Griffiths, Bente Clausen

Abstract

A streamflow recession formula for natural basins is derived by linear hydrologic routing of the sum of inflows from discrete, independent water storages through a channel storage. Water storages include depression, detention, snow and ice, channel bank, aquifer and cavern. Evapotranspiration is incorporated in the recession formula, but seasonal effects and basin wetness and

storage conditions before storms are not considered. Data from seven basins involving 156 precipitation-free recessions are used to test the performance of two- and three-parameter approximations to the theoretical recession formula. Recessions are defined to last at least 2 weeks and to begin 2 days after the peak of a basin outflow hydrograph, or at a point on the falling limb 2 days after any precipitation occurs. Recessions end when precipitation recommences, or when daily flow data stop decreasing. An inverse square formula explains most variance in the two-parameter case, in contrast to the simple exponential formula usually recommended for recession modelling. With three parameters, equally good performance is shown by formulae involving a constant plus an inverse square, or inverse cubic, or simple exponential term. These theoretically based formulae should be useful at basin scale for interpolating or extrapolating recession data, particularly in basins where little is known about water storage behaviour.

CLIMATOLOGY

Defining area-average parameters in meteorological models for land surfaces with mesoscale heterogeneity
J. Noilhan, P. Lacarrere , A.J. Dolman , E.M. Blyth

Abstract
After a brief review of existing methods developed to describe the subgrid variability of soil and vegetation at large scale, the paper summarizes aggregation results obtained in the framework of the **Hapex-Mobilhy and EFEDA field experiments. The parameter aggregation method is based on the estimation of effective parameters for the soil and for the vegetation, representative of the large area. In conditions of moderate land-surface variability, the effective surface fluxes computed using a single column model forced by effective surface parameters are close to the areally-averaged turbulent fluxes estimated by a mesoscale model. A simple method for accounting for the subgrid variability of intercepted rain is tested.

HYDROLOGICAL DATA NETWORK

Improving single-variable and multivariable techniques for estimating missing hydrological data
S. Bennis, F. Berrada, N. Kang

Abstract
A highly efficient technique is developed to obtain the best

.least-squares approximation of the missing hydrological data in the single-variable case, and this is presented here. The technique is based on an appropriate weighing of the estimated values generated by two autoregressive processes operating, respectively, in the forward and backward directions of time.

For the multivariable case, the originality of the work presented here consists in the use of the linear regression model with variable coefficients to estimate missing data. As for the single-variable case, two multivariable regression models are calibrated recursively on available data preceding and following the period of missing data.

The use of Kalman filter (KF) has improved the accuracy in the estimation of the first missing data including the peak flow. For subsequent missing data the confidence of the estimates is greater when using a static model identified by the ordinary least squares (OLS) technique. It has been found that there is a critical rank for which there is an inversion of performance between the KF and OLS technique. When the period of missing data is smaller than the critical rank we use only KF technique. When the period of missing data extends past the critical rank, it is recommended that KF be used to estimate the first missing data and then use OLS technique to estimate data coming after the critical rank.

ENVIRONMENTAL HYDROLOGY

Numerical solution of transport equation for applications in environmental hydraulics and hydrology

M. Rashidul Islam, M. Hanif Chaudhry*

Abstract
The advective term in the one-dimensional transport equation, when numerically discretized, produces artificial diffusion. To minimize such artificial diffusion, which vanishes only for Courant number equal to unity, transport owing to advection has been modeled separately. The numerical solution of the advection equation for a Gaussian initial distribution is well established however, large oscillations are observed when applied to an initial distribution with steep gradients, such as trapezoidal distribution of a constituent or propagation of mass from a continuous input. In this study, the application of seven finite-difference schemes and one polynomial interpolation scheme is investigated to solve the transport equation for both Gaussian and non-Gaussian (trapezoidal) initial distributions.

The results obtained from the numerical schemes are compared with the exact solutions. A constant advective velocity is assumed throughout the transport process. For a Gaussian distribution initial condition, all eight schemes give excellent results, except the Lax scheme which is diffusive. In application to the trapezoidal initial distribution, explicit finite-difference

schemes prove to be superior to implicit finite-difference
schemes because the latter produce large numerical oscillations
near the steep gradients. The Warming-Kutler-Lomax (WKL)
explicit scheme is found to be better among this group. The
Hermite polynomial interpolation scheme yields the best result
for a trapezoidal distribution among all eight schemes
investigated. The second-order accurate schemes are sufficiently
accurate for most practical problems, but the solution of unusual
problems (concentration with steep gradient) requires the
application of higher-order (e.g. third- and fourth-order)
accurate schemes.

SNOW HYDROLOGY

Physics of the spatially averaged snowmelt process
Federico E. Horne, M. Levent Kavvas

Abstract
It has been recognized that the snowmelt models developed
in the past do not fully meet current prediction requirements.
Part of the reason is that they do not account for the spatial
variation in the dynamics of the spatially heterogeneous snowmelt
process. Most of the current physics-based distributed snowmelt
models utilize point-location-scale conservation equations which
do not represent the spatially varying snowmelt dynamics over a
grid area that surrounds a computational node. In this study,
to account for the spatial heterogeneity of the snowmelt
dynamics, areally averaged mass and energy conservation equations
for the snowmelt process are developed. As a first step, energy
and mass conservation equations that govern the snowmelt dynamics
at a point location are averaged over the snowpack depth,
resulting in depth averaged equations (DAE). In this averaging,
it is assumed that the snowpack has two layers. Then, the point
location DAE are averaged over the snowcover area. To develop
the areally averaged equations of the snowmelt physics, we make
the fundamental assumption that snowmelt process is spatially
ergodic. The snow temperature and the snow density are
considered as the stochastic variables. The areally averaged
snowmelt equations are obtained in terms of their corresponding
ensemble averages. Only the first two moments are considered.
A numerical solution scheme (Runge-Kutta) is then applied to
solve the resulting system of ordinary differential equations.
This equation system is solved for the areal mean and areal
variance of snow temperature and of snow density, for the areal
mean of snowmelt, and for the areal covariance of snow
temperature and snow density. The developed model is tested
using Scott Valley (Siskiyou County, California) snowmelt and
meteorological data. The performance of the model in simulating
the observed areally averaged snowmelt is satisfactory.

NUCLEAR HYDROLOGY

Recent advances in dating young groundwater: chlorofluorocarbons,^{3}H/ ^{3}He and ^{85}Kr

P.G. Cook, D.K. Solomon

Abstract

Chlorofluorocarbons, ^{3}H/^{3}He and ^{85}Kr are tracers of atmospheric origin that can be used to date groundwater over periods from 0 to 40 years. In suitable aquifers, measured groundwater ages can be used to estimate groundwater flow paths, and vertical and horizontal flow velocities. In simple, piston flow systems they can be used to estimate groundwater recharge rates with an accuracy of 20% or less, better than can be achieved with traditional hydraulic-based methods. Groundwater dating methods have also been used to reconstruct past releases of contaminants to aquifers.

GROUND WATER HYDROLOGY

A unified model for infiltration and redistribution during complex rainfall patterns

Corrado Corradini, Florisa Melone, Roger E. Smith

Abstract

A relatively simple conceptual model for infiltration during complex rainfall sequences is presented. It is a reformulation of an analytically derived model developed earlier by Smith et al. (1993) [Water Resour. Res., 29(1): 133-144] and Corradini et al. (1994) [Water Resour. Res., 30(10): 2777-2784] in a more homogeneous version suitable for hydrologic applications. The model relies on a single ordinary differential equation through which successive cycles of infiltration-redistribution can be described. The wetting profile, $\theta(z)$, is described by a single similarity curve which is stretched in both z and θ dimensions in accordance with the curve area, I, representing infiltrated water. The actual profile of soil water content after rewetting may be compound, composed two parts, each part represented by a similarity profile shape which evolves in time. The model is calibrated using a silty loam soil and is then tested on a variety of soils, from fine-textured to sandy loam soil types, by comparison with a numerical solution of the Richards equation. Like the earlier formulation, the model simulates infiltration rate particularly well, and the greater simplicity of this model sacrifices very little accuracy of the earlier, more complex model.

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HYDROLOGIC MODELLING

Uncertainty in rainfall-runoff model simulations and the implications for predicting the hydrologic effects of land-use change

N. Nandakumar, R.G. Mein

Abstract

This paper quantifies the levels of uncertainty in rainfall-runoff model predictions due to the errors in hydrological and climatic data, and considers the implications for prediction of the hydrologic effect of land-use changes. In this study, a rainfall-runoff model, the Monash model, was calibrated on one catchment from each of at five experimental areas in Victoria, Australia. The validity of the optimised parameters was first examined by comparing them with independent estimates. Using the posterior distribution of the pan coefficient and model parameter estimates, the uncertainty of model predictions was determined by 90% prediction limits obtained from a Monte-Carlo simulation. The effects of systematic errors in the model parameters and model inputs (rainfall and evaporation) on runoff were also investigated. The analysis showed that systematic errors in rainfall have the most serious effect on predicted flows, but that estimation errors (random) in pan coefficient and model parameters also have significant effects. With this level of background ,noise', up to 65% of the catchment forest area would have to be cleared to produce flow increases detectable at the 90% prediction level, depending on the type of errors and the catchment in question.

NUCLEAR HYDROLOGY

Chemical and isotopic indicators of point-source recharge to a karst aquifer, South Australia

A.L.Herczeg, F.W.J.Leaney, M.F.Stadter et. al.

Abstract

Several hundred sinkholes, swamps and open drainage boreholes throughout the semi-arid to subhumid areas of the southeast of South Australia are potential recharge sites to the upper part of the Garnbier Limestone aquifer. This paper presents the results from a hydrochemical (Cl^- and carbonate chemistry) and isotopic (δ^2H, $\delta^{18}O$ and ^{36}Cl) study used to estimate the importance of localised recharge from these point-source features to the karstic groundwater system. Results show that water recharging the groundwater via point-source features is detectable only on a local scale. Chemical and isotopic

compositions of groundwater more than 150 m from the larger of the point-source features are indistinguishable from regional groundwater compositions. Chloride concentrations, carbonate chemistry, and isotope data show that annual input of water via point sources contributes less than 10% of total recharge, with diffuse recharge providing the remainder to the study area as a whole. Point-source recharge is generally intermittent, and was observed to occur only for a few days at a time and only after a threshold of sustained rainfall had been exceeded (i.e. greater than 2.5 mm day^{-1} for more than 3 days).

The stable isotopic composition of waters recharging via sinkholes tends to be enriched in ^{2}H and ^{18}O relative to regional groundwater and local precipitation. This is probably caused by a small degree of evaporation (less than 5% of water falling within the catchment) occurring during winter at high relative humidity (greater than 95%) before recharge. ^{36}Cl from weapons testing is detectable in groundwaters near sinkholes and indicates significant retardation of Cl$^-$ within soils of. the respective sub-drainage systems. Recharge has therefore occurred within the past 30 years, but cannot be quantified with any reliable precision from the ^{36}Cl data.

GROUND WATER HYDROLOGY

Evaluation of unconfined-aquifer parameters from pumping test data by nonlinear least squares

Manoutchehr Heidari, Allen Moench

Abstract

Nonlinear least squares (NLS) with automatic differentiation was used to estimate aquifer parameters from drawdown data obtained from published pumping tests conducted in homogeneous, water-table aquifers. The method is based on a technique that seeks to minimize the squares of residuals between observed and calculated drawdown subject to bounds that are placed on the parameter of interest. The analytical model developed by Neuman for flow to a partially penetrating well of infinitesimal diameter situated in an infinite, homogeneous and anisotropic aquifer was used to obtain calculated drawdown. NLS was first applied to synthetic drawdown data from a hypothetical but realistic aquifer to demonstrate that the relevant hydraulic parameters (storativity, specific yield, and horizontal and vertical hydraulic conductivity) can be evaluated accurately. Next the method was used to estimate the parameters at three field sites with widely varying hydraulic properties. NLS produced unbiased estimates of the aquifer parameters that are close to the estimates obtained with the same data using a visual curve-matching approach. Small differences in the estimates are a consequence of subjective interpretation introduced in the visual approach.

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NUCLEAR HYDROLOGY

55. Journal of Hydrology 192 (1997) 314-320

Tracer transport in a stony hillslope soil under forest

B. Buchter*, C. Hinz, J. Leuenberger

Abstract

To study water and solute movement in a stony sloping (35%) soil, two tracers were applied to a Rendoll soil under a beech forest. From May to November, the movement of the tracers (Cl⁻ and Br⁻) induced by natural rainfall was monitored by soil water sampling. Although the soil water transported the tracers mainly vertically, part of them flowed parallel to the soil surface within the topmost 15 cm. At the end of the experiment, the peak concentrations reached depths between 65 and 105 cm. These values, together with the measured mean water content, showed that about 40% of the throughfall was evaporated by the understory vegetation.

HYDROLOGIC MODELLING

56. Journal of Hydrology 193 (1997) 45-60

Critical rainfall duration for overland flow from an infiltrating plane surface

Bernhard H. Schmid

Abstract

Design flows from infiltrating micro-catchments are investigated using a kinematic model of overland flow and a physics-based representation of the infiltration process. Critical storm duration is shown to be governed by two relationships, one equivalent to the traditional approach of setting concentration time equal to rainfall duration and the other yielding a potentially critical duration independent of plane length. In case of two competing results, the valid one is recognized as giving the shorter of the two durations calculated. Derivation of the governing equations has been carried out preserving as much generality as possible. In addition to the equations mentioned, a "rainfall window" describing all overland flow producing storms in accordance with a given intensity duration-frequency (IDF) relationship is identified and mathematical expressions for its evaluation are given. Practical application is demonstrated by a number of sample computations.

GROUND WATER HYDROLOGY

57. Journal of Hydrology 193 (1997) 270-292

An improved dual porosity model for chemical transport in macroporous soils
Chittaranian Ray, Timothy R. Ellsworth , Albert J. Valocchi, Charles W. Boast

Abstract
The often observed processes involved in preferential water flow and chemical transport in porous media appear to be realistically described using a dual-continuum (dual-porosity) approach. In this approach, the porous medium is conceptualized as two coexistent continua, one representing the bulk matrix and the other the macropore region. Fluid and solute mass transfer between the two regions in the conceptual model occurs under pressure and concentration gradients. However, oscillatory behaviour (overshoot problems in the macropore region) of the transport equation was observed for high values of the advective solute flux relative to the diffusive solute flux between the two regions. To circumvent this oscillatory behaviour, the fluid coupling term in the transport equations was treated as an element-averaged, rather than a nodal property. The model was extended to two space dimensions for evaluating the impact of agricultural practices on solute leaching. A linear kinetic sorption module in the transport equations and a simple plant root extraction routine in the flow equations were also added. Although the simulation results show promise, additional work will be needed to determine realistic model parameter values.

SNOW HYDROLOGY

Impact assessment of climate change on the hydrological response of a snow and glacier melt runoff dominated Himalayan river
Pratap Singh, Naresh Kumar

Abstract
The effect of climate change on snow water equivalent, snowmelt runoff, glacier melt runoff and total streamflow and their distribution is examined for the Spiti river. This is a high altitude Himalayan river located in the western Himalayan region. The total streamflow of this river has a significant contribution from snow and glacier melt runoff. Plausible hypothetical scenarios of temperature and precipitation changes based on the simulation of climate change over the Indian subcontinent by the Hamburg climate model are adopted in the present study. The UBC watershed model was used to simulate the hydrological response of the basin under changed climatic scenarios. The adopted changes in temperature and precipitation covered a range from 1 to 3°C and from -10 to +10%, respectively. Snow water equivalent reduces with an increase in air temperature. However, no significant change is found in the snow water equivalent of the Spiti basin by the projected increase in air temperature (T + 1 to T + 3°C). An increase of 2°C in air temperature reduced annual snow water equivalent in the range of 1 to 7%. Changes in precipitation caused proportional changes

in snow water equivalent. It is found that annual snowmelt runoff, glacier melt runoff and total streamflow increase linearly with changes in temperature (1-3°C), but the most prominent effect of increase in temperature has been noticed on glacier melt runoff for this high altitude basin. For example, an increase of 2°C in air temperature has enhanced annual snowmelt runoff, glacier melt runoff and total streamflow in the range of 4-18%, 33-38% and 6-12% respectively. The effect of change in precipitation (P-10 to P+10%) suggests a linear increase in snowmelt runoff and total streamflow, while, in general, glacier melt runoff is inversely related to changes in precipitation. Snowmelt runoff is found more sensitive than glacier melt runoff to changes in precipitation (P-10 to P+10%). Under a warmer climate scenario, snowmelt runoff and glacier melt runoff cause an earlier response of total streamflow and a change in flow distribution. The seasonal analysis of total streamflow indicates that an increase in air temperature produces an increase in the pre-monsoon season followed by an increase in the monsoon season. Implications of such seasonal changes are also briefly discussed.

HYDROLOGIC MODELLING

59.   Journal of Hydrology 197 (1997) 203-229

Methods for combining the outputs of different rainfall-runoff models
Asaad Y. Shamseldin, Kieran M. O'Connor and G.C. Liang

Abstract
      The present paper promotes the concept of combining the estimated output of different rainfall runoff models to produce an overall combined estimated output to be used as an alternative to that obtained from a single individual rainfall-runoff model. Three methods of combining model outputs are considered, namely the simple average method (SAM), the weighted average method (WAM) and the neural network method (NNM). The estimated discharges of five rainfall-runoff models for 11 catchments are used to test the performance of these three combination methods. The results confirm that better discharge estimates can be obtained by combining the model outputs of different models.

SURFACE WATER HYDROLOGY

60.   Journal of Hydrology 197 (1997) 230-257

Development of regional parameter estimation equations for a macroscale hydrologic model
Fayez A. Abdulla, Dennis P. Lettenmaier

Abstract

A methodology for developing regional parameter estimation equations, designed for application to continental scale river basins, is described. The approach, which is applied to the two-layer Variable Infiltration Capacity (VIC-2L) land surface hydrologic model, uses a set of 34 unregulated calibration or "training" catchments (drainage areas 10^2-10^4 km²) distributed throughout the Arkansas-Red River basin of the south central U.S. For each of these catchments, parameters were determined by:
a) prior estimation of two of the model parameters (saturated hydraulic conductivity and pore size distribution index) from the U.S. Soil Conservation Service State Soil Geographic Data Base (STATSGO) data base; and
b) estimation of the remaining seven parameters via a search procedure that minimizes the sum of squares of differences between predicted and observed streamflow. The catchment parameters were then related to 11 ancillary distributed land surface characteristics extracted from STATSGO, and 17 variables derived from station meteorological data. The seven regression equations explained from 54 to 76% of the variance of the parameters. The most frequently occurring ancillary variables were the average permeability, saturated hydraulic conductivity, and SCS hydrologic Group B (typically soils with moderately high infiltration rates) fraction derived from STATSGO, and the average temperature and standard deviation of fall precipitation. The method was tested by comparing simulations using the regional (regression equation) parameters for six unregulated catchments not in the parameter estimation set. The model performance using the regional parameters was quite good for most of the calibration and validation catchments, which were humid and semi-humid. The model did not perform as well for the smaller number of arid to semi-arid catchments.

HYDROLOGICAL MODELLING

Parameterisation, calibration and validation of distributed hydrological models
Jens Christian Refsgaard

Abstract

This paper emphasizes the different requirements for calibration and validation of lumped and distributed models. On the basis of a theoretically founded modelling protocol, the different steps in distributed hydrological modelling are illustrated through a case study based on the MIKE SHE code and the 440 **km Karup catchment in Denmark. The importance of a rigorous and purposeful parameterisation is emphasized in order to get as few "free" parameters as possible for which assessments through calibration are required. Calibration and validation using a split-sample procedure were carried out for catchment discharge and piezometric heads at seven selected observation

wells. The validated model was then used for two further validation tests. Firstly, model simulations were compared with observations from three additional discharge sites and four additional wells located within the catchment. This internal validation showed significantly poorer results compared to the calibration/validation sites. Secondly, the validated model based on a 500 m model grid was used to generate three additional models with 1000m, 2000m and 4000m grids through interpolation of model parameters. The results from the multi-scale validation suggested that a maximum grid size of 1000m should be used for simulations of discharge and ground-water heads, while the results deteriorated with coarser model grids.

SEDIMENTATION IN RESERVOIRS

Nature of solute loads in the rivers of the Bengal drainage basin, Bangladesh

Dilip K. Datta and V. Subramanian

Abstract

The Bengal drainage basin is geologically one of the youngest and tectonically most active denudation regimes of the world, and encompasses the total lower reaches of the Ganges - Brahmaputra-Meghna (GBM) drainage basin. The GBM river system contributes around 4.5% of the total annual global freshwater flux to the oceans. The solute load of the GBM river system is dominated by the carbonate weathering products of the transport-limited denudation regime. However, in the Meghna basin, which drains a mountainous region, silicate weathering is slightly more predominant, and the solute load tends to be more influenced by the atmospheric contribution.

The river system represents about 5% (152 x $10^6 tyr^{-1}$) of the annual global chemical flux to the world's oceans. The chemical denudation rate of the GBM system in the Bengal basin, is one of the world's highest (79-114 t km^{-2}/yr), suggesting intensive weathering and erosion in the drainage basin both in Bangladesh as well as in the hinterlands of India and China.

SURFACE WATER HYDROLOGY

Technical note : Linearised Boussinesq equation for modelling bank storage - a correction

W.L. Hogarth , R.S. Govindaraju, J.Y. Parlangec, J.K. Koelliker

Abstract

In a recent paper, Govindaraju and Koelliker used the Boussinesq equation to describe the horizontal one-dimensional flow of water into an unconfined aquifer from a channel. An

improved analytical approach is suggested both for constant and time dependent boundary conditions using the linearised Boussinesq equation. The results are compared with those of Govindaraju and Koelliker and the numerical solution of the Boussinesq equation. The new analytical approach yields better results, especially for positive fluxes from stream to aquifer, and is as easy to apply as the method of Govindaraju and Koelliker. When the flux is negative more theoretical studies are needed.

SURFACE WATER HYDROLOGY

Statistical development and validation of discharge equations for natural channels

S. Lawrence Dingman and Keshav P. Sharma

Abstract

Although the Manning equation is widely accepted as the empirical flow law for rough turbulent open-channel flow, using the equation in practical situations such as slope-area computations is fraught with uncertainty because of the difficulty in specifying the value of the reach resistance, Manning's n. Riggs (1976, J. Res. US Geol. Surv., 4: 285-291) found that n was correlated with water-surface slope, and proposed a multiple-regression equation that obviates the need for estimating n in slope-area estimates of discharge. Because his relation was developed from a relatively small sample (N = 62), had potential flaws owing to multicollinearity, and was not thoroughly validated, we used an expanded data base (N = 520) and objective methods to develop a new relation for the same purpose:

$$Q = 1.564 A^{1.173} R^{0.400} S^{-0.0543 \log S}$$

where Q is discharge $(m^3 s^{-1})$, A is cross-sectional area (m^2), R is hydraulic radius (m), and S is water-surface slope. We validated Riggs's model and our model using 100 measurements not included in model development and found that both give similar results. Riggs's model is somewhat better in terms of actual $(m^3 s^{-1})$ error, but ours is better in terms of relative (log Q) error. We conclude that either Riggs's or our model can be used in place of Manning's equation in slope-area computations, but that our model is preferable because it has less bias, minimizes multicollinearity, and performs better when applied to discharge changes in individual reaches. We also found that our model performs better than those of Jarrett (1984, J. Hydraul. Eng., 110: 1519-1539) or Riggs in the range of applicability of Jarrett's equation (0. 15 m$\leq$R$\leq$2.13 m; 0.002$\leq$S$\leq$0.052). Both Riggs' S and our models significantly overestimate Q in flows satisfying both of the following conditions: $Q < 3$ m^3 s^{-1} and Froude number less than 0.2.

