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THE NEWSLETTER OF THE BRITISH HYDROLOGICAL SOCIETY

Circulation

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The devilish Dr. M

or

Some comments on the identification of hydrologic models

Based on the Penman Lecture, presented at the Seventh Hydrology Symposium at Newcastle-upon-Tyne by *Hoshin Gupta*, Adjunct Professor & Associate Director SAHRA (Sustainability of semi-Arid Hydrology and Riparian Areas), University of Arizona, USA

This talk is concerned with a rather practical problem faced by hydrologic science, which is the development of watershed models for estimating and forecasting streamflow. I will not dwell here on the history of hydrologic model development as much has been written on that subject. Instead, I ask your indulgence as I tell a story about the somewhat uneasy relationship that has arisen between the "hydrologist" and his/her nemesis, the "mathematician". Here I visualize the former (whom I shall call "Dr. H") as a moderately well dressed fellow sitting in front of a computer screen, busily calibrating a watershed model, while I visualize the latter (whom I shall call "Dr. M") as a somewhat scruffy looking "devilish" fellow with horns, tail, trident and wearing dark glasses (looks a bit like me and some of my friends, actually!). Dr. H has, of course, spent many years out in the natural world studying watershed behaviour, developing conceptual rainfall-runoff (CRR) models of various shapes and sizes, and then fitting them to the watershed of interest using manual calibration methods. On the other hand, having been thoroughly schooled (read 'indoctrinated') in statistics and other forms of black magic, Dr. M is convinced that Dr. H needs help! Funding agencies are, initially at least, only too happy to encourage the rogue, and so our story begins.

I think it is fair to say that our hydrologist has a healthy respect for the power of the human mind and believes that while computers are "b&*@#%... good" for doing various mundane tasks such as number crunching, they should not be allowed anywhere near anything resembling a "decision". Dr. H is happy to use this

Plus new 4-page Circulation* PLUS *section:

On an acceptable criterion for model rejection
Keith Beven, University of Lancaster

A Matlab toolkit for conceptual rainfall-runoff modelling and the analysis of Monte-Carlo simulations
Thorsten Wagener, Matthew Lees & Howard Wheater, Imperial College London

"beast-of-burden" to help in representation and visualization of data, and to crunch the data through the watershed model. Then, to "calibrate" the model, Dr. H, with sleeves rolled up, sits down in front of a computer and "manually" tweaks the parameters until satisfied that the simulated streamflow hydrograph looks sufficiently like the historical measured one. However, this is not a simple task as there are quite a few model parameters that can be adjusted (typically 10-20) and many of them seem to affect the simulated hydrograph in seemingly similar ways. The calibration effort therefore proves to be surprisingly time-consuming and difficult. However, with considerable practice, our Dr. H gets quite good at it and is understandably proud of this hard-won new skill.

I think it is equally fair to say that, while being equally impressed with the mind, our mathematician friend is firmly convinced that computers can be made to be somewhat "intelligent" and can (and should) be allowed to have a go at various kinds of decision making. "Certainly", thinks Dr. M, "the model calibration problem is not so difficult that the computer could not be programmed to solve it! All that needs doing is to formulate the calibration problem as one of those "optimization" problems describe in systems and statistical theory, and the rest is trivial. In fact, because of its awesome power and speed, my computer should be able to find at least as good (if not better) a result, but in only a small fraction of the time that Dr. H needs to do this. Dr. H should be very pleased".

So Dr. M goes to work. The formulation of the "optimization problem" seems straightforward, requiring only that an "objective function" measuring the closeness between the observed and simulated hydrographs be defined. The statistics textbook indicates that the "mean squared error" (MSE) criterion is a good choice for the objective function, because it has the impressive property of being an "unbiased minimum variance estimator" under what seem to be some reasonable mathematical conditions. Next our mathematician needs a decent "optimization algorithm" that can be used to search for the parameters that minimize the objective function. Picking one off the shelf Dr. M links everything together in the computer, pushes the "start" button, and heads off to the cafeteria for a well-earned cup of tea. Problem solved.