GROUND WATER HYDROLOGY

A finite-element linked model for analysis of solute transport in 3-D space of multilayer subsurface systems

M. Ghulam Rabbania, James W. Warner

Abstract

The computational burden and instability of the fully 3-D saturated-unsaturated unified approach can be lessened considerably by using the linked model of the quasi 3-D approach. This approach is applicable to a multi-layer subsurface system consisting of aquifers and aquitards. In this approach, 1-D vertical flow and solute transport is assumed in the vadose zone and aquitards, and 2-D horizontal flow and quasi 3-D solute transport are assumed in the aquifers to simulate flow and transport in 3-D space. In this paper, the aquifers are sliced into sublayers. In an aquifer with 2-D flow, transport in the horizontal direction is assumed to be caused by advection and dispersion while transport in the vertical direction is assumed to be caused solely by dispersion. As a mathematical simplicity, the equations for vertical flow and transport in the vadose zone and confining layers and the equations for flow and transport in the aquifer are solved separately in two different solution packages. During this time-marching analysis, the output in terms of source/sink obtained from one solution package is coupled with the equations in the other solution package. This linked model quasi 3-D approach was tested with other widely used numerical models and analytical solutions, and was found stable and technically robust.

SNOW HYDROLOGY

Effect of orography on precipitation in the western Himalayan region

Pratap Singh and Naresh Kumar

Abstract

The present study deals with precipitation distribution with altitude for the Satluj and Beas basins in the western Himalayas. Rainfall increases linearly with elevation for both basins in the outer Himalayan range. The middle Himalayan range of the Beas basin has exceptionally heavy rainfall on the windward side and much less rain (less than half) on the leeward side. Rainfall gradients are 106mm per 100m to windward and 13mm per 100m to leeward of this range. Different trends of rainfall variation with elevation are observed in different seasons in the middle Himalayan range with a linear increase in annual rainfall. Rainfall follows an exponential decreasing trend with altitude

in the greater Himalayan range. Average annual rainfall decreases from the outer Himalayas to the greater Himalayas in the Satluj basin. In the greater Himalayas, it is about one-sixth of outer Himalayas rainfall. Maximum rainfall is in the middle Himalayan range in the Beas basin. Monsoon rainfall contributes the largest part of the annual rainfall for all the Himalayan ranges. Spatial correlation is higher in the outer Himalayas range than in the other ranges.

Snowfall increases linearly with elevation in the greater Himalayas. Snowfall gradients for the Spiti and Baspa sub-basins are 43mm per 100m and 10mm per 100m, respectively. The ratio of snowfall to annual precipitation varies linearly with altitude. All stations recorded more than 60% snow contribution to annual precipitation. Extrapolation of the relationship indicates that snow and rain contribute equally at about 2000m, and all the precipitation occurs as snow above 5000m.

GROUND WATER HYDROLOGY

Comparison of three hydraulic property measurement methods
Dirk Mallants, Diederik Jacques, Peng-Hsiang Tseng et.al.

Abstract

Hydraulic functions of soils may differ depending on the different measuring methods used. The performance of three different methods for measuring soil-hydraulic properties of a heterogeneous field were evaluated. The experiments were conducted using three different sizes of undisturbed soil cores collected systematically along a 31m long transect of a well drained sandy loam soil having three soil horizons (Ap, 0-0.25 m; Cl, 0.25-0.55 m; C2, 0.55-1.00 m). The laboratory studies involved: (1) detailed unsteady drainage-flux experiments performed on fifteen columns of 1 m length and 0.3 m diameter; (2) combined crust test and hot-air methods applied to thirty columns of 0.2 m length and 0.2 m diameter and to a subset of sixty cylinders of 0.1m length and 0.045m diameter, respectively, taken from the Ap horizon; and (3) desorption experiments carried out on a total of one hundred eighty cores of 0.051 m length and 0.05 m diameter collected evenly from the three horizons. Mean soil hydraulic properties were inferred from experimental data characterizing either selected depths or the soil profile as a whole. The results revealed considerable differences among estimated mean soil properties as obtained with different measuring techniques. Although the application of scaling theory substantially reduced variation in the measured pressure heads (h) and conductivities (K), the results revealed that scaling parameters determined from soil pressure head were not identical to scaling factors determined from hydraulic conductivity. The results also show that K scaling factors in general were much more variable than h scaling factors, and that the observed variability in scaling factors also depend upon the measurement

technique used.

SURFACE WATER HYDROLOGY / FLOOD FORCASTING

68. Journal of Hydrology 200 (1997) 164-178

A non-linear perturbation model considering catchment wetness and its application in river flow forecasting
J. Xia, K.M. O'Connor, R.K. Kachroo and G.C. Liang

Abstract

A non-linear perturbation model for river flow forecasting is developed, based on consideration of catchment wetness using an antecedent precipitation index (API). Catchment seasonality, of the form accounted for in the linear perturbation model (the LPM), and non-linear behaviour both in the runoff generation mechanism and in the flow routing processes are represented by a constrained non-linear model, the NLPM-API. A total of ten catchments, across a range of climatic conditions and catchment area magnitudes, located in China and in other countries, were selected for testing daily rainfall-runoff forecasting with this model. It was found that the NLPM-API model was significantly more efficient than the original linear perturbation model (the LPM). However, restriction of explicit non-linearity to the runoff generation process, in the simpler LPM-API form of the model, did not produce a significantly lower value of the efficiency in flood forecasting, in terms of the model efficiency index R^2.

GROUND WATER HYDROLOGY

69. Journal of Hydrology 201 (1997) 211-229

Water flow modelling in the unsaturated zone with imprecise parameters using a fuzzy approach
K. Schulz and B. Huwe

Abstract

An alternative approach, based on fuzzy set theory, is presented to express imprecision of parameters in a non-probabilistic sense. Imprecision may originate from indirect measurements, estimation routines, subjective interpretation and expert judgement of available information. One dimensional, steady state water flow in the unsaturated zone of homogeneous soils, which is described by the Darcy-Buckingham equation, was chosen to evaluate and to incorporate fuzzy soil hydraulic properties and boundary conditions in the modelling procedure. It is here used to describe soil water pressures with depth, as well as to calculate maximum evapotranspiration rates under steady state conditions. Solving the fuzzy equation for steady

state water flow results in minimizing/maximizing procedures, from where resulting membership functions of the dependent variable are calculated. A comparison to a more classical stochastic approach points out the main differences between fuzzy and stochastic concepts to account for uncertainties. Finally, a sensitivity analysis shows the strong impact of different shapes of membership functions of the input parameters on the resulting membership functions of maximum evapotranspiration rates and soil water pressures.

NUCLEAR HYDROLOGY

Stable isotope tracers: natural and anthropogenic recharge, Orange County, California
Alan E. Williams

Abstract
    Stable isotopic techniques have been utilized to locate occurrences and trace movements of a variety of naturally and anthropogenically recharged waters in aquifers of Orange County, California. This basin is of particular interest not only because it provides the dominant water supply for the two million residents of this well-populated county, but also because it is representative of a common and environment where natural recharge is dominated by distant, high-elevation precipitation transported by a major river. Such arid basins are particularly sensitive to climatic and anthropogenic disturbance of their recharge and their subsurface hydrology.
    In order to identify distinctive waters, oxygen and hydrogen stable isotope ratios from Orange County wells have been compared with a regional database including an array of surface water samples representative of watershed runoff. Four distinctive subsurface water types can be resolved. Waters of "local" rainfall and imported, "Colorado" River aqueduct origins are easily distinguished from dominant, "native" Santa Ana river compositions by use of hydrogen and oxygen stable isotope analysis. Recent human interference with Santa Ana river flow and recharge is also marginally resolvable by isotopic techniques. Distinguishable isotopic signatures of "recent" Santa Ana recharge appear to be due to evaporative loss, perhaps during storage in the Prado Reservoir or in percolation ponds, prior to recharge into Orange County aquifers. Characterization of traceable isotopic signatures of distinct natural and anthropogenic recharge components provides a major advance towards use of such techniques for developing a well constrained, three-dimensional hydrologic model for this complex basin.

WATER HARVESTING

A macro-scale natural hydrologic cycle water availability model
Adam H. Slutsky, Ben C. Yen

Abstract
        Long term water usage can be no more than that which is naturally available through the hydrologic cycle. To help in the determination of the hydrologically desirable water usage from surface and groundwater sources, a simple, idealized long-term analysis of water availability based solely on the natural hydrologic cycle is suggested. The concept of a hydrologic replacement time is introduced to determine the water availability from ground and surface water sources. Hydrologic replacement time is defined as the average time for water to complete a trip through a particular phase of the hydrologic cycle. The hydrologically desirable amount of water utilization from groundwater and surface water is proportional to the amount available from these sources. The available water is calculated on the basis of hydrologic replacement time, volume and any allowable water source depletion. The water availability problem is addressed at two spatial scales - global and continental. For each spatial scale two cases are considered: one in which no groundwater depletion is allowed and one in which a small amount of groundwater depletion is permissible. On the basis of the hydrologic characteristics of groundwater and surface water sources, it is desirable to utilize more surface water than groundwater for both spatial scales.

WATER QUALITY

Occurrence of mineral water springs in the stream channel of the Allier River (Massif Central, France): chemical and Sr isotope constraints
Philippe Negrel, Christian Fouillac, Michel Brach

Abstract
        The French Massif Central has long been recognized as an area with numerous mineral water springs. It is often very difficult to measure the flow rate of mineral springs since they are spread out over extensive areas. Water from the Allier River has been sampled monthly over a 13-month period and a spatial cross-section survey carried out at base flow conditions in order to estimate the discharge of mineral water in the Allier River streambed.
        For the monthly survey, the $^{87}Sr/^{86}Sr$ ratios vary between 0.709511 and 0.712656. A good correlation exists between $^{87}Sr/^{86}Sr$ and $1/Sr$ ratios and defines binary mixing between

mineral waters and the Allier River sensu-stricto. The mixing processes have been studied using the Sr isotopic systematic and a conservative species (chloride). Except for one sample, the mineral water input never exceeds 2%. However, the mineral water discharge into the Allier streambed could not he precisely estimated because effluent seepage of mineral water may occur in a part of the channel representing only a small volume of the cross-sections.

Variations in the solute concentrations across the river channel were measured at 14 sites chosen as being representative of areas where: (a) mineral water emerges, (b) no mineral water emerges, and (c) mixing is complete. A model developed for the monthly study using Cl as a reference was used in the spatial survey. The input of mineral water in the Allier streambed ranges from 0.1-0.15% in most of the samples and is greater than 2% at two points. The general mass balance of the proportions of mineral water and Allier River water (sensu-stricto) using the sum of cations and anions was calculated and the input of mineral water into the Allier streambed was determined at the cross-section nearest the Allier gauging station (0.134%). The discharge of the Allier River at the gauging station was about 17.7 m³/s during the sampling period, which gives a discharge of mineral water of about 0.02 m³/s into the Allier channel.

DROUGHT HYDROLOGY

Long-range persistence in climatological and hydrological time series: analysis, modelling and application to drought hazard assessment

Jon D. Pelletier and Donald L. Turcotte

Abstract

We present power spectra of time-series data for tree ring width chronologies, atmospheric temperatures, river discharges and precipitation averaged over hundreds of stations worldwide. The average power spectrum S for each of these phenomena is found to have a power-law dependence on frequency with exponent -1/2: $S(f) x f^{-1/2}$ An advection-diffusion model of the vertical transport of heat and water vapour in the atmosphere is presented as a first-order model of climatic and hydrological variability. The model generates variability with the observed spectrum. The model is validated with a correlation analysis of temperature and water vapour concentration measurements from the TIROS operational vertical sounder (TOVS). Drought frequency analyses based on synthetic lognormal streamflows with the above power spectrum are presented. We show that the presence of long memory as implied by the power-law power spectrum has a significant effect on the likelihood of extended droughts compared with the drought hazard implied from standard autoregressive models with short memory.

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American Water
Resources Bulletin

GROUND WATER HYDROLOGY

Ground water solute transport, optimal remediation   Planning, and decision making under uncertainty
Miguel A. Medina, Jr., Timothy L. Jacobs, Weichao Lin, and Kuo- Ching Lin

ABSTRACT

A groundwater quality modelling advisory system has been developed for the U.S. Air Force for use in investigating remediation alternatives for the cleanup of subsurface contamination. The system is capable of accounting for uncertainty, not only in the prediction of solute transport but also in the optimization of the remediation scheme through chance constraints. The system guides users in the selection of appropriate transport models through an algorithm independently tested with machine learning codes. An application to Hill Air Force Base, Utah, is presented for which different pump-and-treat strategies are considered: the results are evaluated in terms of the cumulative distribution of the contaminant concentration for each case and the tradeoff relationship between the cost of remediation and the probability that the remediation strategy exceeds an established maximum allowable contaminant concentration.

GROUND WATER HYDROLOGY / HYDROLOGICAL MODELLING

MODELLING GROUND WATER FLOW USING FLUX BOUNDARY CONDITIONS
Rolando Bravo, Jerry R. Rogers, and Theodore G. Cleveland

ABSTRACT

Determination of the boundary conditions for modelling ground water flow is a critical point especially in regional models. Normally the regional models require model areas that are greater than the given area of interest. This work focuses on the prediction of hydraulic heads in regional models using flux boundary conditions. The model uses flux boundary conditions that were estimated using a radial flow analog and Darcy's law. The regional model that is presented uses no parameter identification (inverse estimation) procedures. In the present work, the Houston area was used. The simulation of the hydrological conditions of the Chicot and Evangeline Aquifers that underlie the Houston area were made using the available information about the geological profile in the Houston region and the current information about the existing production wells. The regional model works as a forward problem. The system parameters such as hydraulic conductivity, specific storage, and

hydrological stresses were specified, and the model predicts the hydraulic head. Actual data from piezometers operated by the U.S. Geological Survey (USGS) in many places throughout Houston were used as initial conditions. Some piezometric head data were generated using the regional variable theory called kriging to supply head estimates in areas where data were unavailable. The Modular Three Dimensional Finite Difference Groundwater Flow Model developed by the USGS was used to predict the hydraulic heads. The predicted ground water heads are compared to the actual data. The results show that the model performs well for locations where data were available.

GROUND WATER HYDROLOGY

Using sensitivity analysis to assist parameter Zonation in ground water flow model

Jiu J. Jiao and David N. Lerner

ABSTRACT

For numerical modelling of ground water movement in a real aquifer system, the aquifer is usually divided into hydrogeo-logically defined zones, each with its own parameter values. The responses of the system, such as head or drawdown, are often available only in some of the zones. The estimated parameters of all the zones are based on the measured response in these limited zones. However, the estimates for some of the zones may be very uncertain, and these zones are therefore not justified by the data. In this paper, an approach is presented to understand which zone may produce uncertain parameter values and should be lumped with its neighbour. This approach is demonstrated using a regional numerical model for pumping test analysis in the Nottinghamshire aquifer, UK. A step-by-step process is used in identifying the aquifer zones and estimating their parameters based on the principle of using the smallest possible numbers of zones and parameters for adequate representation of the drawdown response. After the parameters of each zone are estimated, the sensitivity features of these parameters are examined. The results show that the parameters in one zone can be estimated properly by the drawdown in another zone only when there is significant sensitivity. For transmissivity, sensitivity between zones occurs when there is significant flow between them. For storativity, sufficient sensitivity can occur without large flows between the zones, provided that one zone causes significant drawdown in the other. This idea can be extended to the flow model for a large aquifer system. If the aquifer is divided in such a way that aquifer responses are not sensitive to the parameters in some of the zones, the parameters in those zones cannot be estimated properly and should be lumped into their neighbouring zones. In this way, a simple but more reasonable model can be built.

SNOW HYDROLOGY

A comparison of geostatistical methodologies used to estimate snow water equivalent

Steven S. Carroll and Noel Cressie

ABSTRACT

The need to monitor and forecast water resources accurately, particularly in the western United States, is becoming increasingly critical as the demand for water continues to escalate. Consequently, the National Weather Service (NWS) has developed a geostatistical model that is used to obtain areal estimates of snow water equivalent (the total water content in all phases of the snowpack), a major source of water in the West. The areal snow water equivalent estimates are used to update the hydrologic simulation models maintained by the NWS and designed to produce extended streamflow forecasts for river systems throughout the United States. An alternative geostatistical technique has been proposed to estimate snow water equivalent. In this research, we describe the two methodologies and compare the accuracy of the estimates produced by each technique. We illustrate their application and compare their estimation accuracy using snow data collected in the North Fork Clearwater River basin in Idaho.

GROUND WATER HYDROLOGY/ENVIRONMENTAL HYDROLOGY

Assessing the economic benefits of ground water for environmental policy decisions

John C. Bergstrom, Kevin J. Boyle, Charles A. Job and Mary Jo Kealy

ABSTRACT

The full range of environmental and economic services of ground water need to be accounted for in policy decisions. Non-recognition of these services imputes a lower value for the ground water resource in establishing policies. We describe a conceptual framework for identifying and measuring the economic value of groundwater. The valuation framework links changes in physical characteristics of ground water to services provided by ground water and the economic effects of changes in ground water services. In addition to the framework, we develop a general protocol to follow for assessing the benefits of ground water policies. Application of the protocol will aid in establishing structure and consistency across policy assessments and improve the accuracy and completeness of benefit estimates, avoid double-

counting problems, and eliminate duplication of ground water valuation efforts.

SURFACE WATER HYDROLOGY

79. WATER RESOURCES BULLETIN , VOL. 32, NO. 2,1996, PP. 305

A comparison of methods for calculation of Radar-Rainfall hourly accumulations
Chunyan Liu and Witold F Krajewski

ABSTRACT

We compared two interpolation schemes for calculation of hourly accumulation of radar-rainfall. The schemes are: (1) the Advection Method, and (2) the Space-Time Kriging Method. The performance of the methods is investigated using numerical simulation experiments. Space-time evolution of rainfall fields is generated from a stochastic model. The generated fields are sampled following typical radar scanning strategies, and the investigated schemes are applied to obtain accumulated rainfall patterns. The statistical results and a visual analysis of the graphical images suggest that it is advisable to use an interpolation scheme for radar observations even when storm velocity is not high. The Space-time Kriging Method provides the best results for low wind velocity. The Advection Method has the smallest standard deviation and mean absolute error, and preserves well the true rainfall pattern for high wind velocity.

CLIMATOLOGY

80. WATER RESOURCES BULLETIN, VOL. 32, NO. 2,1996, PP.357

Integrating a geographic information system, a scientific Visualization system,and a precipitation model
L. E. Hay and L. K Knapp

ABSTRACT

Investigating natural, potential, and human-induced impacts on hydrologic systems commonly requires complex modelling with overlapping data requirements, plus massive amounts of one- to four-dimensional data at multiple scales and formats. Given the complexity of most hydrologic studies, the requisite software infrastructure must incorporate many components including simulation modelling and spatial analysis with a flexible, intuitive display. Integrating geographic information systems (GIS) and scientific visualization systems (SVS) provides such an infrastructure. This paper describes an integrated system consisting of an orographic precipitation model, a GIS, and an SVS. The results of this study provide a basis for improving the understanding of hydro-climatic processes in mountainous regions. An additional benefit of the integrated system, the value of

which is often underestimated, is the improved ability to communicate model results, leading to a broader understanding of the model assumptions, sensitivities, and conclusions at a management level.

HYDROLOGICAL MODELLING / WATERSHED MANAGEMENT

81. WATER RESOURCES BULLETIN, VOL. 32, NO.3,1996, PP.541

SWMHMS - Small watershed monthly hydrologic modelling system
B. Allred and C. T Haan

ABSTRACT

SWMHMS is a conceptual computer modelling program developed to simulate monthly runoff from a small nonurban watershed. The input needed to run model simmulations include daily precipitation, monthly data for evapotranspiration determination (average temperature, crop consumptive coefficients, and percent daylight hours), and six watershed parameter values. Evapotranspiration was calculated with the Blaney-Criddle equation while surface runoff was determined using the Soil Conservation Service curve number procedure. For watershed parameter evaluation, SWMHMS provides options for both optimization and sensitivity analysis. Observed runoff data are required along with the model input previously mentioned in order to conduct parameter optimization. SWMHMS was tested with data from six watersheds located in different regions of the United States. Model accuracy was generally found to be very good except on watersheds having substantial snowfall accumulation.

In having only six watershed parameters, SWMHMS is less complex to use than many other computer programs that calculate monthly runoff. Consequently, SWMHMS may find its greatest application as an educational tool for students learning principles of hydrologic modelling, such as parameter evaluation procedures and the impacts of input data uncertainty on model results.

SURFACE WATER HYDROLOGY

82. WATER RESOURCES BULLETIN, VOL.32, NO. 4,1996, pp. 753

Runoff simulation using radar rainfall data
John C. Peters and Daniel J. Easton

ABSTRACT

Rainfall data Products generated with the national network of WSR-88D radars are an important new data source provided by

the National Weather Service. Radar-based data include rainfall depth on an hourly basis forgrid cells that are nominally 4 km square. The availability of such data enables application of improved techniques for rainfall-runoff simulation. A simple quasi-distributed approach that applies a linear runoff transform to gridded rainfall excess has been developed. The approach is an adaptation of the Clark conceptual runoff model, which employs translation and linear storage. Data development for, and results of, an initial application to a 4160 km² watershed in the Midwestern U.S. are illustrated.

WATER QUALITY

83. WATER RESOURCES BULLETIN

Using uncensored trace-level measurements to detect trends in ground water contamination
Maxine E. Dakins, P. Steven Porter, Michele West, and S.Trivikrama Rao

ABSTRACT
Environmental decision making involving trace-levels of contaminants can be complicated by censoring, the practice of reporting concentrations either as less than the limit of detection (LOD) or as not detected (ND) when a test result is less than the LOD. Censoring can result in data series that are difficult to meaningfully summarize, graph, and analyse through traditional statistical methods. In spite of the relatively large measurement errors associated with test results below the LOD, simple and meaningful analyses can be carried out that provide valuable information not available if data are censored. For example, an indication of increasing levels of contamination at the fringe of a plume can act as an early warning signal to trigger further study, an increased sampling frequency, or a higher level of remediation at the source. This paper involves the application of nonparametric trend analyses to uncensored trace-level groundwater monitoring data collected between March 1991 and August 1994 on dissolved arsenic and chromium for seven wells at an industrial site in New York.