Well, not quite. Being well versed in the scientific method, our mathematician knows that several successful replications of the experiment must be done, if the publication (already half written in Dr. M's imagination) is to bring the fame so richly deserved. So, after a tweak of the starting conditions the computer is unleashed again, and again, and again, and.... We look back in on our friend a few days later to discover a rather worried person. "I can't get the computer to find the optimal solution," explains Dr. M. "The optimization method I chose must be no good, I'll have to try another one".

Years pass, and while our mathematician friend does gain some respect and recognition from colleagues, the Holy Grail remains elusive. Many of Dr. M's colleagues are also pressed into action and eventually some understanding emerges. It turns out that some chaps in the US are able to show that the optimization problem is plagued by vast numbers of "local minima" that trap the optimization algorithm and prevent it from proceeding to the "global" solution. But even better, they invent a method called the "Shuffled Complex Evolution" algorithm that is clever at avoiding such traps and can reliably find the correct solution [1,2]. The Dr. M's around the world spring into action, busily testing and verifying the method and are soon satisfied that it does indeed work. But this time, the older and somewhat wiser Dr. M, having become well acquainted with the teachings of the philosopher Dr. Murphy, is careful to not fall into the trap of believing that the problem has been solved.

So Dr. M wanders off to show these new results to Dr. H. "Yes, yes", says Dr. H impatiently, "I can see that you have found this so-called 'optimal solution', but quite frankly it doesn't look very much like the one that I would pick. I guess I might use your method if I was really pressed for time. But to tell the truth, this calibration game is more of an 'art' than a science and it really needs the human touch! Still, I can see that you are really motivated by this problem, so I am willing to collaborate with you and see how far we can take your approach."

The truth, of course, is that Dr. H is getting somewhat overwhelmed by the large number of watersheds that are becoming instrumented and for which calibrations are required. And it is rapidly becoming a huge national and international problem. Large populations of people like to live along the banks of rivers, and unpredictable storms often cause the rivers to flood resulting in significant loss of life and property damage. Accurate flood forecasts can help to mitigate these losses, and these require properly calibrated watershed models.

So, Dr. H and Dr. M sit down together with some bright students and begin sharing their knowledge. They soon recognize that a severe limitation of Dr. M's mathematical approach was that the procedure was founded on the use of a ***single*** aggregate measure of the difference between the simulated and observed hydrographs. In contrast, Dr. H has always been implicitly concerned with multiple ways of looking at the differences, trading off the fit to the rising limb with the fit to the peaks, the quick and slow recessions, the overall volume balance and numerous other aspects of the hydrograph. "How can we get the computer to do something like that", muses Dr. H, thereby voicing the magical words that re-energize our poor Dr. M. "Yes, that's it!" cries Dr. M in excitement, and streaks out the door to find a quiet place to ponder the new challenge. For as we know, there is little in life that is able to get Dr. M quite so excited as a mathematical problem that needs solving.

And here I will take my leave of the two actors in our little play. Drawing on the mathematics of multi-criteria problem solving, much of which emerged from the fields of economics and systems theory, a crude multi-objective calibration approach was soon proposed and tested [3] and is now being studied and refined by a number of hydrologists worldwide. In brief, the idea is to partition the hydrograph into a number of different parts (e.g., rising limb, quick recession, and slow recession), for each of which a different objective function is defined (Figure 1). This results in a vector

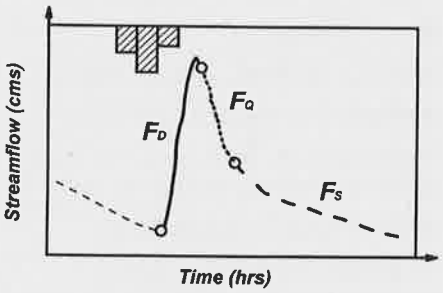


Figure 1 *Example of partitioning the streamflow hydrograph into three exclusive portions (rising limb or 'driven' part, quick recession and slow recession), for which different measures (F_D, F_Q and F_S) are defined (after Boyle et al., 2001).*

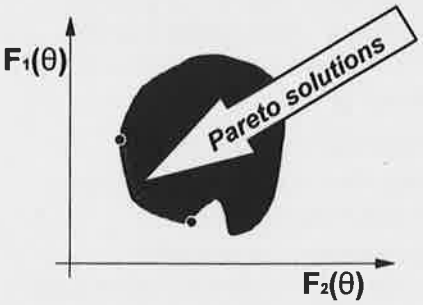


Figure 2 *Example showing a map of the feasible parameter space onto the space of two measures (objective functions) that are to be minimized. The shaded area is the feasible measure space, and the heavy line indicates the "Pareto" solutions. Note that as we move from one Pareto solution to another, we must "trade-off" one measure against the other.*

optimization problem for which there is no single "best solution", but instead a set of "Pareto" or trade-off solutions [4]. Each such solution differs from the others in that it is better with respect to one or more of the objectives, but worse on at least one of the other objectives (Figure 2).

To find a sufficient number of such solutions, a multi–objective optimization strategy is required. One such approach is the MOCOM algorithm [5]. When the methodology is used to calibrate a watershed model, it provides the user (our friend Dr. H) with a number of solutions to examine. If the objective functions have been selected in a sensible manner, these solutions will be in the region of the parameter space towards which Dr. H would proceed when using the manual approach. This saves Dr. H a considerable amount of time that is better spent in the cafeteria over cups of tea (while the computer churns away), later only needing to pick from the multi-objective solution set a parameter set that matches the observed hydrograph in "just the right way". Of course, Dr. M (never one to leave well alone) is still happily trying to get the computer to emulate even this part of Dr. H's decision process, and so the story continues to play itself along. See the partial reading list for more on these ideas [8-14] — and of course stay tuned to the literature for more exciting things to come!

In conclusion, I will take some liberties and make a few brash claims that will, I hope stimulate our students to further developments in hydrologic modelling.

(1) All model identification problems are inherently multi-criteria in nature. I seriously doubt that we can design a single "correct" objective function that will capture all of the issues that need to be considered when calibrating a model, and will work for all models. If I am correct about this, there is a serious need to review how we test and evaluate model performance.

(2) The use of multiple criteria in computerized model fitting is not new, particularly to hydrology. We have been using the "method of moments" to fit statistical distributions for decades. This involves using different criteria for estimating each parameter.

(3) Every assumption that goes into the modelling process should (if at all possible) be tested for violations. This therefore implies that every assumption "hides" a criterion of some kind. Most if not all interesting advances in science seem to come from taking a new look at (i.e. questioning) assumptions that have become taken for granted. I advise my own students to try and discover (and carefully examine) the underlying assumptions to any issue they are studying. Because this requires a look at one's belief structure, this is surprisingly difficult to do.

(4) Traditional model fitting procedures are based on statistical methods which, it seems to me, were developed largely for the fitting of "static" regression models. I question the suitability of such methods for the identification of "dynamical conceptual models" (e.g. watershed models), particularly as such models become even more complex. For example, do we *really* care if the model residuals are Gaussian and uncorrelated, etc.? While that might be mathematically pleasing were it to actually happen, I suggest that it is somewhat irrelevant to the bigger problem at hand – which is to get an accurate flood forecast that is reliable (has minimal uncertainty). To go a little further down this track, I think that we (as a community) need to be careful to not be so seduced by mathematics that we ignore good empirical methods and ideas just because the person who suggests them is unable to bring rigorous mathematical descriptions to bear. I am reminded of the lament of the systems scientist: "Oh, if only the world were Gaussian and linear"!