WATERSHED MANAGEMENT

84. WATER RESOURCES BULLETIN, VOL.32, NO.5, 1996, pp. 1039

A watershed-level ecological risk Assessment methodology
W. CullY Hession, Daniel E. Storm, C. Thomas Haan et.al.

ABSTRACT
We present an ecological risk assessment methodology at the watershed level for freshwater ecosystems. The major component is a Pollutant transport and fate model (a modified EUTROMOD)

with an integrated Uncertainty analysis utilizing a two-phase Monte Carlo procedure. The uncertainty analysis methodology distinguishes between knowledge uncertainty and stochastic variability. The model assesses the ecological risk of lentic (lake) ecosystems in response to the stress of excess phosphorus resulting in eutrophication. The methodology and model were tested on the Wister Lake watershed in Oklahoma with the lake and its trophic state as the endpoint for ecological risk assessment. A geographic information system was used to store, manage, and manipulate spatially referenced data for model input.

GROUND WATER HYDROLOGY

85. WATER RESOURCES BULLETIN, VOL.32, NO.5, 1996, pp.1081

Simulating three-dimensional ground water Response in a small mountainous watershed

G. N. Flerchinger, Shuangling Shang, and J. L Finnie

ABSTRACT

Snowmelt from deep mountainous snowpacks is seldom rapid enough to exceed infiltration rates; thus, the source of streamflow in many mountainous watersheds is snowmelt recharge through shallow ground water systems. The hydrologic response and interaction between surface and sub-surface flow processes in these watersheds, which is controlled by basin structure, the spatial distribution of snowmelt, and the hydrogeology of the subsurface, are not well understood. The purpose of this study was to test a three-dimensional ground water model using simulated snowmelt input to simulate ground water response to spatially distributed snowmelt on the Upper Sheep Creek Watershed located within the Reynolds Creek Experimental Watershed in Southwestern Idaho. The model was used to characterize the mountainous aquifer and to delineate the subsurface flow mechanisms. Difficulty in finding a reasonable combination of grid spacing and time stepping within the model was encountered due to convergence problems with the Picard solution to the non-linear variably saturated ground water flow equations. Simulation results indicated that flow may be either unconfined or confined depending on inflow rate and hydrogeologic conditions in the watershed. The flow mechanism had a much faster response time when confined flow occurred. Response to snowmelt from a snow drift approximately 90m away took only a few hours when flow was confined. Simulated results showed good agreement with piezometer measurements both in magnitude and timing; however, convergence problems with the Picard solution limited applicability of the model.

GROUND WATER HYDROLOGY

86. WATER RESOURCES BULLIETIN, VOL. 32,NO.6, 1996, pp.1209

Evaluation of an Induced infiltration model as applied to glacial aquifer systems
Loren P. Conrad and Milovan S. Beljin

ABSTRACT

Numerical models were used to examine the limitations of the assumptions used in an analytical induced infiltration model. The assumptions tested included negligible streambed effects, negligible areal recharge, two-dimensional ground water flow, fully penetrating rivers and wells, and constant surface water flow. For situations that deviate from the underlying assumptions, the analytical model becomes a less reliable predictor of induced Infiltration. The numerical experiments show that streambed effects cannot be neglected if the streambed conductivity is more than one order of magnitude lower than the aquifer hydraulic conductivity. Areal recharge cannot be neglected if the ground water basin receives more than 5 in/yr of areal recharge. Three-dimensional flow effects due to well partial penetration cannot be neglected if the ratio of horizontal hydraulic conductivity to vertical hydraulic conductivity (K_h/K_v) is greater than 10. Surface water elevation fluctuations can significantly influence the induced infiltration rate, depending on the degree of fluctuations and the ground water hydraulic gradient.

RESERVOIR ROUTING

Decision support system for reservoir operation
Wen-Cheng Huang

ABSTRACT

A decision support system to determine reservoir releases in an uncertain environment during the dry season was developed. A key characteristic of the decision support system is its recursive procedure that processes observations to obtain the most feasible estimate. The system consists of three components: (1) a hydrologic model; (2) an optimization model, and (3) a fuzzy decision model. This methodology was applied to the operation of the Techi reservoir in central Taiwan. Three criteria (public water supply, irrigation, and hydropower) were taken into account within the operation process. Simulation results show that the decision support system can successfully assist government officials in determining operating policy for the Techi reservoir during the dry season. Also, the system is simple enough to lead to a rapid transfer of theoretical knowledge into practice.

GROUND WATER HYDROLOGY

Stable Isotope characterization of the impacts of artificial ground water recharge
Li Ma and Roy F. Spalding

ABSTRACT

Stable isotopes of deuterium and oxygen-18 of surface and ground water, together with anion concentrations and hydraulic gradients, were used to interpret mixing and flow in ground water impacted by artificial recharge. The surface water fraction (SWF), the percentage of surface water in the aquifer impacted via recharge, was estimated at different locations and depths using measured deuterium/hydrogen (D/H) ratios during the 1992, 1993, and 1994 recharge seasons. Recharged surface water completely displaced the ground water beneath the recharge basins from the regional water table at 7.60 m to 12.16 m below the land surface. Mixing occurred beneath the recharge structures in the lower portions of the aquifer (>12.16 m). Approximately 12m downgradient from the recharge basin, the deeper zone (19.15m depth) of the primary aquifer was displaced completely by recharged surface water within 193, 45, and 55 days in 1992, 1993, and 1994, respectively. At the end of the third recharge season, recharged surface water represented ~50 percent of the water in the deeper zone of the primary aquifer ~1000m downgradient from the recharge basin. A classic asymmetrical distribution of recharged surface water resulted from the recharge induced horizontal and vertical hydraulic gradients. The distribution and breakthrough times of recharged surface water obtained with stable isotopes concurred with those of major anions and bromide in a tracer test conducted during the 1995 recharge season. This stable isotope procedure effectively quantified mixing between surface and ground water.

REMOTE SENSING / SEDIMENTATION IN RESERVOIRS

The potential for remote sensing of loess Soils suspended in surface waters
Mahtab A. Lodhi, Donald C. Rundquist, Luoheng Han et.al

ABSTRACT

The potential for detecting the concentration and type of soils suspended in surface water through remote sensing techniques was investigated by studying the spectral reflectance of two types of soils in suspension. In a large tank filled with 7510 litres of water, 20 levels of suspended sediment (soil) concentration (SSC), ranging from 50 to 1000 mg/l were prepared. A high resolution spectroradiometer was used to measure the reflectance at each SSC level. The reflectance spectra of two

contrasting soils were distinct in the visible and near infrared (NIR) portions of the electromagnetic spectrum. The wavelength range between 580-690 nm (visible) was found to be optimal for indicating the type of soil, whereas, the wavelength range between 714-880 (NIR) was found to be appropriate for estimating the concentration of sediment suspended in surface waters.

DROUGHT MANAGEMENT

A low cost drip irrigation system for small Farmers in developing countries
Paul Polak, Bob Nanes, and Deepak Adhikari

ABSTRACT
    In areas where water is scarce, drip irrigation provides the most efficient way to conserve irrigation water, but its cost of $1000 an acre is prohibitive for most small farmers in developing countries. The cost was reduced by 90 percent by (1) making dripper lines moveable, so that each line reaches ten rows instead of one; (2) replacing 25-cent emitters with simple 0.70 mm holes punched by a heated needle; and (3) using $3.00 off-the-shelf 20 litre containers with cloth filters in place of expensive filter systems. This reduced the cost of a half-acre system to $50. The low cost system was field tested in the bill areas of Nepal, and in mulberry cultivation in Andhra Pradesh, India. Uniformity of flow from emitters was 73-84 percent. Small farmers reported that the low cost trickle irrigation system cut labour requirements in half, and doubled the area irrigated by the same amount of water. The low cost drip system is likely to be widely adopted by small farmers in semi-arid and hilly regions.

HYDROLOGICAL DATA NETWORK

Quality of hydrometeorological data in cold regions
Eugene L. Peck

ABSTRACT
    Many users of hydrometeorological records are not aware of the number of inconsistencies and biases that occur in hydrometeorological records. Examples are presented illustrating how the exposures of sites for measurement of precipitation, wind, snow on the ground, and evaporation determine to a large extent how useful the records are for estimating areal conditions. For areas where precipitation in the form of snow produces a significant portion of the runoff, a smaller number of quality records may be more valuable for modelling than a much

larger number of lower quality. Information is presented to show that the overall value of an operational hydrometeorological network is dependent upon how consistent and representative of average conditions the collected records are, especially for mountainous areas in cold regions.

ENVIRONMENTAL HYDROLOGY

Sensitivity analysis of simulated Contaminated sediment transport

Thomas A. Fontaine and Vanusa M. F. Jacomino

ABSTRACT

A simulation analysis of contaminated sediment transport involves model selection, data collection, model calibration and verification, and evaluation of uncertainty in the results. Sensitivity analyses provide information to address these issues at several stages of the investigation. A sensitivity analysis of simulated contaminated sediment transport is used to identify the most sensitive output variables and the parameters most responsible for the output variable sensitivity. The output variables included are streamflow and the flux of sediment and C_s^{137}. The sensitivities of these variables are measured at the field and intermediate scales, for flood and normal flow conditions, using the HSPF computer model. A sensitivity index was used to summarize and compare the results of a large number of output variables and parameters. An extensive database was developed to calibrate the model and conduct the sensitivity analysis on a 6.2 mi^2 catchment in eastern Tennessee. The fluxes of sediment and C_s^{137} were more sensitive than streamflow to changes in parameters for both flood and normal flow conditions. The relative significance of specific parameters on output variable sensitivity varied according to the type of flow condition and the location in the catchment. An implication section illustrates how sensitivity analysis results can help with model selection, planning data collection, calibration, and uncertainty analysis.

WATER QUALITY / WATERSHED MANAGEMENT

Watershedss: a decision support system for watershed- scale nonpoint source water quality problems

D. L. Osmond, R. W Gannon, J. A. Gale et.al.

ABSTRACT.

A significant portion of all pollutants entering surface waters (streams, lakes, estuaries, and wetlands) derives from

nonpoint source (NPS) pollution and, in particular, agricultural activities. The first step in restoring a water resource is to focus on the primary water quality problem in the watershed. The most appropriate NPS control measures, which include best management practices (BMPS) and landscape features, such as wetlands and riparian areas, can then be selected and positioned to minimize or mitigate the identified pollutant(s). A computer-based decision support and educational software system, WATERSHEDSS (WATER, Soil, and Hydro-Environmental Decision Support System),has been developed to aid managers in defining their water quality problems and selecting appropriate NPS control measures. The three primary objectives of WATERSHEDSS are (1) to transfer water quality and land treatment information to watershed managers in order to assist them with appropriate land management/land treatment decisions; (2) to assess NPS pollution in a watershed based on user supplied information and decisions; and (3) to evaluate, through geographical information systems-assisted modelling, the water quality effects of alternative land treatment scenarios. WATERSHEDSS is available on the World Wide Web (Web) at httpJ/h2osparc.wq.ncsu.edu.

WATER QUALITY

Sampling and analytical tolerance requirements for detecting trends in water quality

Graham B. McBride and David G. Smith

ABSTRACT

In designing a water quality sampling program, the detection threshold (equivalent to 'effect size' in a power analysis) can be calculated as a function of the Type I and II error risks, sampling frequency and duration, and (if appropriate) autocorrelation. Then the impact of sampling and analytical errors on the trend ,that can be detected within that threshold should be considered. A procedure for doing so is described, enabling a priori prescription to laboratory and field staff of the analytical tolerances expected of them in their work. It assumes that the trend (a linear or step change) can be described by a parametric model.

WATER QUALITY

Cumulative impacts of landuse on water quality in a southern appalachian watershed

Paul V. Bolstad and Wayne T. Swank

ABSTRACT.

   Water quality variables were sampled over 109 weeks along
Coweeta Creek, a fifth-order stream located in the Appalachian
mountains of western North Carolina. The purpose of this study
was to observe any changes in water quality, over a range of flow
conditions, with concomitant downstream changes in the mix of
landuses. Variables sampled include pH, HCO_3^{2-}, conductivity, NO_3^--
N, NH_4^+ N, PO_4^{3-}-P, Cl-, Na+, K+, Ca^2+, Mg^2+, SO_4^2 , SiO_2 turbidity,
temperature, dissolved oxygen, total and fecal coliforrn, and
fecal streptococcus. Landcover/landuse was interpreted from
1:20,000 aerial photographs and entered in a GIS, along with
information on total and paved road length, building location and
density , catchment boundaries, hydrography, and slope. Linear
regressions were performed to relate basin and near-stream land-
scape variables to water quality.

   Consistent, cumulative, downstream changes in water quality
variables were observed along Coweeta Creek, concomitant with
downstream, human-caused changes in landuse. Furthermore, larger
downstream changes in water quality variables were observed
during stormflow when compared to baseflow, suggesting cumulative
impacts due to landscape alteration under study conditions were
much greater during storm events. Although most water quality
regulations, legislation, and sampling are promulgated for
baseflow conditions, this work indicates they should also
consider the cumulative impacts of physical, chemical, and
biological water quality during stormflow.

WATERSHED MANAGEMENT

Hydrology of a drained forested **pocosin watershed
D.M. Amatya, R.W Skaggs, J.D. Gregory,and R.B.Herrmann

ABSTRACT

   In order to assess the effects of silvicultural and drainage
practices on water quality it is necessary to understand their
impacts on hydrology. The hydrology of a 340 ha artificially
drained forested watershed in eastern North Carolina was studied
for a five-year period (1988-92). Effects of soils, beds and
changes in vegetation on water table depth, evapotranspiration
(ET) and drainage outflows were analyzed. Total annual outflows
from the watershed varied from 29 percent of the rainfall during
the driest year (1990) when mostly mature trees were present to
as much as 53 percent during a year of normal rainfall (1992)
after about a third of the trees were harvested. Annual ET from
the watershed, calculated as the difference between annual
rainfall and outflow, varied from 76 percent of the calculated
potential ET for a dry year to as much as 99 percent for a wet
year. Average estimated ET was 58 percent of rainfall for the
five-year period. Flow rates per unit area were consistently
higher from a smaller harvested block (Block B - 82 ha) of the
watershed than from the watershed as a whole. This is likely due

to time lags, as drainage water flows through the ditch-canal network in the watershed, and to timber harvesting of the smaller gaged block.

NEURAL NETWORK

97.   WATER RESOURCES BULLETIN, VOL. 33,NO. 3, 1997, pp.625

Prediction of two-year peak stream discharges using neural networks
Ranjan S. Muttiah, Raghavan Srinivasan, and Peter M. Allen

ABSTRACT
        The cascade correlation neural network was used to predict the two-year peak discharge (Q_2) for major regional river basins of the continental United States (US). Watersheds ranged in size by four orders of magnitude. Results of the neural network predictions ranged from correlations of 0.73 for 104 test data in the Souris-Red Rainy river basin to 0.95 for 141 test data in California. These results are improvements over previous multilinear regressions involving more variables that showed correlations ranging from 0.26 to 0.94. Results are presented for neural networks trained and tested on drainage area, average annual precipitation, and mean basin elevation. A neural network trained on regional scale data in the Texas Gulf was comparable to previous estimates Of Q_2 by regression. Our research shows Q_2 was difficult to predict for the Souris-Red Rainy, Missouri, and Rio Grande river basins compared to the rest of the US, and acceptable predictions could be made using only mean basin elevation and drainage areas of watersheds.

CLIMATOLOGY

98.   WATER RESOURCES BULLETIN, Vol.33 No.4,1997, pp.767

Stream water chemistry in watersheds receiving different atmospheric inputs of H^+, NH_4^+, NO_3, and SO_4^{2-}
Robert Stottlemyer

ABSTRACT
        Weekly precipitation and stream water samples were collected from small watersheds in Denali National Park, Alaska, the Fraser Experimental Forest, Colorado, Isle Royale National Park, Michigan, and the Calumet watershed on the south shore of Lake Superior, Michigan. The objective was to determine if stream water chemistry at the mouth and upstream stations reflected precipitation chemistry across a range of atmospheric inputs of H^+, NH_4^+, NO_3, and SO_4^{2-}. Volume-weighted precipitation H^+, NH_4^+, NO_3, and SO_4^{2-} concentrations varied 4 to 8 fold with concentrations highest at Calumet and lowest in Denali. Stream water chemistry varied among sites, but did not reflect precipitation chemistry.

The Denali watershed, Rock Creek, had the lowest precipitation NO_3^- and SO_4^{2-} concentrations, but the highest stream water NO_3^- and SO_4^{2-} concentrations. Among sites, the ratio of mean monthly upstream NO_3^- concentration to precipitation NO_3^- concentration declined ($p < 0.001$, $R^2 = 0.47$) as precipitation NO_3^- concentration increased. The ratio of mean monthly upstream to precipitation SO_4^{2-} concentration showed no significant relationship to change in precipitation SO_4^{2-} concentration. Watersheds showed strong retention of inorganic N (> 90 percent inputs) across inputs ranging from 0.12 to > 6 kg N ha^{-1} y^{-1}. Factors possibly accounting for the weak or non-existent signal between stream water and precipitation ion concentrations include rapid modification of meltwater and precipitation chemistry by soil processes, and the presence of unfrozen soils which permits winter mineralization and nitrification to occur.

HYDROLOGICAL MODELLING

99. WATER RESOURCES BULLETIN, VOL. 33 NO. 4,1997, pp.811

An illustration of model structure identification
Song S. Qian

ABSTRACT
The purpose of this article is to discuss the importance of uncertainty analysis in water quality modelling, with an emphasis on the identification of the correct model specification. A wetland phosphorus retention model is used as an example to illustrate the procedure of using a filtering technique for model structure identification. Model structure identification is typically done through model parameter estimation. However, due to many sources of error in both model parameterization and observed variables and data, error-in-variable is often a problem. Therefore, it is not appropriate to use the least squares method for parameter estimation. Two alternative methods for parameter estimation are presented. The first method is the maximum likelihood estimator, which assumes independence of the observed response variable values. In anticipating the possible violation of the independence assumption, a second method, which coupled a maximum likelihood estimator and Kalman filter model, was presented. Furthermore, a Monte Carlo simulation algorithm is presented as a preliminary method for judging whether the model structure is appropriate or not.

GROUND WATER HYDROLOGY

100. WATER RESOURCES BULLETIN, VOL. 33, NO. 6, 1997, pp.1209

Detecting changes in the spatial distribution Of nitrate contamination in ground water

Zhi-Jun Liu, George R. Hallberg, Dale L. Zimmerman et.al.

ABSTRACT

Many studies of ground water pollution in general and nitrate contamination in particular have often relied on a one-time investigation, tracking of individual wells, or aggregate summaries. Studies of changes in spatial distribution of contaminants over time are lacking. This paper presents a method to compare spatial distributions for possible changes over time. The large-scale spatial distribution at a given time can be considered as a surface over the area (a trend surface). The changes in spatial distribution from period to period can be revealed by the differences in the shape and/or height of surfaces. If such a surface is described by a polynomial function, changes in surfaces can be detected by testing statistically for differences in their corresponding polynomial functions. This method was applied to nitrate concentration in a population of wells in an agricultural drainage basin in Iowa, sampled in three different years. For the period of 1981-1992, the large-scale spatial distribution of nitrate concentration did not show significant change in the shape of spatial surfaces; while the magnitude of nitrate concentration in the basin, or height of the computed surfaces showed significant fluctuations. The change in magnitude of nitrate concentration is closely related to climatic variations, especially in precipitation. The lack of change in the shape of spatial surfaces means that either the influence of land use/nitrogen management was overshadowed by climatic influence, or the changes in land use/management occurred in a random fashion.

SURFACE WATER HYDROLOGY

Hydraulic geometry and stream channel Behaviour: an uncertain link
Michael E Merigliano

ABSTRACT

The at-a-station hydraulic geometry of stream channels can serve as a predictor of alluvial stream channel behaviour. This geometry is the empirical relations describing changes in water surface width, mean depth, and mean velocity with changing discharge. The exponent values are correlated with channel morphology and behaviour such as scour and fill, flow resistance, bank resistance, and competence. Channel behaviour and morphology are apparently related, but some causes for effects are uncertain. Several studies, using empirical and theoretical bases, are reviewed here to illustrate the relation between hydraulic geometry and channel behaviour, but the relations are not always consistent. Hydraulic geometry variables are easy to measure and readily available, but they do not always reflect what may be more important ones such as turbulence, the velocity

distribution profile, and distribution and cohesion of sediment particles. This paper illustrates some of these problems, provides some solutions, and addresses need for more work to better predict stream channel behaviour from hydraulic geometry.

GROUND WATER HYDROLOGY

Challenges in ground water remediation: Dense nonaqueous phase liquids

Charlotte Dierolf

ABSTRACT

Dense nonaqueous phase liquid (DNAPL) contaminated ground water has proven to be exceptionally difficult to remediate for both physical and chemical reasons. Since DNAPLs are denser than water, their movement is not governed by the direction of ground water flow as is generally the case for other ground water contaminants. Additionally, DNAPLs' interactions with aquifer solids through processes such as sorption tend to make the pollution linger or sometimes apparently disappear, only to return later. Unfortunately, pump-and-treat systems, the traditional way ground water contamination is addressed, have not been effective in cleaning DNAPL contaminated water. Other remediation technologies continue to be developed to address these problems. Policy changes will also be necessary to effectively address the difficulties associate with ground water remediation.

Hydrological Sciences - Journal
(IAHS)

WATERSHED MANAGEMENT

Physically-based estimation of lag time for forested mountainous watersheds

Athanasios Loukas & Michael C, Quick

Abstract

This study proposes a method for the estimation of lag time of forested mountainous watersheds. Hydrological flood-flow design methods require a time parameter, such as lag time or time of concentration, to estimate peak discharge and the flood hydrograph shape. Most existing methods used to compute the time parameter of a watershed are empirical and have been developed for urban or rural watersheds. Use of these methods for forested mountainous watersheds may result in severe underestimation of watershed response time and consequently, in overestimation of peak flood discharge. The water flow in a watershed is separated and analysed in two phases, viz. the land or hillslope phase and the stream channel phase. Most of the flow in a forested steep watershed is generated through subsurface pathways, and this knowledge, acquired from field experiments, is combined with kinematic wave equations to describe the generation of flow from steep forested hillslopes. This hillslope runoff is then used as input to the stream channels. Kinematic wave equations are developed for the runoff movement in the channels by assuming that both the roughness coefficient and the stream channel slope vary with the distance from the outlet of the watershed. These assumptions are validated and confirmed with data from the USA and Coastal British Columbia, Canada. The resulting equations are integrated to obtain an equation for the lag time. Comparison of the results of the proposed equation with data from two experimental watersheds in Coastal British Columbia and empirical equations used for the calculation of the lag time indicates that the proposed method is reliable and gives a good approximation of the observed lag time. These results are compared with other empirical equation, and it is shown that these earlier methods can result in severe underestimation of lag time.

GROUND WATER HYDROLOGY

Estimation of groundwater inflow to irrigation drains in Minia, Upper Egypt, based on a deuterium and oxygen-18 evaporation pan technique

A. El-Bakri & M. A. Tantawi and M. S. Hamza & M. A. Awad

Abstract

The possibility of estimating groundwater inflow to irrigation drains in Minia, Egypt, using stable isotopes has been explored. The evaporation pan technique described here makes use

of small variations in the concentration of naturally occurring
stable isotopes (oxygen- 18 and deuterium) in irrigation-fed
groundwater and surface water as well as agricultural drainage
water. The agreement between the stable isotope pan experiments
carried out at Minia with others conducted at different locations
in Egypt makes it feasible to estimate the inflow of groundwater
to be about 42 % of the total drainage water.

SURFACE WATER HYDROLOGY

Runoff components simulated by rainfall- runoff models
J. Buchtele, V. Elias & M. Tesar and A. Herrmann

Abstract

The conceptual SACRAMENTO soil moisture accounting model and
the physically based forest hydrological BROOK model have been
used in runoff simulations for small and medium sized basins with
the aim of investigating the contributions of different runoff
components to the overall runoff. The simulations seem to
confirm the results of previous experiments with environmental
tracers in which prevailing contributions of groundwater have
been reported.

RESERVOIR ROUTING

Approximate reliability and resilience indices of over-year reservoirs fed by AR(1)
Gamma and normal flows
Richard M. Vogel and T. A.** McMohan

Abstract

Approximate storage-reliability-resilience-yield (S-R-R-Y)
relationships are derived for over-year water supply systems fed
by autoregressive lag one Gamma and normal inflows. It is shown
that a two-state Markov model may be exploited along with S-R-R-Y
relationships to describe the general behaviour of over-year
water supply systems. The two-state Markov model is also used
to relate the probability of n-year no-failure operations (the
concept of reliability used in the USA) to the steady-state
probability of a system failure (the concept of reliability used
in Australia and elsewhere) yielding a unified view of system
reliability. Resiliency criteria are introduced which indicate
whether or not a reservoir system is likely to return to normal
operations once a failure has set in. These criteria indicate
that the resilience of an over-year water supply system is
generally independent of its steady-state reliability. The

conditions under which finite reservoir systems behave like semi-infinite reservoir systems are also documented, and a factor is derived which describes the impact of the serial correlation of the inflows on the derived S-R-R-Y relationship.

CLIMATOLOGY

107. Hydrological Sciences -Journal, 41(1) February 1996, pp. 117

Downscaling two versions of a general circulation model to estimate local hydroclimatic factors under climate change
Istvan Matyasovszky & Istvan Bogardi

Abstract

The regional hydroclimatological effect of global climate change has been estimated and compared using a semi-empirical downscaling method with two versions (T21 and T42) of the general circulation model (GCM) developed at the Max Plank Institute for Meteorology, Germany. The comparisons were performed with daily mean temperature and daily precipitation amounts for the continental climate of the state of Nebraska, USA. Both the T21 and the T42 versions resulted in an increase of daily mean temperature under a 2 X CO_2 climate. The magnitude of warming was substantially greater for T21 than for T42, except for February and June and at some stations in July where the T42 model suggested greater warming. Both GCMs resulted in a slight decrease in precipitation frequency and an increase in the amount of precipitation on wet days. Here, the T42 model again led to smaller changes. Different locations within Nebraska exhibited somewhat different temperature and precipitation responses with both GCM versions.

GROUND WATER HYDROLOGY/REMOTE SENSING

108. Hydrological Sciences -Journal, 41(2) April 1996, pp. 137

Hydrogeomorphological study based on remote sensing of Mulug Taluk, Warangal District, Andhra Pradesh, India
G. Shankar Narayana and N. Laksimaiah & P.V. Prakash Goud

Abstract

Remote sensing (RS) applications have become an important tool for the rapid evaluation of water resources. This paper deals with the utilization of RS data as the main input in an integrated approach for groundwater targeting. The Mulug Taluk, with an areal extent of 3200 km^2, is one of the poor taluks in the Warangal District, Andhra Pradesh, India. A hydrogeomorphological study based on remote sensing (Landsat 5, TM) helped in establishing: (i) a broad demarcation of different

lithological units viz., old Pakhals, Vindhyans, Gondwanas and recent alluvium; (ii) erosional landforms (96%) viz., denudational hills, structural hills, mesa/buttes, linear ridges, a pediment inselberg complex, a shallow weathered pediplain, a moderately weathered pediplain and depositional landforms (4%) such as flood plain areas; and (iii) delineation of minor and major lineaments. The investigations revealed that the potential for groundwater development is in the preferential order of alluvium, Gondwanas and Puranas. A statistical treatment of the data also confirmed that wells on lineaments yield more than wells away from lineaments. NE-SW structural trends cutting across the regional trend appeared to be more favourable for the exploitation of baseflow for shallow groundwater development.

FLOOD HYDROLOGY

109. Hydrological Sciences -Journal, 41(2) April 1996, pp. 153

Use of hysteresis for defining the nature of flood wave propagation in natural channels
S. K. Mishra & S. M. Seth

Abstract
The hysteresis (n) of the non-dimensional site-specific rating curve is used to describe the occurrence of a kinematic wave (KW), a diffusion wave (DW) or a dynamic wave (DYW) in the downstream valleys of the Teton dam, USA, and the Machhu dam II, India. Criteria are developed for the occurrence of these waves. The study reveals that the hysteresis is the energy loss occurring at a particular site and is related to the speed of travel, wave number, phase difference and attenuation characteristics of the flood wave. The role of η is shown to be of vital importance in: (i) choosing a suitable downstream boundary for improving the results; and (ii) identifying the wave zones where approximate models can substitute the complete DYW model.

GROUND WATER HYDROLOGY

110. Hydrological Sciences -Journal, 41(2) April 1996, pp. 171

Soil water, soil chemical and crop variations in a clay soil
Ronny Berndtsson and Akissa Bahri

Abstract
Spatial properties of field soils vary in a complex manner. Especially in arid and semiarid areas, this variability affects plant quality and crop production. An experimental field plot was extensively sampled regarding soil water (378 gravimetrical samples), soil chemical content (314 samples), and crop yield and

chemical content (26 samples) at the Cherfech agricultural field research station in Tunisia. Geostatistical analyses were made to gain a better understanding of the in situ variability of soil water, soil chemical and crop properties. Ranges of correlation were found to vary over distances between 5 and over 40 m. Nugget and sill values for semivariograms were almost an order of magnitude larger for crop samples compared to soil samples. The crop yield components appeared to have larger variability as compared to crop chemical components.

SURFACE WATER HYDROLOGY

Influence of upstream inflow on wave celerity and time to equilibrium on an overland plane

Tommy S. W. Wong

Abstract
Based on the kinematic wave equations, formulae for the wave celerity along an overland plane subject to uniform rainfall excess and with a constant upstream inflow together with the corresponding average wave celerity and time to equilibrium for the entire plane are derived. The formulae are further developed in terms of both the Darcy-Weisbach resistance coefficient and the Manning resistance coefficient. By comparing the wave celerities, the average wave celerities and the time to equilibrium for planes with and without upstream inflow show that the upstream inflow causes the wave celerity and the average wave celerity to be faster and the times to equilibrium to be shorter. The effect of upstream inflow is greater with increasing inflow, but the marginal effect decreases with increasing inflow. The effect is greatest for laminar flow and least for turbulent flow. For the wave celerity, the effect is also greatest at the upstream end of the plane and least at the downstream end of the plane.

SURFACE WATER HYDROLOGY

Sensitivity of the stability of river flow regimes to small fluctuations in temperature

Irina Krasovskaia

Abstract
A river regime describes the average seasonal behaviour of flow. This seasonal pattern reflects climatic and physiographic conditions in the basin. An inherent characteristic of a flow

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regime is its stability, i.e. regularity or irregularity of the seasonal pattern. A temperature rise, as predicted by climatic models, might cause changes in the patterns˜and stability of river flow regimes. Sensitivity of the stability of flow regimes to small fluctuations in temperature ($\approx \pm 1^{0}C$) is investigated with the help of historical temperature and flow series for Scandinavia. The concept of entropy is utilized for quantification of the stability of the flow regimes conditioned on temperature which also allows forecasting of possible changes in this stability due to changes in temperature. The study shows that the stability cf flow regime types with rain or mixed rain and snowmelt sources of flow formation is already sensitive to small changes in temperature, especially concerning flow minima.

SNOW HYDROLOGY

Determination of snowmelt factor in the Himalayan region
Pratap Singh & Naresh Kumar

Abstract
        Information on the snowmelt factor (SMF) is required for the estimation of snow and glacier melt runoff. In the present study, SMF is computed for a normal snowpack over a glacier at an altitude of about 4000 m in the Garhwal Himalayas. The effect of natural dusting on SMF is also examined. For this purpose, natural dust available at the site of the experiment was uniformly spread over the snow surface to form a 2 mm thick layer. The melt runoff from the snow blocks and air temperature at 2 m above the snow surface were observed. Mean daily SMF values for normal and dusted snow blocks were computed to be 5.94 and 6.62 mm $^{0}C^{-1}$/day, respectively. Mean daily SMF for the dusted snow block was found to be always higher than that of the dust free snow block. Maximum hourly values of SMF for the normal and dusted snow blocks were obtained in the range of 0.583-0.632 and 0.785 - .824 mm $^{0}C^{-1}$/h, respectively, while the minimum value was zero for all cases. Maximum hourly value of SMF occurred at about 1400 h for both blocks. A comparison of the daily SMF with information already available in the literature is presented.

HYDROLOGICAL MODELLING

A model to forecast flow with uncertainty analysis
Pao-Shan Yu & Tsain-Yih Tseng

Abstract

Incorporating the variance in forecast flow at various lead times was attempted in this study taking into account the uncertainty in models. The probability of exceeding a specific discharge was therefore estimated to provide further information for flood warning. The model for forecasting flow was composed of an autoregressive model for upstream flow forecasting and a Muskingum-type model for channel routing. The uncertainties in both models were represented by the variance of input parameters and previous forecast values. Both Mean Value First-Order Second Moment and Monte Carlo methods were adopted to estimate a reliability index and the probability of exceedence of a specific discharge at various lead times. Both methods yielded similar results. From the stochastic viewpoint, the model for flow forecasting had reasonable forecasting ability around the peak flow based on the verification from five historical storm events.

NEURAL NETWORK

Artiricial neural networks as rainfall- runoff models
A. W. Minns & M. J. Hall

Abstract

A series of numerical experiments, in which flow data were generated from synthetic storm sequences routed through a conceptual hydrological model consisting of a single nonlinear reservoir, has demonstrated the closeness of fit that can be achieved to such data sets using Artificial Neural Networks (ANNs). The application of different standardization factors to both training and verification sequences has underlined the importance of such factors to network performance. Trials with both one and two hidden layers in the ANN have shown that, although improved performances are achieved with the extra hidden layer, the additional computational effort does not appear justified for data sets exhibiting the degree of nonlinear behaviour typical of rainfall and flow sequences from many catchment areas.

REMOTE SENSING

Satellite estimation of precipitation over land
Grant W. Petty and Witold F. Krajewski

Abstract

The availability of satellite-derived rainfall products to hydrologists and other natural scientists has increased

enormously in the last five years. The purpose of this paper is to review concisely the current state-of-the-art of satellite precipitation estimation over land and the availability of standard products, and to highlight some of the strengths and limitations of satellite-derived rainfall data for hydrological applications. Methods based on infrared, visible and passive microwave radiation measurements are discussed. Results of several international activities aimed at evaluating the performance of the estimation algorithms are briefly summarized.

REMOTE SENSING

Remote sensing applications to hydrology: runoff
Gert A. Schultz

Abstract
Since no remote sensing (RS) devices have been developed allowing the measurement of river runoff directly, information from RS sources is used to compute runoff values indirectly. This is done with the aid of hydrological models, where RS data are used in two different ways: (1) in the form of model input data; and (2) for model parameter estimation. Three types of models are discussed, the parameters of which are estimated - at least Partially - with the aid of RS information. A mathematical model is demonstrated, which reconstructs monthly river runoff volumes on the basis of IR data obtained by the Meteosat geostationary satellite. The second model computes flood hydrographs with the aid of a distributed system rainfall/runoff model. A major model parameter, viz. the soil water storage capacity, which varies in space, is determined on the basis of Landsat imagery and digital soil maps. The third model discussed is a water balance model which computes all relevant variables of the water balance equation including runoff on a daily basis. Parameters used in the model components for interception, evapotranspiration and soil storage are estimated with the aid of RS information originating from Landsat and NOAA data. Examples of the performance of all three models are presented. Input to hydrological models computing runoff is usually either rainfall or snowmelt or both. An example for model input estimation on the basis of satellite data is presented as well as the use of ground-based weather radar rainfall measurements for real time flood forecasting. An example of snowmelt runoff modelling is mentioned, followed by a brief discussion of future perspectives of runoff computations with the aid of RS data.

REMOTE SENSING/SNOW HYDROLOGY

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Spaceborne remote sensing for snow hydrology applications

A. Rango

Abstract

Certain satellite-based remote sensing for snow hydrology applications has been very positive, namely, snow areal extent mapping using visible and near-infrared sensors and snow water equivalent using passive microwave techniques. Although certain problems are yet to be solved, very specific applications have become operational. Data from the NOAA-AVHRR sensor are used to produce snow extent maps for about 4000 basins in North America and the data are distributed electronically by the NWS National Operational Hydrologic Remote Sensing Centre. At the Canadian Climate Centre, a method has been developed for real time estimation of areal snow water equivalent over the Canadian prairies using microwave brightness temperatures, and the snow water equivalent maps are distributed to operational hydrological forecasters. Current research may also prove fruitful for estimates of snow wetness or active melting, snow albedo and snow grain size. It appears that forthcoming improvements in passive microwave spatial resolution should increase the applicability of the data for snow hydrology. The spectral and spatial resolution of the visible/near-infrared data will also be improved with the launch of EOS/MODIS. Combinations of sensors and integration with other types of data will further improve the suitability of spaceborne data.

REMOTE SENSING

Use of remote sensing for evapotranspiration monitoring over land surfaces

W.P. Kustas and J. M. Norman

Abstract

Monitoring evapotranspiration (ET) at large scales is important for assessing climate and anthropogenic effects on natural and agricultural ecosystems. This paper describes techniques used in evaluating ET with remote sensing, which is the only technology that can efficiently and economically provide regional and global coverage. Some of the empirical/statistical techniques have been used operationally with satellite data for computing daily ET at regional scales. The more complex numerical simulation models require detailed input parameters that may limit their application to regions containing a large database of soils and vegetation properties. Current efforts are being directed towards simplifying the parameter requirements of these models. Essentially all energy balance models rely on an estimate of the available energy (net radiation less soil heat flux). Net radiation is not easily determined from space, although progress is being made. Simplified approaches for estimating soil heat flux appear promising for operational

applications. In addition, most ET models utilize remote sensing data in the shortwave and thermal wavelengths to measure key boundary conditions. Differences between the radiometric surface temperature and aerodynamic temperature can be significant and progress in incorporating this effect is evident. Atmospheric effects on optical data are significant, and optical sensors cannot see through clouds. This has led some to use microwave observations as a surrogate for optical data to provide estimates of surface moisture and surface temperature; preliminary results are encouraging. The approaches that appear most promising use surface temperature and vegetation indices or a time rate of change in surface temperature coupled to an atmospheric boundary layer model. For many of these models, differences with ET observations can be as low as 20% from hourly to daily time scales, approaching the level of uncertainty in the measurement of ET and contradicting some recent pessimistic conclusions concerning the utility of remotely sensed radiometric surface temperature for determining the surface energy balance.

REMOTE SENSING / GROUND WATER HYDROLOGY

Remote sensing applications to hydrology: soil moisture
T. J. Jackson & J. Schmugge and E. T. Engman

Abstract

Passive and active microwave remote sensing instruments are capable of measuring the surface soil moisture (0-5 cm) and can be implemented on high altitude platforms, e.g. spacecraft, for repetitive large area observations. The amount of water present in a soil affects its dielectric properties. The dielectric properties, along with several other physical characteristics, determine the microwave measurement. In addition, the significance of the dielectric properties depends upon the sensor design, especially the wavelength. Instruments operating at longer wavelengths (>5 cm) have fewer problems with the atmosphere and vegetation, sense a deeper soil layer and maximize soil moisture sensitivity. Another instrument concern is whether to use an active or passive microwave approach. Active approaches, especially synthetic aperture radar, can provide extremely good ground resolution from space (< 100 m). Passive methods currently provide much coarser resolution data (> 10 km). The existing data interpretation algorithms for passive data are well tested for bare soil and vegetation and can be applied to a wide range of conditions. At the present time, the active microwave algorithms have not been widely verified. There has been a significant amount of recent research using both active and passive methods as a result of the availability of new sensor systems. With these new instruments have also come greater efforts to integrate the observations in large scale multidisciplinary investigations. A greater emphasis on the

spatial distribution and temporal behaviour of soil moisture has produced some very interesting and valuable data sets that demonstrate the potential of a dedicated observing system for scientific and operational studies.

REMOTE SENSING / WATER QUALITY

121. Hydrological Sciences -Journal, 41(4) August 1996, pp. 531

Remote sensing, ecological water quality modelling and in situ measurements: a case study in shallow lakes
A. G. Dekker, Z. Zamurovic,Nenad, H. J. Hoogenboom & S.W.M.Peters

Abstract

The application of high spectral and spatial resolution airborne remote sensing has developed to an almost operational level. This paper investigates the role of remote sensing especially coupled to the two other available water quality assessment tools: in situ measurements and ecological water quality modelling data. A case study is presented for three shallow lakes varying in trophic level. Based upon a similarity index it is demonstrated that remote sensing provides valuable additional information for chlorophyll-α, seston dry weight and Secchi depth measurements, as compared to the two other water quality assessment tools.

REMOTE SENSING / GROUND WATER HYDROLOGY

122. Hydrological Sciences -Journal ,41(4) August 1996, pp. 549

Remote sensing applications to hydrology: groundwater
A. M. J. Meijerink

Abstract

The traditional use of remotely sensed image interpretation lies in the qualitative characterization of hydrogeological mapping units and the detection of specific features. Most applications pertain to crystalline basements, limestones and Quaternary volcanic terrain. More recent developments pertain to groundwater emergence in the discharge areas of groundwater flow systems, using thermal and multispectral imagery, and to the management of groundwater. For the latter, spatial recharge patterns and contamination assessment will focus attention on defining the parameters of vegetation and terrain mapping units and on monitoring hydrogeologically relevant surface features embedded in spatial groundwater models.

REMOTE SENSING / HYDROLOGICAL MODELLING

Remote sensing applications in hydrological modelling

G. W. Kite & A. Pietroniro

Abstract

Previous studies have suggested that remotely sensed data should provide major benefits to hydrology and water resources and yet there are few case studies that show practical benefits. One of the reasons for this is the lack of tools to convert remotely sensed data to the type of information useful to water resource systems operators. Hydrological models can play an important role in this translation of data to information. This paper reviews some of the techniques presently used in hydrological models to make use of remotely sensed data and provides a comprehensive reference list.

REMOTE SENSING / HYDROLOGICAL MODELLING

Remote sensing and geographic information systems

Michael F. Baumgartner & Gabriela M. Apfl

Abstract

Remote sensing and Geographic Information Systems (GIS) play a fundamental role in hydrological applications. In this paper the most commonly used processing procedures for remotely sensed data in particular image processing techniques - and the capabilities of GIS technologies are presented. The aim of this paper is to show the merit of a combination of these tools with hydrological models. An important aspect herein is the use of image processing systems, GIS, database management systems (DBMS) and hydrological models in a integrated analysis system.

REMOTE SENSING

Remote sensing applications to hydrology: imaging radar

Dorothy K. Hall

Abstract

Synthetic Aperture Radar (SAR) data are very useful for hydrological studies because the dielectric properties of materials are generally dependent on the amount of liquid water in the material, and this affects the strength of the radar

backscatter, σ^0. Additionally, the ability of microwaves to penetrate the surface of many materials often permits analysis of subsurface properties. Further, SAR sensors can image the Earth through both clouds and darkness which enables dynamic hydrological events, e.g. floods, to be captured. Both radar system parameters and surface characteristics affect σ^0. In the case of snow, σ^0 is the sum of the surface scattering at the air/snow interface, volume scattering within the snowpack, scattering at the snow/soil interface and volumetric scattering from the underlying surface (if applicable). For glaciers, σ^0 is dominated by scattering from the surface and is dependent upon the roughness of the glacier surface in relationship to the radar wavelength. Imaging radar is proving to be an important tool for measuring flooding beneath a variety of herbaceous and woody vegetation. Use of multi-frequency and multi-polarization sensors is necessary to improve the accuracy of mapping flooded vs non-flooded land in floodplains. SAR data have been shown to have potential for measuring stream discharge in braided rivers and for studying key characteristics of frozen lakes. Work with polarimetric SAR data is becoming increasingly significant in hydrological studies.

REMOTE SENING / SURFACE WATER HYDROLOGY

126. Hydrological Sciences -Journal,41(4) August 1996, pp. 625

Remote sensing applications to hydrology: airborne laser altimeters
Jerry C. Ritchie

Abstract

   Shortly after the development of the first laser instrument in 1960, studies began on using laser distancing technology from airborne platforms to measure surface features on the landscape. Airborne laser altimeter studies in the 1960s and 1970s were used to measure terrain features and sea ice roughness. Research in the 1980s and 1990s has shown that airborne laser measurements can be used to measure directly topography, stream channel cross sections, gully cross sections, soil surface roughness, and vegetation canopy height, cover and distribution. These laser measurements can be used to estimate forest biomass and volume, aerodynamic roughness and leaf area indices. Airborne laser altimeters provide quick and accurate measurements for evaluating changes in land surface features and can be an additional tool in the arsenal of remote sensing equipment used to understand watershed properties and to develop plans to manage water resources.

REMOTE SENSING

127. Hydrological Sciences -Journal,41(4) August 1996, pp. 637

Remote sensing applications to hydrology: future impact
Edwin T. Engman

Abstract
The case is made that the hydrological sciences are data limited and that future progress in understanding hydrological processes is hampered by the lack of adequate data. The future applications of remote sensing to hydrology should provide new types of data that enable hydrologists to address the previously unsolved questions.