(5) A model identification procedure must have "Power". By this I mean that the procedure must be able to cleanly discriminate between model behaviours that are clearly different. Therefore, we must be cautious to not jump too quickly to the conclusion of "Equifinality" (defined in excellent fashion by Dr. Beven and his colleagues as "...many parameter sets ... are equally acceptable as simulators of a catchment ... and come from very different regions of the parameter space. There may be *no rigorous basis for differentiating* between these parameter sets ... (which) arises due to error and uncertainty in the modelling process..." [6]). The question must be asked as to whether "aggregate measures of model performance" (such as the MSE used by Dr. M) really provide a *rigorous* basis for differentiating between parameter sets. It is easy to show that many different simulated hydrographs, that fit the observations in quite different ways, have the same or similar MSE values [7]. The appearance of equifinality, if based on only a single aggregate measure of model performance, may tempt one to conclude that a model is overparameterized or "too complex". While I am definitely in favour of parsimony in model construction, let us proceed with caution and work towards developing "powerful" model identification procedures that allow us to have confidence in our conclusions.

(6) A single measure (objective function) has the power to identify cleanly only 3-5 parameters at most. This is an unproven conjecture on my part, but is based on my own understanding of how parameter interactions function in conceptual watershed models. I strongly suspect that the idea that rainfall-runoff data can only support watershed model complexity of about five parameters, may in fact be based on the fact that the objective function has only the power to discriminate five parameters. I suggest, therefore, that we cannot, and should not, make inferences about "the information content of the data" or "the amount of supportable model complexity" by use of only a single aggregate measure such as MSE.

(7) This raises two important and related questions, which are central to the further development of model calibration methods. The first is "how may measures (objective functions) do we need?" I suggest that the principle of parsimony applies just as much to measures as it does to parameters. In general, I believe that the number of measures (N_{mes}) should not exceed the number of parameters (N_{par}). If each measure can identify up to five parameters, this suggests that the number of measures to be used will be approximately $N_{par}/5$. For a fifteen-parameter model, this amounts to approximately three measures, which is the number used by Boyle *et al.* (2001a,b). The second, perhaps more important question is, "how do we select the measures (objective functions)"? This is, of course, a more interesting and difficult question to answer. In [3] I suggest that the chosen measures must be complementary – i.e. they must represent different attributes of system behaviour (such as the rising limb, peaks, recessions etc.). However, I believe that in addition to these "Local Measures" we also need "Global Measures" that represent overall system properties such as volume balance and residual variance (e.g. Bias and MSE) [7]. How to combine the information form all these different measures in a synergistic way is not well understood, and much interesting work remains to be done in this area. On the one hand, good physical reasoning and understanding of hydrology must be brought to bear. On the other, various novel mathematical techniques such as wavelet decomposition and other methods that quantify the "information content" of the data should also prove to be useful. Dr. H and Dr. M need to continue to work together on this issue.

Finally, I would like to conclude with two admonitions to the aspiring student of hydrology. The first is "Question conventional wisdom"! Do be careful to take everything told to you by your professors or read in published articles (such as this one) with a healthy "pinch of salt". Remember, it is the invalid but hidden assumptions that get in the way of progress. A wise person once said, "The unexamined life is a life not worth living". Well, perhaps there is an analogy for science. The final

admonition is "Share your ideas freely!" An idea can do little good if it is treated as a possession. It is through sharing our ideas that important progress is made, not through trying to save them for ourselves just to get the publishing credit. The more you share your ideas, the more and better ideas you will have. Call it a law of the universe, or call it the way the mind works, but that is my experience. Thank you for letting me share a little of how my mind works with you!

Acknowledgements

The ideas presented in this article are the result of a long collaboration with my mentor, friend and colleague, Soroosh Sorooshian, to whom I am very grateful. Other people who have strongly influenced these ideas are Qingyun Duan, Patrice Yapo, Luis Bastidas, Kuolin Hsu, Douglas Boyle, John Schaake, Steve Burges, Keith Beven, George Kuczera and Howard Wheater. Partial funding to investigate these ideas was provided, over the years, by the Hydrologic Research Laboratory of the US National Weather Service, as well as NASA, NOAA, NSF and SAHRA.