SURFACE WATER HYDROLOGY

128. Hydrological Sciences -Journal,41(5) October 1996, pp.659

Analysis of paradoxes arising from the Chezy formula with constant roughness:
1. Depth-discharge curve
Witold G. Strupczewski and Romuald Szymkiewicz

Abstract
The Chezy friction formula for steady flow in a uniform symmetrical channel with constant slope-friction factor is examined mathematically. Firstly, a wide rectangular channel and a semi-circular channel are compared in respect of the mean flow velocity using the Chezy formula with the Manning, Chezy and logarithmic laws for velocity. Then the inverse Chezy problem, i.e. the determination of the channel shape above the reference level for a given depth/discharge rating curve, is posed and the differential-integral equation for its solution is derived. The rating curves used for computation are the results of multiplying the discharge for a trapezoidal shape above the reference level by an exponential function. To facilitate interpretation of the numerical results, the relationship between side slope and discharge is analysed. It is shown by the inverse problem solution that an exponential reduction of channel flow capacity changes linear channel sides into convex sides (making the cross section shape wider) while an exponential increase of capacity causes changes into concave sides (reducing a section width) which is against common sense.

SURFACE WATER HYDROLOGY

129. Hydrological Sciences -Journal, 41(5) October 1996,pp.675

Analysis of paradoxes arising from the Chezy formula with constant roughness:
II. Flow area-discharge curve
Witold G. Strupczewski and Romuald Szymkiewicz

Abstract

The Chezy formula for steady flow in a uniform symmetrical channel with constant slope-friction factor is mathematically examined. The problem of the determination of the channel shape above a reference level for a given rating curve of flow area vs discharge with a constant ratio (m) of slope to mean velocity above a reference level is posed and then solved. It is shown that there is a double solution of the problem. One solution (being of main interest) is unlimited and gives a shape widening with depth, while the other has an upper bound and yields a shape narrowing with depth. It is shown that a solution to the problem exists for a negative value of m. A relationship is examined between the width-to-depth ratio of a rectangular initial shape and a shape above a reference level for m values close to zero. In particular, the solutions for negative values of m, i.e. for discharge decreasing with increasing flow area, are evidently against common sense.

SURFACE WATER HYDROLOGY

Ranking of river basin alternatives using ELECTRE
P. Anand Raj and D. Nagesh Kumar

Abstract
Ranking of river basin planning and development alternatives under a multi-criterion environment, including both qualitative and quantitative aspects, is examined. The purpose is to find the most suitable planning for reservoirs with their associated purposes aimed at the development of the major peninsular river (Krishna) basin in India. A total of seven reservoirs and a diversion network are considered for the formulation of 24 alternative systems with 18 criteria, of which nine are qualitative and the remainder are quantitative in nature. A set of best alternatives with their ordering is obtained using ELECTRE (ELimination Et (and) Choice Translating Reality).

CLIMATOLOGY

Sensitivities of groundwater-streamflow interaction to global climate change
Dionysia Panagoulia and George Dimou

Abstract
The sensitivities of groundwater-streamflow interaction to global climate change over the medium-sized mountainous Mesochora catchment in central Greece have been analysed. The global climate change was simulated through a set of hypothetical and monthly GISS (Goddard Institute for Space Studies) scenarios of

temperature increases coupled with precipitation changes. The catchment hydrological regime, which is dominated by spring snowmelt runoff, was simulated by the coupling of the snowmelt and soil moisture accounting models of the US National Weather Service River Forecast System (US NWSRFS). The groundwater was represented through a lower zone one-tension water storage and two free water storages parameterized by the soil moisture model, while the streamflow was the sum of direct runoff, surface runoff and interflow from the upper zone free water, plus the primary and secondary baseflows yielded by the model. The interaction between groundwater and streamflow was expressed by the ratio of the two variables on a seasonal and monthly basis. Both representations of global climate change resulted in a moderate influence on the groundwater streamflow interaction during the winter months and in a very high one in the spring and summer months. In particular, the major seasonal shift in the snow accumulation pattern related to climate change, as well as the large runoff reduction and evapotranspiration increase occurring in spring and summer months, boosted considerably the groundwater to streamflow ratio. This latter would probably have negative impacts on various problems of water resources management (e.g. droughts, water supply, irrigation, water pollution).

HYDROLOGICAL MODELLING

132. Hydrological Sciences -Journal, 41(6) December 1996, pp. 889

Introduction of the soil/vegetation/ atmosphere continuum in a conceptual rainfall/runoff model
C. Loumagne, N. Chkir, M. Normand, C. Ottle, and D. Vidal-Madjar

Abstract

This paper presents the inclusion of the soil-vegetation-atmosphere interactions in a proven conceptual model. This new scheme simulates the daily streamflows over small catchments by taking into account the average characteristics of the surface (soil and vegetation) for the calculation of actual evaporation and evapotranspiration. The model also simulates the daily evolution of soil moisture in two layers: the surface layer representing the first ten centimetres of the soil and the bulk layer representing the root zone. The results of the model calibration on a test site, and the results of the model validation on 36 watersheds, show its good capability to simulate streamflows and soil moisture in the surface layer and in the bulk soil layer. These first results are very encouraging and open the possibility of using these quantities for hydrological applications.

CLIMATOLOGY

133. Hydrological Sciences -Journal, 41(6) December 1996, pp. 915

A simplified climate model with combined atmospheric-hydrological processes

M. Nakatsugawa and M. Anderson & M. L. Kavvas

Abstract

Global climate change can be reproduced in detail by using three-dimensional general circulation models (GCMs). However, such complex models require super-computers and extensive hours of computational time for a single attempt at reproducing long term climate change. An alternative approach is to make simplifying assumptions that retain the essential physics for the desired simulation. Energy balance and radiative-convective models are examples of such models. The model in this study follows the simplified approach using physics-based climate processes as well as interactions between atmospheric and hydrological processes. The vertically and latitudinally averaged mean temperature and mean water vapour content between $30°N$ - $50°N$ latitudes are considered as atmospheric state variables while soil and sea temperatures and water storage amount are considered for describing the behaviour of the hydrological system. Temperatures in both the atmosphere and ground are calculated by a thermal energy equation that considers the physically-based processes of shortwave radiation, longwave radiation, sensible heat flux, and latent heat flux. Precipitation and evaporation processes transport moisture between the atmosphere and ground. In this study, the radiation parameterization of the simplified climate model is tested in the investigation of the various effects of global warming due to doubling and quadrupling of CO_2. Changes of temperature, soil water content, evaporation rate and precipitation rate are investigated by numerical experiments. The simplified climate model provides acceptable simulation of climate change and holds promise for practical investigations such as the interactions of physical processes in the evolution of drought phenomena.

LAKE HYDROLOGY

Trophic classification and ecosystem checking of lakes using remotely sensed information

Serwan M. J. Baban

Abstract

Both the conventional and the Carlson trophic state index (TSI) classification methods were employed to assess the eutrophication state of 26 lakes in the Norfolk Broads, UK. The parameters employed were: Secchi depth, chlorophyll a and total phosphorous which had been obtained previously by using Landsat TM imagery, ground reference data and empirical algorithms for the Norfolk Broads (Baban, 1993). The conventional method did not provide sufficient differentiation between the Broads. The Carlson TSI provided sufficient information to differentiate

between all 26 Broads. Consequently, using the Carlson TSI information, these Broads were classified into three groups. The classification was based on the relationship between the calculated Carlson TSI of the external phosphorous loading and its influence on the eutrophication process as deduced from the calculated TSI values for the other two parameters. The results were consistent with all the available knowledge and experience concerning these Broads and demonstrated the potential of combining remote sensing techniques and Carlson TSI in eutrophication assessment, ecosystem checking and watershed analysis.

GROUND WATER HYDROLOGY

Hydraulics of one and two dimensional flow Fields in aquifers
Z. J. Kabala and B.Thorne

Abstract

New solutions in the Laplace and time domains are developed that describe the transient response of a leaky aquifer to constant and transient discharge into a fully or partial penetrating sink with storage. A parameter estimation procedure based on the Newton-Raphson algorithm is found to be robust in a synthetic example involving a pumping test of a large diameter well situated in a leaky strip aquifer. The analytical solution presented may find applications in describing water movement in strip aquifers, in aquifers discharging into channels or streams, or in thin laboratory tanks.

DROUGHT MANAGEMENT

On the definition and modelling of streamflow drought duration and deficit volume
Lena M. Tallaksen and Henrik Madsen and Bente Clausen

Abstract

The threshold level approach is used to define drought characteristics, i.e. drought duration and deficit volume from time series of daily streamflow. Three different procedures for pooling dependent droughts are compared: a method based on an inter-event time and volume criterion (IC), a moving average procedure (MA), and a method based on the sequent peak algorithm (SPA). The extreme values of drought duration and deficit volume are analysed using both an annual maximum series (AMS) and a partial duration series (PDS) approach. Two Danish catchments with very different flow regimes were used in the study. The IC

and MA methods provided virtually the same sample statistics of the AMS of drought duration and deficit volume for all thresholds considered. The results of the SPA method differed significantly from the other two methods for high thresholds due to the presence of multi-year droughts. For analysis of seasonal droughts the SPA method is restricted to low thresholds. The occurrence of a large number of zero-drought years for low thresholds may significantly reduce the information content of the AMS, and in this case the PDS model is superior. The problem of minor droughts in the PDS was implicitly reduced by using the MA and SPA methods, and in this respect these methods have an important advantage as compared to the IC method.

HYDROLOGICAL MODELLING / GROUND WATER HYDROLOGY

Modelling uncertainty in estimates of recharge to a shallow coastal aquifer
Andrew Binley & Kevin Buckley et.al.

Abstract
Due to the difficulty of field characterization, one is often forced to employ hydrological models in order to determine estimates of aquifer recharge. A Geographical Information System (GIS) and Digital Elevation Model (DEM) may provide the basic support for such hydrological models. Unfortunately, despite the availability of these tools, the values of many parameters within distributed models remain uncertain for application to real world problems. Using the Bisagno basin (100 km^2) in the Liguria region of Italy, the role of model parameter uncertainty on estimates of recharge to the Bisagno Aquifer is demonstrated. Uncertainty estimation is achieved through Monte Carlo simulations with the aid of the Generalised Likelihood Uncertainty Estimation procedure of Beven & Binley (1992).

FLOOD HYDROLOGY / RESERVOIR ROUTING

Flood routing in a wide channel with a quadratic lag-and-route method
Piter I. F. Bentura & Claude Michel

Abstract
In hydrological practice, flood routing is rarely achieved using the complete Saint-Venant equations. Instead, hydrological methods have been developed to provide users with simple methods that are robust yet efficient. The lag-and-route method has been widely used but its parameters have never been related to the physical parameters of channels. Moreover, the linear reservoir

in this method is not well suited to reproduce effectively actual channel routing. A quadratic reservoir coupled with a lag component results in a far more accurate method while remaining numerically workable. This latter method depends on only two parameters which have been successfully related to physical channel features. This simple and efficient method enables one to gain insight into the main features of flood propagation in river channels.

ENVIRONMENTAL HYDROLOGY

Hyporheic temperature patterns within riffles
E. C. Evans & G. E. Petts

Abstract

This paper outlines the results of a pilot study using data at 12 min intervals from 20 miniature temperature dataloggers to establish vertical and longitudinal temperature patterns within a river bed. Data are presented from two adjacent riffles immediately below the Blithfield Reservoir on the River Blithe, Staffordshire, UK, for a five day period in July 1994. Hyporheic temperatures were warmer than those of groundwater, colder than those of surface water and decreased with depth into the river bed. At the heads of the riffles shallow sites (20 cm depth) mirrored surface temperature patterns but were on average 1.53°C cooler while deeper sites (40 cm depth) were 2.60°C cooler on average. Hyporheic temperatures lagged behind the surface water pattern and lag times increased with depth. Sites at the riffle tails generally displayed temperature patterns similar to those of the groundwater system: on average, temperatures were 4.32°C cooler than surface water temperatures and showed no significant variation. Hyporheic temperature patterns at the heads of the riffles suggested downwelling surface water, while the tails appeared to be influenced by upwelling groundwater. Both riffles displayed similar hyporheic temperature patterns but riffle 1 was on average 1.22°C warmer per site than riffle 2. Temperature differences between the riffles are attributed to bed form and substratum composition. These factors may have significant ecological implications including rates of organic matter decomposition, invertebrate life cycles and salmonid egg hatching times.

HYDROLOGICAL DATA NETWORK

Multivariate analysis in hydrology: the factor correspondence analysis method applied to annual rainfall data

L. Silveira

Abstract
    Most research on hydrology in developed countries does not
emphasize problems that are often encountered by hydrologists in
developing countries, problems such as the scarcity and poor
quality of data. In developing countries the available data base
is often a major constraint and a limiting factor in any
hydrological study. This paper analyses the consistency of a
network of nonrecording raingauges based on the annual rainfall
recorded by six representative stations in the Tacuarembo River
basin in Uruguay. The identification of possible errors not
revealed in the printed records was accomplished by application
of the factor correspondence analysis method and verified with
success by the classical double-mass analysis. This ability to
identify suspicious data with very modest requirements for data
management implies that the methodology based on factor
correspondence analysis could find wide application.

FLOOD HYDROLOGY / CLIMATOLOGY

141. Hydrological Sciences-Journal, 42(2) April 1997, pp. 225

**A worldwide comparison of regional flood estimation methods and climate
J. R. Meigh & F. A. K. Farquharson and J. V. Sutcliffe**

Abstract
    A summary of the results of regional flood frequency
analyses that have been carried out in many tropical and sub-
tropical countries is presented. The results provide a set of
flood estimation methods which should be of immediate usefulness
in practical applications, bearing in mind the errors of
generalization. By defining the representative values of the
mean annual flood and of the flood frequency curves for each
region, an attempt has been made to develop relationships between
the methods and climatic characteristics. These show that
adequate relationships can be obtained based solely on the median
annual average rainfall and the median catchment area for the
regions. In particular, the steepness of the regional flood
frequency curve can be estimated reasonably well from these two
parameters. The relationships confirm that, broadly speaking,
for humid regions the "average" flood - the flood that occurs
regularly every one or two years - is relatively large, but the
flood frequency curve is not very steep; rare floods (occurring
once in every 100 to 1000 years) are not very much larger than
the average flood. Conversely, in arid regions, the average
flood is small, but rare floods can be extremely large multiples
of the average. These relationships provide a useful initial
indication of the type of regional flood frequency estimation
method likely to be found in tropical and sub-tropical regions
throughout the world.

GROUND WATER HYDROLOGY

Nonequilibrium transport and sorption of organic chemicals during aquifer remediation

Cors Van Den Brink and Willem J. Zaadnoordijk

Abstract

Aquifer remediation operations are often behind schedule. Usually, a rather sharp concentration decrease shortly after the start of an operation is followed by a situation in which hardly any concentration decrease is observed. Furthermore, the concentration increases after stopping the groundwater recovery. These phenomena are caused by so-called tailing. An important cause of tailing is the phenomenon that equilibrium is not reached for some of the transport and sorption processes involved. To predict these effects of tailing, IWACO has developed a program SORWACO, which describes the behaviour of solutes along a path line. Processes for which equilibrium is reached quickly as well as processes for which equilibrium is reached only slowly are taken into account. The program has been verified against breakthrough curves observed in column experiments reported in the literature. The program parameters were calibrated using the data of several experiments. The resulting set of parameter values accurately described the transport for different flow velocities. The fact that quite good results can be obtained without a lot of data from a specific site makes the program a valuable tool for the design of remediation operations. The program is especially useful when extensive input data are not available so that detailed three-dimensional or stochastic models cannot be applied. The use of the program is illustrated by means of a case study. The progress was monitored and the data show good correspondence with the predictions of the program.

HYDROLOGICAL MODELLING

Comparing several genetic algorithm schemes for the calibration of conceptual rainfall-runoff models

Marco Franchini and Giorgio Galeati

Abstract

The Genetic Algorithm (GA) is often associated with local search optimisation techniques in the calibration process of Conceptual Rainfall-Runoff Models (CRRMS) (Wang, 1991; Franchini, 1996), i.e. the GA is used for approaching the region encompassing the global solution and then its results are used as a starting point for the local optimizer in the subsequent

"fine-tuning" process. However, the GA can be formulated in very many ways. This study analyses various GA structures and their robustness and efficiency. In addition, a sensitivity analysis of the various schemes to their own parameters is performed. The analysis is conducted using an 11-parameter CRRM, called A Distributed Model (ADM), applied to both a theoretical case without model and data errors and two cases of the real world in which there are both model and data errors. Finally, assuming the same role as the GA for the "Pattern Search" (PS) method in a two-step optimisation technique (Hendrickson et al., 1988), the results of the two algorithms are compared, showing that, in the calibration of the ADM, the PS may give a slightly superior performance.

GROUND WATER HYDROLOGY

144. Hydrological Sciences-Journal, 42(3) June 1997, pp. 381

One-dimensional springflow model for time variant recharge
A. K. Bhar & G. C. Mishra

Abstract
The linear mathematical model for springflow suggested by Bear (1979) can simulate springflow for an initial instantaneous recharge. A springflow model has been developed, using the Bear model and Duhamel's approach, which can simulate springflow for time variant recharge. The suggested model can also be used to compute the time variant recharge to the springflow domain from a given springflow time series. The inverse problem, which contains linear recharge terms and nonlinear depletion terms, has been solved using the Newton-Raphson method for solving a set of nonlinear equations. The model has been tested to compute recharge for Kirkgoz spring, a first magnitude karst spring in the Mediterranean region of Turkey. The estimated annual recharge computed by the model on a monthly basis compared well with the annual recharge which had been estimated (Korkmaz, 1990) using the Bear model.

WATER MANAGEMENT

145. Hydrological Sciences-Journal, 42(4) August 1997, pp. 467

Water resources for sustainable development
Zbigniew W. Kundzewicz

Abstract
The significance of water availability for sustainable development is discussed. A review of water-related areas of concern in Agenda 21, the blueprint for sustainability, is offered, with particular reference to its Chapter 18 devoted to freshwater resources. The problems of water resources of

vulnerable areas are tackled for the examples of arid and semiarid lands, mountains and small islands. The importance of water resources assessment and its building block, hydrological observations, for sustainable development is demonstrated and the adverse tendencies of declining hydrological observation networks are reported. Hydrological network density is seen as one of the indicators of sustainable development. Hydrological and water resources systems are perceived only as a component of the complex global system. Therefore a holistic perspective is advocated, looking at the existing inter relationships and interfaces with other sub-systems, including social, economic, institutional, etc.

HYDROLOGICAL DATA NETWORK

Hydrological information for sustainable development
Donald H. Burn

Abstract
This paper presents the development of a framework for data collection network design that considers sustainable development goals. The proposed framework adopts sustainable development principles and incorporates and revises traditional methodologies used in data collection network design. Important components of the framework include a focus on hydrological information, the preservation of long term gauging stations, and the adoption of integrated ecosystem monitoring. The eventual adoption of the framework should ensure that hydrological information required for effective decision making in water resources is available even as hydrometric data collection networks are rationalized.

GROUND WATER HYDROLOGY

Sustainable groundwater resources development
A. Das Gupta & Puspa R. Onta

Abstract
Sustainable groundwater resources development implies use of groundwater as a source of water supply, on a long term basis, in an efficient and equitable manner sustaining its quality and environmental diversity. An understanding of the behaviour of a groundwater system and of its interaction with the environment is required to formulate a sustainable management plan. Mathematical models supported by field information play a key role in assessing the future behaviour of a system to stresses and to find effective operating conditions for sustainable development and management of groundwater resources. Basic

principles for sustainable development are stressed and a brief review of two case studies is provided to illustrate how a systems approach and its computational framework of mathematical models can be used in addressing the main issue of water allocation satisfying some of the technical and environmental constraints.

ENVIRONMENTAL HYDROLOGY/RESERVOIR ROUTING

Least marginal environmental impact rule for reservoir development
K.Takeuchi

Abstract
The needs of reservoirs grow with population, standard of living, urbanization in the form of water supply, flood control, hydroelectric generation, navigation, recreation etc. Their development inevitably involves a substantial degree of environmental impact. The impact of reservoirs, on an average, increases in an exponential way with their size. If the marginal net benefit were assessed at the margin of the capacity, many giant reservoirs for primarily hydroelectric purpose would not be justified when the negative environmental impacts are counted. The reservoir size should not exceed the size whose marginal negative environmental impact becomes more than that of any alternative means elsewhere that can provide the same level of incremental gain in the global objectives. This is called the least marginal environmental impact rule. In order to make such a rule operational, many alternative means should be made available that can be sought along a holistic approach to water problems, that is, integrated water resources management, where a reservoir is only one of many options to be chosen.

SURFACE WATER HYDROLOGY

Hydrological changes in the Ganges system in Bangladesh in the post-Farakka period
M. Monirul Qader Mirza

Abstract
The basin area of the Ganges River in Bangladesh is extremely dependent on a regular water supply from upstream to meet requirements for agriculture, fisheries, navigation, salinity control, and domestic and industrial sectors. In 1975, India commissioned a barrage on the Ganges River at Farakka to divert a significant portion of the dry season flow in order to make the Calcutta Port navigable. Statistical analyses of

discharge and water level data have been carried out to determine if significant changes have occurred in the hydrology of the Ganges system in Bangladesh in the post-Farakka period. Siltation of the Gorai River (an offtake of the Ganges River) has also been examined using the stage-discharge relationship and regression analysis. The analyses show that the diversion has caused considerable hydrological changes in the Ganges system in Bangladesh. The water supply in the dry season has been reduced substantially, while siltation of the Gorai River has increased significantly.

SEDIMENTATION IN RESERVOIRS

Further remarks on a distributed approach to sediment delivery
Vito Ferro

Abstract

In this paper the sediment delivery relationship, i.e. the relationship between the basin sediment delivery ratio SDR_w, and the sediment delivery ratio SDR_i, of each morphological unit, i, into which a basin is divided, is firstly tested using morphological data (length, steepness and area of each unit) from six Sicilian and three Calabrian basins. Then a coefficient alpha of the sediment delivery relationship is related to several channel network parameters affecting the sediment transport efficiency. Finally, the spatial distribution of ^{137}Cs activity measured in a small Australian basin is used for validating the predictive capability of the proposed distributed approach to sediment delivery.

CLIMATOLOGY

Extreme hydrological events, palaeo-information and climate change
J. C. Knox and Z. W. Kundzewicz

Abstract

Extreme flood events have been and continue to be one of the most important natural hazards responsible for deaths and economic losses. Extreme floods result in direct destructive effects during the time of the event, and they also may be followed by a related chain of indirect calamities such as famines and epidemics that produce additional damages and suffering. Extreme hydrological events that have occurred in the historical past may also occur in the future. Knowledge about magnitudes and recurrence frequencies of past extreme hydrological events in most regions are too short to adequately evaluate potential magnitudes and recurrence frequencies of extreme hydrological events. Stationary climate in which the

mean and variance do not change over time is a basic underlying assumption of standard methodological procedures for estimating recurrence probabilities of extreme hydrological events. Palaeo-archives contained in river and lake sediments, fossil plant and animal matter, ice layers, and other natural archives show that the assumption of stationary climate is not valid when the time scale is extended beyond centuries and millennia. Records of past extreme floods that occurred long before the period of instrumentation can be reconstructed from the distribution of slackwater flood deposits or from derivation of water depths competent to transport the largest rocks found in flood deposited sediment. Palaeo- flood records reconstructed from the Upper Mississippi and Lower Colorado River systems in the United States confirm nonstationary behaviour of the mean and variance in hydrological time series. These stratigraphic records have shown that even very modest climatic changes have resulted in very important changes in the magnitudes and recurrence frequencies of extreme floods. A close relationship was found between the palaeo-flood record of extreme floods in the Upper Mississippi River system and a palaeo-record of stable isotopes of oxygen and carbon preserved in speleothem calcite from a local cave. The relationship suggests that isotopic records elsewhere might be calibrated to provide insight about how future potential climate changes might impact extreme flood magnitudes and recurrence frequencies there. Atmospheric global circulation models (GCMS) mainly simulate average climatic conditions and are presently inadequate sources of information about how future climate changes might be represented at the extreme event scale. Palaeo-flood archives, however, provide basic information about how magnitudes and recurrence frequencies of extreme hydrological events responded to past climate changes and they also provide a reference base against which GCM simulations can be calibrated regionally and be better interpreted to decipher hydrological information at the extreme event scale.