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New members

We welcome the following new members to the Society:

Andy Baker ..... Dept of Geography, University of Newcastle-upon-Tyne
Martin J. Berry ..... Bristol Water, Bristol
Katherine Briscall ..... Environment Agency, Addington, Kent
Stephen Chapman ..... Environment Agency, Warrington, Cheshire
Joanna M. Claric ..... School of Geography, University of Leeds
Gamal M. El-Kassar ..... Water Research Group, Dept of Civil Engineering, University of Newcastle-upon-Tyne
F. Helen James ..... SEPA, Perth
Paul Kay ..... SSLRC, Cranfield University, Shardlow, Derby
Tanguy Le Borgne ..... Dept of Civil Engineering, Imperial College London
Leonora J.E. Lee ..... Research Institute of Sedimentology, University of Reading
Aaron Lockwood ..... School of Geography, University of Leeds
Neil Macdonald ..... Geography Department, University of Dundee
John J. Maclean ..... Dept of Civil Engineering, Imperial College London
Constantine C Mbajiorgh ..... WRSRL, Dept of Civil Engineering, University of Newcastle-upon-Tyne
Florian Pappenberger ..... Dept of Environmental Sciences, Lancaster University
Katherine A. Roberts ..... Ewan Associates, Leeds
Paul J. Rodgers ..... Department of Geography, University of Aberdeen
Christopher Rogers ..... Pell Frischmann, Exeter
Claire J. Taylor ..... Environment Agency, Solihull
Craig White ..... SEPA, Galashiels
Ruth Whitehead ..... Symonds Group Ltd, East Grinstead, Sussex

News from Wales

Following a period of uncertainty for the future of the Welsh Hydrological Group (WHG), due in part to the unfilled secretary's post, a re-launch is being planned for March 2001. The intention is to get the WHG back on track with regular, well attended meetings and field visits. The group has a long history of such events, which have traditionally been well supported, with interest across the hydrological fraternity in Wales and often drawing attendance from further afield, beyond Offa's Dyke!

Active members of the committee will be meeting up in the near future to discuss plans for this first event in March (presentation and EGM) and subsequent meetings. They will also formulate how best to advance the WHG, satisfying the requirements of existing members while attracting new people with an interest in hydrology and water resources. It is essential that we update our membership records and this will be a priority over the coming months, using various means. Anybody wishing to be included on the WHG mailing list — or any existing member who wants to make sure that they are not omitted during our updating process — should contact either of the people below:

Tim Arkell *(tel: 01437 760 081, email: tim.arkell@environment-agency.gov.uk)*
Claire Hammond *(tel: 02920 235 556, email: chammond@srk.co.uk)*

President's piece

Time marches on, and from the perspective of January 2001 a President's Presidency seems to be remarkably short. We now have our next President-Elect and I am well into my last year of Office. Where have all those new initiatives got to?

Since the last *Circulation*, there has been the usual flurry of Autumn meetings and activity. For example, I represent BHS on the ICE Water Board, the CIWEM Water Resources Panel, the Inter-Departmental Committee on Hydrology and the new ICE Reservoir Safety Working Group. There is no particular news from the first two, except to note that our Memorandum of Understanding with CIWEM has led to **Hilary Smithers** representing the Water Resources Panel on BHS Main Committee (a very welcome return), and that a major collaborative meeting was held on the Water Framework Directive at the ICE on *23 January*. More of that will be reported in due course, but undoubtedly the directive will have far reaching effects on catch-ment planning and management, and will need a much more holistic approach to hydrological research and practice.

The Inter-Departmental Committee on Hydrology, now chaired by **Jim Wallace**, meets once a year and has asked me to report on its activities to BHS members. This essentially represents relevant Government Departments and national agencies with interests in hydrology, e.g. DETR, MAFF, DfID, EA, Scottish Executive, SEPA, the National Assembly for Wales and the Northern Ireland agencies. OST is represented by NERC, and CEH, BGS and the Met Office are also members. BHS is represented by me as President, and **Bruce Webb** as Chair of the IAHS Committee; the Water industry was represented for the first time by Water UK.

The Committee takes reports from each of its members on current news and issues. For example, MAFF reported additional expenditure for flood defence (including Catchment Flood Management Plans) in the light of the recent floods, and a new series of guides on project appraisal for grant aid. DfID reported £23 million expenditure on water management projects in 1999/2000 and tabled some institutional strategy papers. DETR noted that the Water Bill was out for consultation, but would probably not be in the next Parliament. Interestingly, the Met Office has a new vision and direction, including the delivery of environmental and hydrological research. NERC reported the funding of the new Tyndall Centre at the University of East Anglia and the NICHE (National Infrastructure for Catchment Hydrology Experiments), as reported to BHS at Newcastle. Water UK presented a set of strategic concerns: diffuse pollution, point source groundwater contamination, groundwater monitoring, climate change and the water framework directive. The Committee thus provides a forum for the exchange of news, views, needs and concerns.

A new and important initiative was launched with a meeting at the ICE on *15 December*. BHS is providing the main hydrological input to the ICE Reservoirs Safety Working Group, which provides advice to DETR on reservoir safety research. As many members will be aware, the implications of differences between *FSR* and *FEH* estimates of extreme floods for spillway design is of immediate concern, and it is likely that further work will be needed to produce appropriate guidance. ***Technical comments from BHS members on this issue would be welcomed – to me in the first instance, please.***

Concerning our various strategic initiatives, I am pleased to report that position statements have been finalised by **Celia Kirby** on publications and **Bruce Webb** for international affairs. The regional strategy group led by **Roger Simpson** is seeking members' views (see the questionnaire enclosed with this mailing), and following the relaunch of the South West Section, the Welsh Hydrological Group is reforming. A new initiative on membership is being finalised by **Steve Parsons**. Discussions with ICE are still proceeding on improved procedures for hydrologists to become chartered through the ICE route, and I met the outgoing ICE President, **George Fleming**, to discuss current and future progress. Six BHS members have put their names forward to become ICE examiners (others are still welcome); **Peter Midgley**'s strategy group on Education and Training continues to work on defining core objectives for professional hydrologists as input to the ICE procedure.

We are aware that the web-site needs urgent attention: although there have been some continuity problems since Matthew Lees left us, we are most grateful to **Kevin Tilford** and **Jenny Thorne** for filling the gap, and to **Steve Wade** for taking on the strategic review.

Finally, we are aware of some administrative delays, for which we ask your patience. A new membership directory is long overdue, there have been some mailing problems and there are delays in requests for subscription renewal. These are due to problems in installing a new membership database at ICE: we are chasing these and expect them to be resolved imminently. In the meantime, if members are having problems with mailings, for example due to changes of address, please tell me or the Hon. Secretary, **Tim Jolley**.

Howard Wheater
Imperial College (h.wheater@ic.ac.uk)

Membership administration

The ICE is implementing a new membership database, MEMSYS. When fully operational, this will provide tremendous benefits to the Institution and Societies in maintaining contact with members. However, there have been some teething problems as the ICE transfers its records onto the new system, and a small number of members have not been receiving BHS mailings. The committee has expressed its concern strobngly to the ICE over this and would ask anyone who is aware of other members experiencing problems with mailings to ask them to contact Tim Fuller, the BHS Secretary at the ICE *(see front page)*.

Membership directory – are your details up to date?

An updated version of the Membership Directory will be circulated with the next (May) issue of *Circulation*. So that this is as accurate as possible, I urge all members to return the form that was enclosed with the November issue of *Circulation* (No. 67). If we do not receive your form by *28th March*, your current details will be used. However, if the Society does have to use your current records that will in no way affect your rights under the Data Protection Act, 1998. If you have any queries about the form, or the Data Protection Act, please contact the Institution's Membership Registry Department *(tel. 0207 665 2125)* or **Tim Fuller** *(see front page)*.

Revision to BHS Statutes

The proposed changes to the Society's statutes to reflect the recent name change of the Institute of Hydrology, and to introduce "Honorary" for the purposes of clarification, have been approved following the result of the poll in *Circulation*. We received 157 returns, of which 155 were in support and only 2 voted against the change.

Tim Jolley, Hon. Secretary

Supplement

The report on the Scottish Hydrological Group's meeting on geochemical modelling and groundwater remediation (20 November) and a few other items squeezed out from this issue are on a supplementary sheet (pp20 & 21).