DROUGHT MANAGEMENT

A drought frequency formula

T. C. Sharma

Abstract

The important elements of a drought phenomenon are the longest duration and the largest severity for a desired return period. These elements form a basis for designing water storage systems to cope with droughts. At times, a third element, drought intensity, is also used and is defined as the ratio of severity to duration. The commonly available statistics for the causative drought variables such as annual rainfall or runoff sequences are the mean, the coefficient of variation and the lag one serial correlation coefficient, and occasionally some indication of the probability distribution function (pdf) of the

sequences. The extremal values of the duration and severity are modelled in the present paper using information on the aforesaid parameters at the truncation level equal to the mean of the drought sequence, which is generally taken as the truncation level in the analysis of droughts. The drought severity has been modelled as the product of the duration and intensity with the assumption of independence between them. An estimate of drought intensity has been realized from the concept of the truncated normal distribution of the standardized form of the drought sequences in the normalized domain. A formula in terms of the extremal severity and the T-year return period has been suggested similar to the flood frequency formulae, commonly cited in hydrological texts.

LAND AND SOIL EROSION

153. Hydrological Sciences-Journal,42(6) December 1997, pp. 833

Sediment yield estimation using GIS
Umesh C. Kothyari and Sanjay K. Jain

Abstract
A method has been developed in the present study for the determination of the sediment yield from a catchment using a GIS. The method involves spatial disaggregation of the catchment into cells having uniform soil erosion characteristics. The surface erosion from each of the discretized cells is routed to the catchment outlet using the concept of sediment delivery ratio, which is defined as a function of the area of a cell covered by forest. The sediment yield of the catchment is defined as the sum of the sediments delivered by each of the cells. The spatial discretization of the catchment and the derivation of the physical parameters related to erosion in the cells are performed through a GIS technique using the Integrated Land and Water Information Systems (ILWIS) package.

WATER QUALITY / GROUND WATER HYDROLOGY

154. Hydrological Sciences-Journal, 42(6) December 1997, pp. 877

The occurrence and behaviour of fluoride in the groundwater of the Lower Vamsadhara River basin, India
N. Srinivasa Rao

Abstract
Reports on the occurrence of fluoride in natural water resources and the associated health hazards due to human consumption have been made from many parts of India during the last decade. With the objective of organizing a systematic scientific programme to understand the behaviour of fluoride in

natural water resources in relation to the local hydrogeological and climatic conditions and agricultural use, a typical area constituting the lower Vamsadhara River basin was chosen for a detailed study. High fluoride concentrations in the groundwater reaching a maximum of 3.4 mgl^{-1} were observed to be associated with weathered formations of pyroxene amphibolites and pegmatites. The groundwater in the clayey soils contained much less fluoride as compared to the sandy soils. The complex depositional pattern of these sandy and clayey soils plays an important role in the uneven spatial distribution of fluoride in the groundwater. The contribution of fluoride from geological formations is far greater than that from agriculture: the maximum yield of fluoride by superphosphate fertilizer to irrigation water is observed to be 0.34 mgl^{-1}. The fluoride concentration is expected to be increased in the future as the groundwater is subsaturated with respect to fluorite. An inverse relationship between F and Ca and positive relationships of F with Na, HCO3, P04 and electrical conductivity were observed. Best relationships were obtained in the fluoride range of 1.0-3.4 mgl^{-1}.

Hydrological
Processes Journal

WATER QUALITY

155. HYDROLOGICAL PROCESSES, VOL. 10, 127-149 (1996)

Review of methods for the detection and Estimation of trends with emphasis on water quality applications
Sylvia R. Esterby

ABSTRACT

Methods for the detection and estimation of trends which are suitable for the type of data sets available from water quality and atmospheric deposition monitoring programmes are considered. Parametric and non-parametric methods which are based on the assumption of monotonic trend and which account for seasonality through blocking on season are described. The topics included are heterogeneity of trend, missing data, covariates, censored data, serial dependence and multivariate extensions. The basis for the non-parametric methods being the method of choice for current large data sets of short to moderate length is reviewed. A more general definition of trend as the component of gradual change over time is consistent with another group of methods and some examples are given. Spatial temporal data sets and longer temporal records are also briefly considered. A broad overview of the topic of trend analysis is given, with technicalities left to the references cited. The necessity of defining what is meant by trend in the context of the design and objectives of the programme is emphasized, as is the need to model the variability in the data more generally.

CLIMATOLOGY

156. HYDROLOGICAL PROCESSES, VOL. 10, 357-372 (1996)

Rainfall and temperature trends in India
U. C. Kothyari And V. P. Singh

ABSTRACT

An investigation was carried out to identify trends in the rainfall and temperature regimes of the Ganga basin in India and in India as a whole. Long-term data on the monsoon and annual rainfall and the average annual temperature for India as a whole, and on the monsoon rainfall, number of rainy days and annual maximum temperature of the Ganga basin were analysed. The trends in these data were detected using non-parametric methods. The results of this study showed that the rainfall variables had a decreasing trend and the temperature had an increasing trend. These trends were observed to have begun around the second half of the 1960s, and have implications for the Indian economy. As the Indian economy continues to be based on agriculture, water resource management for irrigation plays a vital part in its

growth. Present methods of design and management for water resource systems assume the climatic regime to be stationary. If indeed the climatic regime has changed, it will be necessary to develop new management approaches which consider this change.

SNOW HYDROLOGY

157. HYDROLOGICAL PROCESSES, VOL. 10, 509-521 (1996)

Effect of snow and firm hydrology on the physical and chemical characteristics of glacial runoff
Andrew G. Fountain

ABSTRACT
Near-surface processes on glaciers, including water flow over bare ice and through seasonal snow and firn, have a significant effect on the speed, volume and chemistry of water flow through the glacier. The transient nature of the seasonal snow profoundly affects the water discharge and chemistry. Water flow through snow is fairly slow compared with flow over bare ice and a thinning snowpack on a glacier decreases the delay between peak meltwater input and peak stream discharge. Furthermore, early spring melt flushes the snowpack of solutes and by mid-summer the melt water flowing into the glacier is fairly clean by comparison. The firn, a relatively constant feature of glaciers, attenuates variations in water drainage into the glacier by temporarily storing water in saturated layer. Bare ice exerts opposite influences by accentuating variations in runoff by water flowing over the ice surface. The melt of firn and ice contributes relatively clean (solute-free) water to the glacier water system.

HYDROLOGIC MODELLING

158. HYDROLOGICAL PROCESSES, VOL. 10, 793-802 (1996)

Application of unit hydrograph techniques to Solute transport in catchments
C. J. Barnes And M. Bonell

ABSTRACT
Current models of solute movement in catchments are based on rainfall-runoff models and are consequently biased towards processes which determine the magnitude and timing of water flux. It is shown here that the instantaneous unit hydrograph (IUH), or runoff response function, obtained from a hydrograph is fundamentally different from the residence time distribution which governs the response to solutes/tracers. Using hydrometric and tracer data obtained from a small (25 ha) catchment in the humid tropics a modification of the IUH technique is demonstrated

which also allows approximate modelling of the tracer data. New features of the modified conceptual model are identified with known hillslope processes.

GROUND WATER HYDROLOGY

Estimation of temporal changes in soil moisture Using resistivity method
V. C. Goyal, P. K. Gupta, S. M. Seth and V. N. Singh

ABSTRACT
The temporal variation in a soil moisture profile can be studied using resistivity sounding data acquired at different times. The layered earth model based estimation of soil moisture from apparent resistivity data is a two-step non-linear inversion. Firstly, the apparent resistivity data are inverted to derive the layer resistivity variations and thicknesses and, secondly, the moisture content is estimated from these layer resistivity variations using a calibration equation. The soil moisture-resistivity problem was studied using the one-dimensional formulation of resistivity problem. A generalized geoelectric earth model was considered to simulate the soil moisture distribution and its temporal variation in the un-saturated zone. An algorithm (RESMOS) for the interpretation of the apparent resistivity data in terms of soil moisture variations through this two-step inversion process is reported.

FLOOD HYDROLOGY

Analytical Hayami solution for the diffusive wave Flood routing problem with lateral inflow
Roger Moussa

ABSTRACT
The diffusive wave equation is generally used in flood routing in rivers. The two parameters of the equation, celerity and diffusivity, are usually taken as functions of the discharge. If these two parameters can be assumed to be constant without lateral inflow, the diffusive wave equation may have an analytical solution: the Hayami model. A general analytical method, based on Hayami's hypothesis, is developed here which resolves the diffusive wave flood routing equation with lateral inflow or outflow uniformly distributed over a channel reach. Flood routing parameters are then identified using observed inflow and outflow and the Hayami model used to simulate outflow. Two examples are discussed. Firstly, the prediction of the hydrograph at a downstream section on the basis of a knowledge

of the hydrograph at an upstream section and the lateral inflow. The second example concerns lateral inflow identification between an upstream and a downstream section on the basis of a knowledge of hydrographs at the upstream and downstream sections. The new general Hayami model was applied to flood routing simulation and for lateral inflow identification of the River Allier in France. The major advantages of the method relate to computer simulation, real-time forecasting and control applications in examples where numerical instabilities, in the solution of the partial differential equations must be avoided.

HYDROLOGIC MODELLING

161. HYDROLOGICAL PROCESSES, VOL, 10 1229-1242 (1996)

Distributed numerical rainfall-runoff modelling In an arid region using thematic mapper data and a geographical Information system

K. D. Sharma, M. Menenti, J. Huygen And P. C. Fernandez

ABSTRACT
    The rainfall-runoff process consists of an excess rainfall process and a runoff concentration process. A transient one-dimensional finite difference model describing the partitioning of precipitation between surface runoff, soil moisture storage and deep percolation, through the coupling of saturated-unsaturated zones, has been implemented in a geographical information system including data on vegetation cover derived from the Landsat Thematic Mapper. The model has been used to simulate both the rainfall excess and the resultant outflow hydrographs for a small and zone drainage basin in the Andean region of Argentina. The overall hydrograph shape, peak discharge, runoff volume and flow duration are predicted within a relative squared error of 13.2%. The spatial input data and the model structure are discussed and suggestions for applications to larger complex basins and for future refinements in the technique are presented.

HYDROLOGIC MODELLING

162. HYDROLOGICAL PROCESSES, VOL. 10, 1401-1409 (1996)

Flood modelling with GIS-derived distributed Unit hydrographs
I. Muzik

ABSTRACT
    The concept of a spatially distributed unit hydrograph is based on the fact that the unit hydrograph can be derived from

the time-area curve of a watershed by the S-curve method. The time-area diagram is a graph of cumulative drainage area contributing to discharge at the watershed outlet within a specified time of travel. Accurate determination of the time-area diagram is made possible by using a GIS. The GIS is used to describe the connectivity of the links in the watershed flow network and to calculate distances and travel times to the watershed outlet for various points within the watershed. Overland flow travel times are calculated by the kinematic wave equation for time to equilibrium channel flow times are based on the Manning and continuity equations. To account for channel storage, travel times for channel reaches are increased by a percentage depending on the channel reach length and geometry. With GIS capability for rainfall mapping, the assumption of a uniform spatial rainfall distribution is no longer necessary; hence the term, spatially distributed unit hydrograph. An example of the application for the Waiparous Creek in the Alberta Foothills is given. IDRISI is used to develop a simple digital elevation model of the 229 kM² watershed, using 1 km x 1 km grid cells. A grid of flow directions is developed and used to create an equivalent channel network. Excess rainfall for each 1 km x 1 km cell is individually computed by the Soil Conservation Service (SCS) runoff curve method and routed through the equivalent channel network to obtain the time-area curve. The derived unit hydrograph gave excellent results in simulating an observed flood hydrograph. The distributed unit hydrograph is no longer a lumped model, since it accounts for internal distribution of rainfall and runoff. It is derived for a watershed without the need for observed rainfall and discharge data, because it is essentially a geomorpho-climatic approach. As such, it allows the derivation of watershed responses (hydrographs) to inputs of various magnitudes, thus eliminating the assumption of proportionality of input and output if needed. The superposition of outputs is retained in simulating flood hydrographs by convolution, since it has been shown that some non-linear systems satisfy the principle of superposition. The distributed unit hydrograph appears to he a very promising rainfall runoff model based on GIS technology.

SURFACE WATER HYDROLOGY

Pipeflow contributing areas and runoff response
J. A. A. Jones

ABSTRACT

Links that have been established between the characteristic responses of hillslope drainage processes and the size of drainage catchments enable valuable extrapolations and comparisons to be made, both within and beyond the range of the field data. To date, flow through natural soil pipes has not

been included in these investigations. A methodology is offered
for achieving this and the first such analyses of field data on
pipeflow. The results indicate that pipeflow responses follow
trends which are broadly similar to other hillslope drainage
processes and are intermediate between throughflow and saturation
overland flow.

SNOW HYDROLOGY

164. HYDROLOGICAL PROCESSES, VOL. 11, 149-167 (1997)

Kinematic wave modelling of vertical movement of snowmelt water through a
snowpack
V. P. Singh, L. Bengtsson and Goran westerstrom

ABSTRACT
    Vertical movement of snowmelt water through snowpacks is
modelled by applying the kinematic wave theory. Analytical
solutions are obtained for moisture flux, particle velocity, time
history and velocity of meltwater front and total moisture
content for a single melt event assuming that the melt rate is
constant. These solutions are extended to the case involving
more than one event.

SNOW HYDROLOGY

164. HYDROLOGICAL PROCESSES, VOL. 11, 177-187 (1997)

Kinematic wave modelling of saturated basal flow in a snowpack
V. P. Singh , I. Bengtsson and Goran westerstrom

ABSTRACT
    Movement of snowmelt water through a thin saturated layer
at the infiltrating base of a snowpack is modelled by applying
the kinematic wave theory. Analytical solutions are obtained for
flow depth, velocity and discharge assuming that the rate of
input to the saturated layer due to vertical percolation is
constant. This assumption results in a linear rise and
recession of the snowmelt hydrograph. The solutions are extended
to the case of time-varying input. An explicit consideration of
infiltration leads to a free boundary problem.

SURFACE WATER HYDROLOGY

166. HYDROLOGICAL PROCESSES, VOL. 11, 297-310 (1997)

Stochastic matrices applied to the probabilistic analysis of runoff events in a semi-arid stream
C. Conesa-Garcia and F. Alonso-Sarria

ABSTRACT

Stochastic models offer an objective and quantitative method of analysing the behaviour of discrete hydrological variables. For the Algeciras semi-arid stream in south-east Spain, homogeneous first- and second-order Markov chains were applied to rainfall and runoff series in order to establish the length of the rainy sequences using probability as well as the beginning and duration of runoff. At the same time, a stochastic process was devised based on two subsystems, one for rainfall, modelled as a four-state n-order Markov chain, and another for transition of runoff depending on the former subsystem. By considering the median rainfall obtained in each season as a class threshold, the possible number of states in the first subsystem is raised to nine, giving more complicated stochastic matrices which, without using an excessive number of parameters, allow better description and prediction of the transition from rainfall to runoff.

CLIMATOLOGY

Evaluation and generalization of 13 mass-transfer equations for determining free water evaporation
V. P. Singh and C.Y. Xu

ABSTRACT

Thirteen equations based on the mass-transfer method for determining free water evaporation were expressed in seven generalized equations. These seven equations were then compared with pan evaporation at four climatological stations in north-western Ontario, Canada. The comparisons were based on monthly evaporation. Equations were compared by calibrating them on the entire data sets as well as by calibrating on part of the data and then verifying them on the remainder of the data. The results of comparison showed that all equations were in reasonable agreement with observed evaporation, and that the effect of wind velocity on monthly evaporation was marginal. However, when an equation with parameters obtained at one site was applied to compute evaporation at another site, the computed evaporation was not in good agreement with observed values.

SURFACE WATER HYDROLOGY

Potential of extending the rainfall Intensity-duration-frequency Relationship to non-recording Rain gauges

Pao-Shan Yu and Chia-Jung Chen

ABSTRACT

Maximum rainfall intensity-duration-frequency (IDF) curves are commonly applied to determine the design rainfall in water resource projects. Normally, the IDF relationship is derived from recording rain gauges. As the network of nonrecording rain gauges (daily rainfall) in Taiwan has a higher density than recording rain gauges. attempts were made in this study to extend the IDF relationship to non-recording rain gauges. Eighteen recording rain gauges and 99 nonrecording rain gauges over the Chi-Nan area in Southern Taiwan provide the data sets. The regional IDF formulae were generated for ungauged areas to estimate rainfall intensity for various return periods and rainfall durations larger than or equal to one hour. For rainfall durations less than one hour, a set of adjustment formulae were applied to modify the regional IDF formulae. The method proposed in this study had reasonable application to non-recording rain gauges, which was concluded from the verification of four additional recording rain gauges.

HYDROLOGICAL MODELLING

Geomorphological transfer function calculated From digital elevation models for distributed Hydrological modelling

Roger Moussa

ABSTRACT

Recently, several attempts have been made to relate the hydrological response of a catchment to its morphological and topographical features using different hypotheses to model the effect of the drainage network. Several transfer functions were developed and some of these are based on the theory of a linear model, the geomorphological unit hydrograph. The aim of this paper is to present a methodology to automatically identify the transfer function, using digital elevation models for applications in distributed hydrological modelling. The transfer function proposed herein is based on the Hayami approximation solution of the diffusive wave equation especially adapted for the routing hydrograph through a channel network. The Gardon d'Anduze basin, southern France, was retained for applications. Digital elevation models were used to extract the channel network and divide the basin into subcatchments. Each subcatchment produces. at its own outlet, an impulse response which is routed to the outlet of the whole catchment using the diffusive wave model described by two parameters: celerity and diffusivity functions of geometrical characteristics of the channel network. Firstly, a geomorphological unit hydrograph obtained by routing

a homogeneous effective rainfall was compared with the unit hydrograph identified by a lumped model scheme, then the distributed model was applied to take into account the spatial variability of effective rainfall in the catchment. Results show that this new method seems to be adapted for distributed hydrological modelling; it enables identification of a transfer function response for each hydrological unit, here subcatchments, and then simulation of the contribution of each unit to the hydrograph at the outlet.

DROUGHT MANAGEMENT

From drought to flood: catchment responses Revealed using novel soil water probes
J.D. Miller, G. J. Gaskin and H. A. Anderson

ABSTRACT
New soil water probes, developed at the Macaulay Land Use Research Institute (MLURI), were used in catchment studies during the transition from drought to flood, revealing insights into both spatial and temporal behaviour of water in the soil profile. Measured soil water content showed that the mineral horizons became progressively wetter upwards from the base of the profile, which was confirmed by linked hydrochemical studies. After severe droughts the amounts of water required to raise soils back to field capacity may have long-term consequences on water abstraction.

WATERSHED MANAGEMENT

The contrasting effects of wildfire and Clearfelling on the hydrology of a small catchment
David F. Scott

ABSTRACT

A wildfire in an afforested research catchment presented the rare opportunity to compare the hydrological effects of wildfire with the effects of clearfelling in the same catchment in the Jonkershoek Valley, in the south-western Western Cape Province of South Africa. The timber plantation, which occupies 57% of the 2 **km^2 catchment, had been clearfelled and re-planted to Pinus radiata roughly five years before the fire. The effects of the two treatments on total flow, stormflow and quick-flow volumes, peak discharge and storm response ratio were determined

by means of multiple regression analysis, employing the dummy variable method to test for the significance of treatments. Both clearfelling and wildfire caused significant increases in all the stream-flow variables analysed. But the clearfelling effect was dominated by large increases in total flow (96% over three years), of which storm-flow and quick-flow volumes formed only minor parts. After the wildfire, by contrast, increases in total flow were small (12%) but the storm flow increases were three- to four- fold in the first year and roughly double in the second year. The wildfire caused fire-induced water repellency in the soils which led to overland flow on mid-slope sites, where soil infiltrability normally far exceeds local rainfall intensifies. It is argued that these results support the hypothesis that stream-flow generation processes were changed by the wildfire in that overland flow made a direct contribution to storm lows, but that clearfelling had no such effect.

HYDROLOGIC MODELLING

172. HYDROLOGICAL PROCESSES, VOL. 11, 587-626 (1997)

The use of entropy in hydrology and water resources
V. P. Singh

ABSTRACT

Since the development of the entropy theory by Shannon in the late 1940s and of the principle of maximum entropy (POME) by Jaynes in the late 1950s there has been a proliferation of applications of entropy in a wide spectrum of areas, including hydrological and environmental sciences. The real impetus to entropy-based hydrological modelling was provided by Amorocho and Espildora in 1972. A great variety of entropy applications in hydrology and water resources have since been reported, and new applications continue to unfold. This paper reviews the recent contributions on entropy applications in hydrology and water resources, discusses the usefulness and versatility of the entropy concept, and reflects on the strengths and limitations of this concept. The paper concludes with comments on its implications in developing countries.

WATERSHED MANAGEMENT

173. HYDROLOGICAL PROCESSES, VOL. 11, 671-694 (1997)

Application of the geographical Information Systems approach to watershed mass Balance studies
Paul I. Richards and lee R. Kump

ABSTRACT

This study was undertaken to test the utility of a geographical information systems (GIS) approach to problems of watershed mass balance. This approach proved most useful in exploring the effects that watershed scale, lithology and land use have on chemical weathering rates, and in assessing whether mass balance calculations could be applied to large multilithological watersheds. Water quality data from 52 stations were retrieved from STORET and a complete GIS database consisting of the watershed divide, lithology and land use was compiled for each station. Water quality data were also obtained from 7 experimental watersheds to develop a methodology to estimate annual fluxes from incomplete data sets. The methodology consists of preparing a composite of daily flux data, calculating a best fit sinusoid and integrating the equation to obtain an annual flux. Comparison with annual fluxes calculated from high resolution data sets suggests that this method predicts fluxes within about 10% of the true annual flux.