NERC lowland permeable catchment thematic research programme (LOCAR)

The problems and issues

Much of the water supply in southern Britain comes from aquifers below lowland permeable catchments, where land-use changes and other environmental pressures are creating ecological impacts and altering groundwater levels and streamflows.

Over-abstraction of groundwater in lowland permeable catchments has led to headwater streams drying out, resulting in serious ecological damage. More concentrated human activity has increased the nutrient loading in aquatic systems. Conversion of rural land to urban uses and the growth in water demands for towns and cities have added to the pressures on aquatic systems and the competition for the groundwater resource. Management of important wetland areas requires accurate knowledge of the impacts of changes in water levels on aquatic life and nutrient supplies.

LOCAR will help to improve the scientific understanding needed to resolve these problems. For the first time for the main UK aquifers, LOCAR will provide state-of-the-art experimental networks for groundwater flow and quality, including stream-aquifer interactions, advanced climate data acquisition systems, shallow and deep unsaturated zone monitoring, stream flow, sediment and water quality monitoring, specialist investigation of the hyporheic zone and fish monitoring. LOCAR seeks to develop integrated science programmes as a focus for development of integrated models that can combine understanding of process interactions and their scale-dependence for predictive studies.

LOCAR objectives

The thematic programme seeks:

- To develop improved understanding of hydrological, hydrogeological, geomorphological and ecological interactions within permeable catchment systems, and their associated aquatic habitats, at different spatial and temporal scales and for different land uses;
- To develop improved modelling tools to inform and support the integrated management of lowland catchment systems;
- To provide an underpinning science base to meet the requirements of the UK and CEC for environmental protection in lowland permeable catchments within a framework of sustainable and integrated river basin management;
- To establish flagship sites as a basis for long-term monitoring, to provide the necessary data to define natural variability and response to environmental change;
- To build strong interdisciplinary links in order to harness the science skill base more effectively to tackle problems of national importance.

Among the key fundamental research questions to be tackled are:

- What hydrological processes control surface water-groundwater interactions and the movement of groundwater in lowland catchments?
- What are the key physical, chemical and biological processes operating within the valley floor corridor that affect the surface water and groundwater?
- How do varying flow regimes affect in-stream, riparian and wetland habitats?
- What are the impacts of land-use management on lowland catchment hydrology, both in water quantity and quality?
- How can the hydrological, hydrogeological, geomorphological and ecological interactions resulting from natural or anthropogenic changes be predicted using integrated mathematical models?

Key applied research questions include:

- The role of soil management in regulating the linkage between surface and groundwater;
- The effects of water levels on biota in floodplains and wetlands;
- Integration of catchment hydrological and hydrogeological models into catchment planning;
- The effects of abstraction on wetlands;
- The impacts of wetland restoration on hydrology and hydrogeology;
- The effects of afforestation on hydrogeology.

The research opportunities

Opportunities in LOCAR focus on the integration of hydrology, hydrogeology, geomorphology and freshwater ecology. Major new insights are likely to come from combining the skills of different disciplines and different institutions to investigate such issues as:

- Water, solute and sediment transfers through surface and unsaturated zone, exploring the key role of processes with the soil;
- The fate of chemicals in the groundwater body, through the analysis of flow paths in aquifers and their links to resurgences in streams;
- The response of freshwater vertebrates to changes in stream flow regimes, such as those produced by flow augmentation or the artificial maintenance of water levels in wetlands;
- The role of land-use practices, such as afforestation and urban development, in changing river sediment loads and thus the quality of aquatic habitats;
- Incorporating seasonal land cover changes into dynamic catchment models at a range of scales;
- Examining the nature of hydrological and ecological responses to specific socio-economic drivers of catchment change;
- Modelling the combined impacts of climatic change and altered land management practices on hydrological and hydrogeological conditions.

The partnership opportunities

The Natural Environment Research Council has an obligation to exploit its science. All recipients of NERC funding must try to ensure that the outcome of their research is used to the advantage of the UK.