Annual magnesium fluxes (moles km^{-2}/yr) were calculated for all stations and adjusted for fluxes from atmospheric deposition. Magnesium flux was found to be a strong function of the amount of carbonate in the watershed, and silica fluxes were found to increase with the fraction of sandstone present in the watershed. All fluxes were strongly influenced by mining practices, with magnesium fluxes from affected watersheds being 6-10 times higher than fluxes from comparable pristine watersheds. Mining practices enhance chemical weathering by increasing the surface area of unweathered rock to which water has access and by increasing acidity and rate of mineral weathering. Fluxes were also found to increase with watershed size. This scale dependence is most likely caused by the sensitivity of weathering fluxes to even minor quantities of carbonates, which are likely to be found in all lithologies at larger scales.

Mass balances were carried out in watersheds where gauged sub-watersheds made up more than 95% of the area. The calculations show large magnesium flux and water balance discrepancies. These errors may be a result of significant groundwater inputs to streams between gauges. The results suggest that improvements in how we measure discharge and estimate fluxes may be required before we can apply mass balance techniques to larger scales.

LAND AND SOIL EROSION

174. HYDROLOGICAL PROCESSES, VOL. 11, 1087-1097 (1997)

Topmodel: A personal view
M. J. Kirkby

ABSTRACT
The minimum set of assumptions underlying TOPMODEL are explored, together with conditions under which they can or cannot be relaxed. It is concluded that it may be necessary to move towards spatially explicit solutions of the governing equations if the underlying q-D relationships are to be modified. The

simplicity of TOPMODEL invites its use as a submodel within a range of geomorphological and ecological models that are driven by hydrology. Some example applications are outlined for both soil erosion and solution.

HYDROLOGICAL MODELLING

175. HYDROLOGICAL PROCESSES, VOL. 11, 1219-1230 (1997)

The problem of scaling in grid-related Hydrological process modelling
P. Braun, Tibor Molnar and H.B. Kleeberg

ABSTRACT
    This article shows some important scaling aspects that exist in hydrological process grid modelling with GIS, with respect to selecting the optimal grid width. Hydrologically relevant space parameter fields should often be regarded as selfsimilar fractals for which certain invariance characteristics are applied. These characteristics are especially important if there is an extensive change in the model grid width. The self-similarity generates simple scaling laws, which can be used for rescaling procedures.

FLOOD HYDROLOGY

176. HYDROLOGICAL PROCESSES, VOL. 11, 1441-1450 (1997)

Characterization of flood inundated areas And delineation of poor drainage soil using ERS-1 SAR imagery
Moussa Badji And Sylvia Dautrebande

ABSTRACT
    Recent years have been marked by a continuous availability of spatial SAR data since the launch of the European remote sensing satellite (ERS-1) in 1991. Consequently, remote sensing techniques now offer an opportunity to map flood inundation fields caused by river overflow or waterlogging in environments characterized by frequent cloud cover. Indeed, inundation fields can clearly be seen on ERS-1 SAR images taken during flooding periods. However, such an identification can be constrained by the similarity in behaviour between water surfaces and other features of the landscape such as extended asphalt areas, permanent water bodies and less illuminated slopes. For consistent flood inundation extent mapping a more robust approach is required. This is provided by a conceptual flood inundation index that is physically sound in relation to radar imaging. Moreover, this index has proved to be useful for highlighting soils located within inundation fields and having significantly different internal drainage. The results achieved in the framework of the research must be seen in the context of intensive use of remote sensing data to support decision methods for sustainable management of land and water resources. Such

decision support methods could be provided by river hydraulic models aimed at assessing environmental effects of inundation floods and at early flood warning systems.

HYDROLOGICAL DATA NETWORK

Sensitivity of mass transfer-based evaporation Equations to errors In daily and monthly Input data
V. P. Singh and C.Y. Xu

ABSTRACT
    The influence of data errors on the performance of mass transfer-based evaporation equations was investigated for both monthly and daily data from a climatological station in the State of Vaud in Switzerland. Evaporation estimates were found to be particularly sensitive to vapour pressure gradient, less sensitive to wind speed and most insensitive to temperature. A quantitative analysis showed that: (1) systematic errors in vapour pressure data influenced evaporation estimates inversely to more or less the same magnitude for both monthly and daily cases; (2) systematic errors in wind speed and temperature data influenced evaporation estimates inversely to the magnitude of about a half and a quarter of the magnitude of the influence of vapour pressure errors, respectively; and (3) evaporation estimates were much more sensitive to random errors in the case of monthly data than daily data.

GROUND WATER HYDROLOGY

Performance of the steady-state dipole flow test In layered aquifers
J. Xiang And Z. J. Kabala

ABSTRACT
    Steady-state numerical simulations of the dipole flow test in layered aquifers demonstrate that the test produces a good estimate of the equivalent hydraulic conductivity anisotropy ratio for the part of the aquifer spanned by the well chambers. The effects of chamber size, different conductivity of layers and layer location on the estimated anisotropy ratios are presented. The steady-state dipole flow test, when performed at different levels in the well, can yield estimates of the down-hole anisotropy ratio distribution. Numerical simulations also illustrate that the skin effect can significantly distort the anisotropy estimates produced by the dipole flow test.

SURFACE WATER HYDROLOGY / WATERSHED MANAGEMENT

179. HYDROLOGICAL PROCESSES, VOL. 11, 1649-1669 (1997)

Effect of spatial and temporal variability in rainfall and watershed characteristics on stream flow hydrograph
V. P. Singh

ABSTRACT

The shape, timing and peak flow of a stream flow hydrograph are significantly influenced by spatial and temporal variability in rainfall and watershed characteristics. Depending upon the size and shape of a watershed, its hydrological response is closely linked with storm dynamics. On an urban watershed a rain storm moving in the direction of flow produces a higher peak than it would if it were moving in the opposite direction. The effect of storm speed on peak discharge is much less for rapidly moving storms than for storms moving at about the same speed as the flow velocity. In a relatively homogeneous watershed the most important effect of spatial variability of rainfall occurs in the timing and shape of the runoff hydrograph. Temporally variable rainfall leads to higher peak flow than does constant rainfall. Significant errors in the prediction of runoff occur when an equivalent uniform hillslope is used to represent a heterogeneous hillslope. When average soil properties are used instead of spatially variable properties, significant differences are observed in infiltration. Spatially variable roughness alters the flow dynamics significantly.

HYDROLOGICAL MODELLING

180. HYDROLOGICAL PROCESSES, VOL. 11, 1685-1705 (1997)

Evaluating three evapotranspiration methods in The slurp Macroscale hydrological model
Alan G. Barr, G. W. Kite, R. Granger1 and C. Smith

ABSTRACT

Hydrological models simulate the land phase component of the global water cycle and provide a mechanism for evaluating the effects of climatic variation and change on water resources. Evapotranspiration (ET) is a critical process within such models. This study evaluates three different methods for estimating ET in the simple lumped reservoir parametric model (SLURP), over a five-year period in the Kootenay Basin of eastern British Columbia. The three ET methods were the Morton implementation of the Bouchet complementary relationship, the Granger modification of Penman's method and the Spittlehouse energy-limited versus soil moisture-limited method. We evaluated the three ET methods indirectly, based on the ability of the SLURP

hydrological model to simulate daily stream flow over several annual cycles. Although the ET methods affected simulated stream flow differently, the Spittlehouse method had more physical significance and gave better agreement between simulated and recorded stream flows. The results showed that using an ET method that included a soil moisture limitation to ET produced a worthwhile improvement in hydrological performance.

SNOW HYDROLOGY

181. HYDROLOGICAL PROCESSES, VOL. 11, 1725-1736 (1997)

Snowmelt resulting from advection
Kevin Shook and D. M. Gray

ABSTRACT

Snowmelt can be estimated by applying an energy balance to a control volume of snow. A major problem with this method is the difficulty of obtaining accurate estimates of the turbulent transfers of sensible and latent heat. This paper uses a modified form of the Penman-Monteith equation, a combined aerodynamic-energy balance approach for calculating evaporation from vegetative surfaces, to estimate the energy available for snowmelt during large-scale advection. The modification requires knowledge of k, the ratio of the energy used for melting to the net energy available for phase changes (vaporization and melting). Comparisons between the melt flux determined by the Penman-Monteith equation and estimates derived from field measurements suggest a value of k in the range of 0.90 0.99. The modified Penman-Monteith equation is used in a detailed simulation of melting of a shallow prairie snow cover. This simulation incorporates the effects of a small-scale advection of energy from bare ground to adjacent patches. It is demonstrated that the contributions by large- and small-scale advective energy transfers to melt depend on the interactions between snow-covered area and meteorological variables.

REMOTE SENSING / FLOOD HYDROLOGY

182.HYDROLOGICAL PROCESSES, VOL. 11, 1777-1795 (1997)

Integrating remote sensing observations of flood hydrology and hydraulic modelling
P. D. Bates, M. S. Horritt, C. N. Smith and D. Mason

ABSTRACT

The further development of two-dimensional finite element models of river flood flow is currently constrained by a lack of data for rigorous parameterization and validation. Remote sensing techniques have the potential to overcome a number of

these constraints thereby allowing a research design for model development. This is illustrated with reference to a case study of a two-dimensional finite element model applied to the Missouri River, Nebraska and compared with a synchronous Landsat TM image of flood inundation extent. The case study allows research needs for the integration of hydraulic modelling and remote sensing to be defined.

REMOTE SENSING

183. HYDROLOGICAL PROCESSES, VOL. 11, 1907-1915 (1997)

Monitoring turbidity with IRS-1A data
V. K. Choubey

ABSTRACT

This study was undertaken to determine the application of Indian Remote Sensing Satellite 1A-Linear Imaging Self scanning (IRS-1A-LISS-I) spectral digital data for estimating turbidity in an inland water body. IRS-1A-LISS-I spectral digital data for 20 October 1988 for the Tawa Reservoir were analysed and compared with field measurements of turbidity and used to develop simple and multiple regression equations to estimate turbidity in the surface water. The turbidity values were positively correlated with increasing wavelength LISS-1 bands, 1, 2 and 3 of the visible region of the spectrum. Simple linear regression analyses indicate that LISS-1 band 3 (0.62-0-.68 μm) is the best for prediction purpose. Multiple regression equations have higher correlations ($r = 0.91$). For validation, the equations were tested using LISS-1 data for 28 September 1988 for the Tawa Reservoir.
IRS-1A-LISS-I data provide a solid foundation for further development of remote sensing as a practical tool in monitoring water quality. The regression technique has strong potential for the future application of IRS-1A-LISS-I data in monitoring water quality of inland water bodies and estuaries.
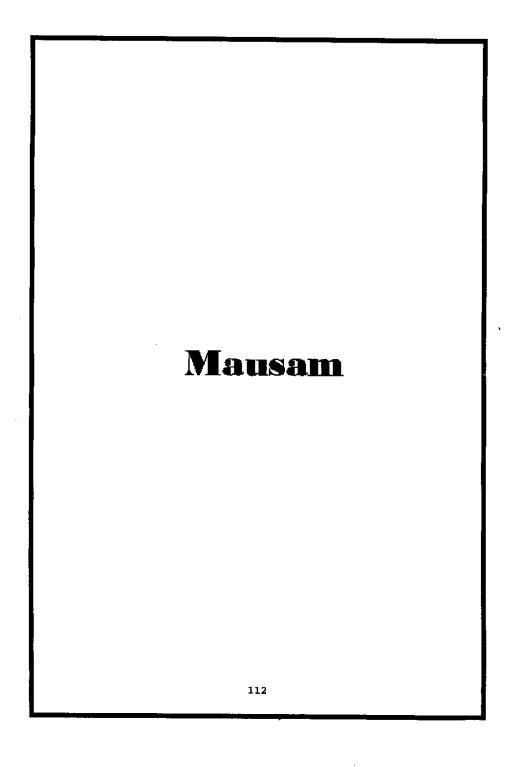
HYDROLOGICAL MODELLING

184. HYDROLOGICAL PROCESSES, VOL. 11, 1917-1926 (1997)

The introduction of runoff routing into Large-scale hydrological models
T. J. Jolley And H. S. Wheater

ABSTRACT

Two alternative schemes are presented that are appropriate for the representation of runoff routing in large-scale grid-based hydrological models and atmospheric general circulation models (AGCMs). The first scheme characterizes routing processes as a single conceptual store. The second scheme, developed by Naden (1992), uses the normalized network width function to

characterize the channel network form and a linear solution to the convective diffusion equation of one-dimensional flow to characterize the routing effect of a single channel. Both schemes are applied to the Severn catchment at the daily time-scale for the period 1981 to 1990 using a grid resolution of 40 km. Comparable results were obtained using both schemes (efficiencies were of the order of 80% in both cases). A combined model using a conceptual reservoir to represent hillslope routing and the network-based scheme to represent channel routing was developed to investigate the relative roles of hillslope and channel routing at the catchment scale. The application of this model demonstrated the important role of hillslope routing in reproducing the low frequency component of the catchment response. However, in terms of goodness-of-fit there was little to choose between the three schemes. Consequently, it is recommended that additional a priori knowledge of the routing processes should be used to condition the choice of model structure.

Mausam

CLIMATOLOGY

A re-examination of ENSO/anti-ENSO events and simultaneous performance of
the Indian summer monsoon

J. Chattopadhyay and R. Bhatla

ABSTRACT.

The relationship between ENSO/anti-ENSO events in the Pacific basin and simultaneous all India monsoon rainfall has been re-examined for the period 1901-1990 using Southern Oscillation index (SOI). The result, shows that there is fairly strong association betwen ENSO events and dry monsoon years. There exists a weak teleconnection between anti-ENSO events and wet monsoon indicating that anti-ENSO events have only a moderate impact on the Indian nionsoon rainfall. Developing ENSO (anti-ENSO) episodes durinig the monsoon season indicates non-occurrence of simultaneous floods (droughts) with a very high degree of confidence. 70 (50) percent of the droughts (floods) during the above period have occured during ENSO,(anti-ENSO) events indicating that extreme monsoon activities in the form of droughts (floods) might be important factors for the occurrence of simultaneous ENSO/anti-ENSO events.

CLIMATOLOGY

An oceanic model for the prediction of southwest monsoon rainfall over India

O.P. Singh and D.S. Pai

ABSTRACT

Nine new oceanic predictors for long range forecasting of Indian summer monsoon rainfall have been identified utilising the marine meteorological data of the north Indian Ocean and the monsoon rainfall data of the period 1961-91. In order to develop a reliable regression model the principal component analysis (PCA) of original variables has been done. Five parameters having maximum influence on first principal component, which is having highest correlation with the monsoon rainfall are: wind power in the atmospheric boundary layer over the north Indian Ocean between Equator and 10°N mean evaporation over the Arabian Sea (0° -15° N) mean sea surface temperature (SST) gradient over the Arabian Sea between 7.5° - 17.5° N mean evaporation over Bay of Bengal between Equator and 10°N and mean sea level pressure (SLP) over the Arabian Sea, each pertaining to the month of May. A multiple regression model for all India rainfall of south west monsoon season has been developed using the principal components which have got good correlations with the monsoon rainfall. The model was tested for all the years from 1987 to 1991 and it has been found that the predicted values of all India summer monsoon

rainfall of all these years except 1989 were very close to the actual values. However, there was a substantial difference between the predicted and actual rainfall of 1989 summer monsoon.

DROUGHT MANAGEMENT

Letters to the Editor

Balancing Penman's formula on potential evaporation at a semi-arid tropical location

1.The original equation suggested by Penman (1948) to estimate evaporation from open water surface was verified in comparison with actual measurements by several workers (Tanner and Pelton 1960, Abdel Azeez et al. 1964, Thompson and Boyce 1967 & Krishnan and Kushwaha 1971) and it was found that the equation underestimates evaporation from open water surface. The under estimation of evaporation by Penman's equation was mainly due to less weightage given to the aerodynamic term in his formula (Baier 1967, Krishnan and Kushwaha 1971). Penman himself was aware of the above mentioned limitations and has stated that he had only suggested a practical and useful method and not one of greater accuracy. Therefore, he suggested the need for verification and calibration of his formula (Penman 1956).

Though the daily evaporation measurements are carried out using standard US open pan evaporimeter, there is a possibility of gaps in these measurements mostly due to inadequate safety to the pan evaporimeter exposed in open area. In order to fill such gaps in open pan evaporation measurements, we have attempted to modify the weightage of aerodynamic component in relation to the energy balance using the multiple correlation methodology suggested by Krishnan and Kushwaha (1971).

2. Daily weather data of Hayathnagar Research Farm, Hyderabad (17° 20'N, 78° 35'E, 515.5 m amsl) on all the meteorological parameters required in Penman's equation are available for the years 1976-80, 1984-86, 1988-89 and 1992, a total of eleven years. Weekly averages were worked out for the different parameters. Available weather data during the years 1976-80 and 1984-86 were used to determine the weightage of aerodynamic vis-a-vis energy term in the Penman's equation.

Data for three years, viz., 1988, 1989 and 1992 were used for testing. Solution of Penman's formula was carried out in a quattro spread sheet. Global radiation (Ra) in equivalent evaporable water was interpolated from the values given by Doorenbos and Pruitt (1975). Albedo (r) for the water surface was taken to be 0.06 as used by Michael et al. (1977). To estimate solar radiation from sunshine hours the constants a and b were taken to be 0.14 and 0.55 as published by Gangopadhyay et al. (1970). Possible sunshine hours (N) was interpolated from values published in Smithsonian tables. Stefan-Boltzmann's

constant σ in equivalent evaporable water was calculated as 1.998467×10^{-9} mm $^\circ K^{-4}$ day^{-1}. Saturation vapour pressure was calculated by Tetens (1930) equation. Actual vapour pressure was worked out using dry and wet bulb temperature and the atmospheric pressure. The rate of change of saturation vapour pressure with temperature (Δ) was worked out by differentiating Tetens (1930) equation. Wind speed at 2 m height was obtained by multiplying wind speed recorded at 3 m height by a factor of 0.933 as used by Rao et al. (1971). Psychroimetric constant (γ) was worked out to be 0.472 mm of Hg/$^\circ$C.,

3.To determine mean relative weightage between energy and aerodynamic term in Penman's formula all the 416 (8 years X 52 weeks) values of Δ were tabulated and it was found that it ranged between 2.338 and 0.953 mm of Hg/$^\circ$C during the eight years period. The average was worked out to be 1.515 mm of Hg/$^\circ$C. Therefore, the existing mean weightage between energy R_n and the aerodynamic term Ea is as follows

Rn: Ea=Δ : γ = 1.515 : 0.472= 3.210 : 1

Krishnan and Kushwaha (1971) also observed that the weightage to energy balance term, was 3 or 4 times more than the aerodynamic term under arid conditions of Jodhpur. Thus, the pan evaporation is underestimated using the above relation which gives more weightage to energy than aerodynamic term.

CLIMATOLOGY

188. Mausam. (1996), 47,2,115-124

Energy balance at the land-surface interface
Sangeeta Saxena, J. S. Pillai, B. S. Murthy and K.G.Vernekar

ABSTRACT
    A small scale field experiment was conducted at the Indian Institute of Tropical Meteorology (IITM), Pashan, Pune and the energy budget at the land surface interface was studied for clear and cloudy days over bare soil. Using instrumented towers, a net radiometer and soil temperature probe, all the components of the energy budget, ie., the sensible heat flux, latent heat flux, soil heat flux and net radiation were measured directly and the energy balance was computed. It is observed that when considered over the whole day, the energy budget is fairly balanced. As a part of energy budget, the Bowen's ratio is also discussed.

CLIMATOLOGY

189. Mausam, (1996)47,2,157-162

E1-Nino southern oscillation and rainfall variation over Bangladesh

A.S.M. Sabbir Ahmed, A.A. Munim and Q.N. Begum and A.M. Choudhury

ABSTRACT

In the present study, an attempt has been made to examine the variations of rainfall over Bangladesh and to find possible correlation with Ei-Nino/Southern Oscillation (ENSO). Four stations have been chosen from four different climatic regions of Bangladesh for this purpose, namely: Jessore, Dhaka, Barisal and Srimangal. The regions have been classified according to annual rainfall amounts. The rainfall data for forty three years (1950-1992) have been analysed. The yearly mean rainfall shows a distinct negative (decreasing) tendency with the occurrence of ENSO. The seasonal analysis shows a somewhat better correlation.

CLIMATOLOGY

190. Mausam (1996), 47, 3, 269-274

Very heavy rainfall over Punjab, Himachal Pradesh and Haryana during 24-27 September 1988 - case study
D.S. Desai, N. B. Thade and M. G. Huprikar

ABSTRACT

Heavy to exceptionally very heavy rainfall over Haryana, Punjab and Himachal Pradesh during 24-27 September 1988 was associated with the low level easterly trough which was overlain by upper level diffluent westerly trough. The case study of this phenomenon is reported here.

CLIMATOLOGY

191. Mausam, (1996), 47,3, 275-280

Importance of meridional winds in forecasting sub-regional summer monsoon rainfall
Dhanna Singh, Suman Goyal, C. V. V. Bhadram and G. S. Mandal

ABSTRACT

Based on 35 years' (1959-1993) data, the zonal and meridional wind components of selected Indian RS/RW stations upto 100hPa level were analysed for the pre-monsoon months of April and May in order to associate them with sub-regional monsoon rainfall of northwest India. Composite values of monsoon rainfall and meridional components for May for excess and deficient years have revealed that anomaly of meridional components for the middle and upper troposphere is northerly/southerly preceeding exceeds/ deficient monsoon year. The meridional winds at most of the levels of Delhi and some of the levels of Jodhpur, Nagpur, Bombay and Madras for the month of May showed significant correlations (significant at 0.1% to

5% level of significance) with sub-divisional monsoon rainfall in northwest India. The temporal behaviour of correlation coefficients for Punjab and Haryana for 10 and 20-year sliding windows has exhibited reasonable temporal stability except for first few years. Multiple regression equations for 30 and 35 year period for Haryana, Punjab and contiguous northwest India were also developed. The regression model for Punjab sub-division has shown quite goal results for the independent period.

CLIMATOLOGY

192. Mausam, (1996), 47, 4, 349-354

Daily rainfall forecasts through a Quantitative precipitation forecasting (QPF) model over Thiruvananthapuram and Madras areas for the monsoons of 1992

Y.E. A. Raj, Jayanta Sarkar and B. Ramakrishnan

ABSTRACT
Quantitative precipitation forecasting (QPF) of daily rainfall of Thiruvananthapuram and Madras for June-September and October-December respectively for the year 1992 has been attempted. A mathematical model of QPF based on the concept of conservation of specific humidity and with upper air data of a network of stations as the data input has been employed. Nearly 66% and 72% correct forecasts were realised respectively for the two stations. Scope for further refinement has been briefly discussed.

DROUGHT MANAGEMENT

193. Mausam(1997), 48, 1, 45-54

Droughts and aridity in northeast Brazil
K. Karuna Kumar, Jose Antonio Tomas Da Silva and Bernardo Barbosa Da Silva

ABSTRACT
Results of a study of droughts and aridity in northeast Brazil are Presented in this paper. The study is based on the analysis of yearly water balances at fifteen stations in the region. Incidence of droughts of varying intensities at the stations is discussed. Climatic shifts at the stations are evaluated on the basis of the moisture index values. The use of the cumulative deviation technique in drought studies is briefly mentioned.

CLIMATOLOGY

194. Mausam, (1997), 48, 1, 55-64

A diagnostic study of interannual variability of Indian summer monsoon using Outgoing longwave radiation (OLR) data

D. S. Pai

ABSTRACT

Using the monthly outgoing longwave radiation (OLR) data obtained from NOAA Polar Orbiting satellites, during the period 1979-92, composite OLR anomalies in respect of good monsoon years (1983 and 1988), bad monsoon years (1982 and 1987 for the case associated with ENSO and 1979 and 1986 separately for the case without ENSO) and normal monsoon years (1980, 1981, 1984, 1985, 1989, 1990, 1991 & 1992) were examined. The computation has been performed over the global tropics (30°N-30°S) bounded between the longitudes 50°E and 130°W (through date line) on 5° longitude X 5° latitude grid.

There are significant differences in the spatial distributions of composite OLR anomalies between these four cases from the month of April to September indicating Spatial and temporal changes in the Organized convective pattern. For the good monsoon years persistent negative anomalies indicating enhanced convective activity were observed over the Indonesian regions, whereas large positive anomalies indicating depressed convective activity were Observed over equatorial Pacific just west of date line. During the bad monsoon years above normal convection was observed over pacific region (ENSO case) and over equatorial Indian ocean (Non ENSO case). During normal monsoon years, the spatial patterns of OLR anomalies were similar to that of good monsoon years, but with weaker' anomalies. These observations can be explained through the relative interaction between tropical convergence zone (TCZ) over the Indian sub-continent and that over the north Indian ocean and Pacific. The eastward shift of the convective activity during El-Nino years can be attributed to shift/reversal of Walker circulation. There are strong signals of OLR anomalies during premonsoon months which may be useful in inferring the nature of the subsequent monson activity.

CLIMATOLOGY

A comparative study of differences in the averages of temperatures and rainfall over the Indian stations during the periods 1931-60 and 1961-90
B.M. Chhabra, G.S. Prakasa Rao and U.R. Joshi

ABSTRACT

The differences in the averages of surface temperature and rainfall during the periods 1931-60 and 1961-90 are studied for 166 individual stations covering major parts of India. To test the significance of the difference, student's 't' test has been applied. The fall in air temperatures in the north Indian stations is mainly due to the significant fall in minimum temperatures and rise in air temperatures in the south Indian stations is due to the significant rise in maximum temperatures.

No significant change is observed in rainfall. However, over hill stations the rainfall has decreased and over urban/industrialised cities the rainfall has increased.

CLIMATOLOGY

196. MAUSAM, 48. 2 (April 1997). 157-168

Satellite-based monitoring and prediction of tropical cyclone intensity and movement
R.R. Kelkar

ABSTRACT.
Capabilities of meteorological satellites have gone a long way in meeting requirements of synoptic analysis and forecasting of tropical cyclones. This paper shows the impact made by the satellite data in the intensity estimation and track prediction of tropical cyclones in the Indian Seas and also reviews the universally applied Dvorak algorithm for performing tropical cyclone intensity analysis.
Extensive use of Dvorak's intensity estimation scheme has revealed many of its limitations and elements of subjectivity in the analysis of tropical cyclones over the Arabian Sea and the Bay of Bengal, which, like cyclones in other ocean basins, also exhibit wide structural variability as seen in the satellite imagery.
Satellite-based cyclone tracking techniques include: (i) use of satellite - derived mean wind flow, (ii) animation of sequence of satellite images and extrapolation of the apparent motion of the cloud system and (iii) monitoring changes in the upper level moisture patterns in the water vapour absorption channel imagery.
Satellite-based techniques on tropical cyclone intensity estimation and track prediction have led to very significant improvement in disaster warning and consequent saving of life and property.

CLIMATOLOGY

197. MAUSAM, 48, 2 (April 1997), 169-188

Radar observations of tropical cyclones over the Indian Seas
S.Raghavan

ABSTRACT
A review is presented of the radar observation of tropical cyclones in the Indian seas. The use of radar in operational cyclone tracking and forecasting as well as the knowledge gained from radar observations of the structure, wind and rainfall distribution and motion of cyclones are discussed. In the context of the expected introduction of operational Doppler

radars in India, the future prospects in the use of radar for operations and research are outlined. Some important areas where our understanding of cyclones can be improved by studies with radar in conjunction with other observations are listed.

CLIMATOLOGY

Prediction of tropical cyclones by numerical models - A review
K. Prasad

ABSTRACT.

This paper contains a review of some past and recent developments in cyclone track prediction problem by dynamical models. The early attempts aimed at predicting tropical cyclone motion by using simple barotropic models based on vertically integrated vorticity tendency equation. Barotropic models are still used operationally in some centres due to their simplicity. However, current emphasis is on advanced primitive equation models incorporating physical processes, like cumulus convection, which are necessary to account for a major component of the cyclone movement. An important aspect of cyclone prediction by dynamical models is prescription of a correctly analysed synthetic vortex in the initial fields for running a forecast model. Several approaches developed by various groups for generating synthetic vortex are discussed. Examples of some cases of track prediction by limited area model in IMD and by global models are illustrated.

CLIMATOLOGY

Tropical cyclones - Synoptic methods of forecasting
A.V.R. Krishna Rao

ABSTRACT.

The tropical cyclone is one of the most destructive natural disasters which is capable of causing loss of life and damage to the property. Strong winds, heavy rains and storm surges associated with the cyclones, are the phenomena which are responsible for causing the damage. The issue of warnings about the impending cyclones in time help to reduce the loss of lives that the cyclone causes. To forecast its formation, structure and movement, the processes involved in its evolution and subsequent movement, are to be understood well. In this article an attempt has been made to review the literature about the

cyclone characteristics and its structure. Synoptic methods of forecasting its formation and movement are also reviewed. Existing literature on their association with QBO and ENSO is also summarised. Some forecasting rules that may be of help to an operational forecaster are mentioned.

SNOW HYDROLOGY

A study of atmospheric boundary layer characteristics with ground snow cover - numerical method

N. Ramanathan and K. Srinivasan

ABSTRACT

A one dimensional version of a mesoscale model was used to simulate the atmospheric variables over ground snow cover after incorporating suitable modifications. Modifications to include the effect of cloud on shortwave and longwave radiation were also made in the model. The model takes into account both the heat balance at the snow surface and at various layers of the snow pack and calculates the melt rate in situ. Srinagar (Jammu & Kashmir) winter data was used for the simulation. The diurnal variation of snowmelt rate and other atmospheric variables were simulated simultaneously by the model. Melt rate values were verified with the values obtained from standard empirical formula. The model-simulated profiles of potential temperature, specific humidity and wind speed were found to be in reasonable agreement with available observations. The results were found to be insensitive to changes in surface drag coefficients.

PhotoNirvachak

REMOTE SENSING\LAKE HYDROLOGY

201. Photonirvachak, Vol. 24, No.1, 1996

Quantification of Suspended Solids in Dal Lake, Srinagar Using Remote Sensing Technology
M. M. Wani, V. K. Choubey and Himanshu Joshi

ABSTRACT

Indian Remote Sensing satellite (IRS)-1B, Linear Imaging Self Scanner (LISS)-II spectral digital data was analysed to determine the feasibility of quantifying the concentration of suspended solids in the surface water of inland water body, Dal Lake, in Srinagar, India. The water samples collected in concurrent with IRS-1B overpass, were analysed to determine the concentration of suspended solids. The results indicate that a positive functional relationship exist between the concentration of suspended solids and the visible wave length bands 1 and 3 and near infrared band 4. It has been observed that as the concentration of suspended solids increase, the spectral response also increases. It is concluded that IRS LISS-II data can be effectively used to quantify suspended sediment concentration in the Dal lake surface water.

REMOTE SENSING \ ENVIRONMENTAL HYDROLOGY

202. Photonirvachak, Vol. 24, No.1, 1996.

Role of Remote Sensign in Demarcation of Alluvial Fan Deposits in Tarai-Bhabar Belt of Nainital District (UP) and the Environmental Impact Assessment.
C. S. Agarwal, N. K. Choudhary and Ashok K. Mishra

ABSTRACT

Remotely sensed data has unique advantage over conventional data collection techniques in the study of geomorphology, as physiographical and geo-structural parameters are mostly discernible on the imagery. In the present study an attempt has been made to identify and evaluate the process of geomorphological evolution and hydrogeological conditions, temporal changes in pattern of geomophic elements and overall impact on environment in alluvial fan region in Nainital District using multidate satellite data from Landsat (1975, 1986) and IRS (1993), through visual interpretation technique. The landuse changes are quite prominent in alluvial fan of upper and lower zone. As a consequence of deforestation, an area of 16 sq.km. of natural forest cover has been lost over a span of 18 years (1975-1993) leading to the increase in rate of erosion as well as environmental degradation in upstream areas. The study suggests that the ground water utilization in Tarai belt without

replenishment of confined aquifers and installation of more tubewells in Bhabar belt may lead to total failure of flowing wells and subsequently disturb the balanced ecosystem.

REMOTE SENSING AND DATA COLLECTION / WATER MANAGEMENT

203.   Photonirvachak, Vol. 24, No.2, 1996

Irrigation Command Area Inventory and Assessment of Water Requirement Using IRS-1B Satellite Data
V. Hari Prasad, A. K. Chakraborti and T. R. Nayak

ABSTRACT
Monitoring the crop acreage and irrigation water requirements vis-a-vis irrigation water supplies is important to obtain a realistic view of the "irrigation potential" and "potential utilised". Satellite data provides information on crop area and thereby net irrigation water requirements of crops. A pilot study was taken up in Mahendragarh distributary canal in Haryana State to estimate net irrigation water requirement of crops under 17 minors for kharif and rabi seasons of 1992-93 period using IRS-1B satellite geocoded FCC images. These water requirements, when analysed with canal and tubewell water supplies for crops, show large-scale deficiencies in the irrigation command area.

GROUND WATER MODELLING

204.   Photonirvachak, Vol. 24 No.2, 1996

Hydromorphogeological Mapping of Panwari Area, Hamirpur District, Uttar Pradesh, Using Satellite Data
S. Ravi Prakash and Rajiva Mohan

ABSTRACT
The area around Panwari town, Hamirpur district, Uttar Pradesh, faces acute water scarcity and chronically drought prone. The groundwater resources in the area have not been fully exploited. The present study was undertaken to evaluate the groundwater prospective zones. Landsat TM and IRS-1A LISS-II data have been used to differentiate different hydromorphological units and to delineate the major trends of lineaments. The digitally enhanced False Colour Composite, Principal Component Analysis and Edge Detections were useful for better correlation. The digital enhancement was helpful with identification of faint lineaments. In addition, the boundaries of various lands forms were better discriminable on the digitally enhanced products. The deeply and moderately weathered burried pediplains are the

most potential zones for groundwater targeting. Occurrence of lineaments in such zones is also a favourable indicator. A number of promising groundwater well sites have been located in the pediplains.

FOREST HYDROLOGY

205. Photonirvachak, Vol. 24, No.3, 1996

Application of GIS for Land-Use/Land-Cover Change Analysis in a Mountainous Terrain
S. Ghosh, K. K. Sen, U. Rana, K. S. Rao and K. G. Saxena

ABSTRACT
Integration of remote sensing data with other spatial/non-spatial data was carried out using ARC/INFO software package. A simple classification technique was adopated for land cover/land-use change analyses in relation to elevation, slope, aspect and bio-climatic classes. Suitability assessment of land where agricultural extension occurred between 1963 and 1993 was made using GIS software package. Expansion of agriculture land was found to be maximum in 2200-2400 m elevation zone and 20-30° slope classes. When topographic aspects were considered expansion was maximum on south east and west facing slopes. The loss of vegetal cover is estimated to be maximum in elevation ranges of 1600-2000 metre and mostly having 20-30° average slope. Land deterioration over the two mapping periods was identified and strategies were suggested to mitigate the problem.

ENVIRONMENTAL HYDROLOGY

206. Photonirvachak, Vol. 24, No.4, 1996

Application of Remote Sensing for Environmental Monitoring in Bijolia Mining Area of Rajasthan
M. L. Jhanwar

ABSTRACT
Impact of mining Vindhyan Sandstone, at 30 centres spread over 617 sq. kms. by Open cast method in Bijolia area, Rajasthan on the environment, both natural and social, assessed over a periods of 20 years (1971-91), revealed that it had affected nearly 20 times the area of lease. The study was carried out using Multidate remote sensing data for 1984 and 1991 and topographical maps 0f 1971, for change detection in land use pattern with the increase in mining activity. Whereas area covered by mining activity increased by 35.3 times in 20 years, the forest cover decreased by 46.3 per cent. The dense forest decreased by 90 per cent and the land under agriculture decreased by 12 per cent. Consequently the waste land increased by 67.4 per cent. Hydrological regime was affected by way of blocking

the channels and lowering of water table. Solid particulate matter (SPM) values in mining centres were found to be more than double the normal, leading to diseases related to lungs and liver such as Silicosis, Bronchitis, Asthama and T.B. Nearly 25 per cent of workers were found to suffer from one or the other disease. 50 per cent of mine workers suffer from malaria as a consequence of breeding mosquitoes in stagnant waters in mine pits and labour colonies. Noise levels at the active zones like drillling, blasting and mine service stations range from 96 to 125 dB as against the permissible limit of 75 dB affecting health and mental faculty of mine workers.

GROUND WATER HYDROLOGY

Hydromorphogeological Mapping for Groundwater Prospecting Using Landsat-MSS Images- A Case Study of Part of Dhanbad District, Bihar

A Tiwari and B Rai

ABSTRACT
The Dhanbad districat in Bihar, faces acute water scarcity and is chronically drought prone. The groundwater resources in the area have not been fully exploited. The present study was undertaken to evaluate the groundwater prospective zones. Landsat-5 MSS data of band-2 and band-4 and false colour composite of band 2,3,4 were interpreted visually to differentiate different hydromorphogeological units and to delineate the major trends of lineaments. The different geomorphic features identified are linear ridges, residual hills, pediplain, buried pediment and dissected pediplain, besides lineaments. The study shows that the pediplain and buried pediments are promising zones for groundwater prospecting.

REMOTE SENSING

Training and Education in Remote Sensing.

S.K.Bhan

ABSTRACT
Remote sensing has emerged as a key technology in recent years to generate spatial information. Exploration of this technology to its maximum potential requires trained personnel and for wider understanding of the subject it needs to be introduced in our educational system. With the rapid technological advances being made by remote sensing information

and decision support systems, it has become very important that training in remote sensing keeps pace with these advances. For wider acceptability of remote sensing well thought of plan needs to be made for human resources development through training and education in Remote Sensing. Various issues for training and education in Remote Sensing have been discussed in this paper.

DROUGHT MANAGEMENT

209. Photonirvachak, Vol. 25 No., No.2, 1997

Evaluation of Multisensor Data for Delineating Salt Affected Soils in Arid Rajasthan
N.K. Kalra and D.C. Joshi

Abstract

The Landsat (MSS and TM),SPOT (PLS and MLA) and IRS (LISS-I and LISS-II) images of crop free period (April, May), rainfed crop (October) and rabi irrigated crop (January, February) have been evaluated for their capabilities of mapping (1) primary salt affecated soils: (slightly, moderately and severely) (2) saline water irrigated saline soils, (3) sodic water irrigated sodic soils and (4) salt affected soils due to tank seepage in the arid region of Rajasthan. The moderately and severe salt affected soils could be mapped with Landsat, (IRS LISS-I) and SPOT, images of any season. However, the summer season imagery provided maximum extent of salt affected soils. The LISS-II imagery also provided delineation of slightly salt affected soils in addition to the moderate and severely salt affected soils. The delineation of saline and sodic water irrigated areas was possibly by using Landsat False Colour Composite for the January month by their characteristic reflectance, existing cropping pattern and the quality of irrigation water being used in the area. The IRS (LISS-II) and SPOT PLA images for the May month were also used for mapping of saline and sodic water irrigated soils.

REMOTE SENSING \ SURFACE WATER HYDROLOGY

210. Photonirvachak, Vol. 25, No.2, 1997
Management and Development of River Basins in North Bengal Using Remote Sensing Techniques
M.M. Jana

Abstract

River basin management and development are most important for utilising and conserving the water resources is any region where the average annual rainfall is highly fluctuating, the North Bengal is one of such region. Though there are a large number of rivers having a large catchment area in the hills and

carry a huge amount of water during rainy season but they are completely dry in winter and summer. The upper part of majority of river basins are highly sensitive to water erosion and land slides due to deforestation, intensive cultivation, increased settlements in sloping and erosion prone areas. So, floods in the rainy season and droughts in summer months are frequent features in North Bengal. In view of this proper management and effective conservation of land and water resources is necessary to develop the region. An integrated river basin management consisting soil conservation, afforestation, flood control, and adoption of suitable cropping pattern is essential for economic development of North Bengal.

DATA COLLECATION / SURFACE WATER HYDROLOGY

Use of Satellite Data In Urban Sprawal and Land Use Studies - A Case of Lucknow City

R. C. S. Taragi and P. P. S. Pundir

ABSTRACT
      The Lucknow Urban Sprawl map for 1972-92 and land use/land cover map of Lucknow area for 1992 were prepared from the satellite imageries of different time period. The analysis has revealed that Lucknow City has been growing at a faster rate especially during the last decade. Most of growth has been towards north-east and South-West direction along major transport routes.

WATER LOGGING/REMOTE SINGING

Detection and Delineation of Waterlogging by Remote Sensing Techniques

V. K. Choubey

ABSTRACT
      The execution of irrigation projects without the provision of adequate drainage system has disrupted the equilibrium between the ground water recharge and discharge resulting in accretions to the ground water table in the command areas in India. The Tawa command area faces the problem of water logging resulting from over irrigation and seepage from canal system.
      The study was undertaken to delineate water logged areas in the Tawa command using IRS-1A-LISS-I data. Land use and drainage maps for the Tawa command were also prepared using IRS-1A-LISS-I, FCC of November 20, 1989 and Marach 23, 1989. IRS-LISS-I digital data (CCT's) of May 19, 1988, October 20, 1988 and November 20, 1989 was analysed to delineate areas affected by water logging

and the areas sensitive to water logging. An attempt has been made to validate the IRS derived water logged area with the available water table depth data.

Density slicing was found to be useful digital technique for the delineation of water logged areas. The results indicate that in October 1988 an area of 80 km^2 was affected by water logging and about 140 km^2 area was sensitive for water logging, where the water table was between 0 and 3 metre. It is suggested that an assessment of water logging using remotely sensed data should be carried out at regular intervals.

WATERSHED MANAGEMENT

213. Photonirvachak , Vol.25, No.3, 1997.

Geomorphology and Landscape Evolution of Bharatpur District, Rajasthan
Iqbaluddin, Saif Uddin and Akram Javed

ABSTRACT

The morphometric analysis of the surface drainage has been carried out for the four micro-watersheds of Bharatpur district, Rajasthan to quantify the drainage morphometry of the district. The morphochronology of landscape evolution has been described. Banaganga represents anomalous drainage, which causes large scale inundation during rainy season. The strain of post-collision Himalayan tectonics resulted in slope mutation in Bharatpur district which changed slope from westerly to easterly. The landform characteristics of Bharatpur district have been archieved at the National Informatics Center, District Data Base, Bharatpur in alpha numeric mode.

REMOTE SENSING

214. Photonirvachak, Vol. 25, No.4, 1997

Remote Sensing Applications: Future Thrust Areas
D. P. Rao, P. S. Desai, D. K. Das and P. S. Roy

ABSTRACT:

Timely and accurate information on natural resources is pre-requisite for their optimal utilization and effective management. By virtue of providing synoptic view of a fairly large area in the narrow and discrete bands of the electromagnetic spectrum at regular interval, the spaceborne multispectral data enable generating timely, reliable and cost-effective information on various natural resources, namely minerals, surface water, ground water, forest cover, land use, land cover, crop acreage and production estimation, soils, etc. and environmental hazards, namely waterlogging, salinity and alkalinity, soil erosion by water and wind, shifting cultivation, etc. Since the launch of the first earth observation satellite - Earth Resources

Technology Satellite (ERTS-I) in 1972 spaceborne multispectral data have been effectively used to generate above-mentioned information.

Initially, only coarse spatial resolution (- 80 m) data was available from Landsat-MSS with 18 days repetivity which permitted thematic mapping and monitoring at scales ranging from 1:1,000,000 to 1:250,000. Subsequent improvements in the spatial and spectral resolution and better repetivity owing to same area coverage by more than one satellite helped in not only mapping and monitoring natural resources and environmental degradation at larger scale (1:50,000 through 1:25,000) but also provided database for newer areas of applications. With further improvements in the observation capabilities, refinement in the existing applications and exploring its potentials in new areas of applications seem feasible.

GROUND WATER HYDROLOGY / REMOTE SENSING

215. Photonirvachak, Vol. 25, No.4, 1997

Groundwater Prospects of Shahbad Tehsil, Baran District, Eastern Rajasthan: A Remote Sensing Approach
K V Ravindran and Jeyaram

ABSTRACT
The relevance of satellite remote sensing in groundwater exploration stems from the utility of satellite images in identifying and delineating various features that may serve as direct or indirect indicators of the presence of groundwater. This paper presents the results of hydrogeomorphological mapping using IRS-1B LISS II data and evaluation of groundwater prospects of each hydrogeomorphologic unit on the basis of lithology, structure, landform and available aquifer data in the Shahbad tehsil, Baran district, Eastern Rajasthan. The study has shown that in the western parts of the area the Vindhyan sandstones (Lower Bhander) in which groundwater occurs under unconfined to confined conditions along bedding planes and fracture zones have vast potential for groundwater development through deep bore-wells or dug-cum-borewells, while in the eastern parts where shales dominate, large diameter dugwells are suitable to tap the limited groundwater resources. Infiltration (or recharge) tube wells have been proposed to augment the sandstone aquifers.

SURFACE WATER HYDROLOGY / REUSE OF WATER

216. Photonirvachak, Vol. 25, No.4, 1997

Site Suitability Evaluation for Locating Sewage Treatment Plants Using Remote Sensing and GIS- A Case Study of Phillaur and Phagwara Townships in Punjab
P. K. Iitoria, Ajay Mathur, P. K. Sharma and Charan Kamal Singh

ABSTRACT

Level-II urban land use information available in the Town and Country Planning maps, Survey of India toposheets for Phillaur and Phagwara towns and the land use information generated through visual interpretation of satellite data was digitized, integrated and analysed using PAMAP GIS.

The land use map of the two towns suggest that the wastelands located near the point of present disposal can be utilised for siting sewage treatment plants in both the towns. The STP sites suggested were away from the thickly habitated area. It was observed that some of the areas earmarked for locating STP's were partially brought under habitation before the execution of the project. Hence, it is necessary that planning and execution of such projects should be done on a real time basis so that the sites identified for locating STP's are not brought under other land uses.

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