NERC is already working with a wide range of businesses, from agriculture to insurance, and from construction to biotechnology. LOCAR touches on many issues from biodiversity in soil and groundwater to achieving a balance between flood control and wetland protection. It impinges directly on many initiatives and much legislation concerned with land management and the impact of chemicals on the environment. LOCAR is thus well placed to foster partnerships with utilities, regulators, water-dependent industries, landholders and farmers, wildlife conservation interests and concerned local communities.

Specific partnership opportunities arise from developing instrumentation, sharing data, and incorporation into catchment abstraction management plans. Key issues that might marry science and water management concerns include:

- improvement of water resource planning in chalk and sandstone aquifers;
- understanding pathways and fate of chemicals in lowland permeable catchments;
- increasing awareness of how changes in water flow and water quality affect fisheries;
- getting better estimates of the impacts of river flow management on wildlife in wetlands;
- improving knowledge of groundwater resurgences and surface stream water losses in chalk streams;
- developing generally applicable models to assist in maintaining flows in winterbourne streams.

The benefits of LOCAR

The LOCAR research programme will bring new insights into the hydrological and ecological functions of mesoscale catchments and will improve characterisation of subsurface flow and transport processes in lowland catchments. It will bring new understanding of the hydrological controls on stream and wetland ecology, of the impacts of a range of anthropogenic activities on hydrological and ecological regimes, and of the sensitivities of the hydrological and ecological regimes to future climatic changes. It will provide validated models of the flow, sediment and water quality regimes of mesoscale catchments, which can be used to make reliable predictions of the impacts of both anthropogenic and climatic changes on these regimes.

The data collected during the programme will provide high quality, detailed, intensive, integrated water and ecological information for specific areas, which are representative of wider areas of the chalk in south-east England and the Permo-Triassic rocks of the Midlands. This good geo-referenced information will be suitable for the detailed analysis of interrelated consequences of ground and surface water management. The LOCAR data management team will have the ability to integrate meteorological, surface hydrology, ecological, groundwater and wetland data.

The working mechanisms and management of LOCAR

The LOCAR programme is supported by a JIF grant to a consortium led by the BHS President, **Professor Howard Wheater** (Imperial College), and by a NERC Thematic Programme grant managed by a steering committee chaired by **Dr Mike Bonell** (UNESCO Water Resources Division, Paris). The key infrastructure development is a £5 million programme of installation and maintenance of high quality field research facilities in three contrasting permeable lowland catchments: the Frome/Piddle in Dorset, the Pang/Lambourn in Berkshire and the Tern in Shropshire. The new equipment will build on existing facilities operated by the Environment Agency and other organisations. Field staff will carry out day-to-day operations in each catchment, with scientists on research projects within the programme working closely with them. A catchment board, led by leading scientists of the JIF consortium and LOCAR steering committee, will oversee the work in each catchment.

Installation of the new equipment is expected to begin early in 2001, and depending on progress, a call for research proposals will be made between April and June 2001. Anyone who requires further information may consult the NERC web pages (http://www.nerc.ac.uk), or contact the LOCAR Science Coordinator, **Professor Ian Douglas**, School of Geography, University of Manchester, Manchester M13 9PL *(tel 0161 275 3642, fax 0161 275 7878, email i.douglas@man.ac.uk).*

Book review

Measuring the Natural Environment. Ian Strangeways. Cambridge University Press, 2000. ISBN 0 521 573106, hardback, 365 pp, 175x250mm, price £45.

This is a valuable book on hydrological instrumentation. The author has worked in the field of hydrology for many years, as head of the Instrument Section at the former Institute of Hydrology, and now as an international consultant in hydrology.

The book consists of 15 chapters. After an introduction on the basics in measuring hydrological variables, past and present, there follows comprehensive well presented state of the art chapters on Radiation; Temperature; Humidity; Wind; Evaporation; Barometric pressure; Precipitation; Soil moisture and groundwater; Data logging; Telemetry (including radio, satellite and meteor-burst with a brief overview of the polar and geostationary communication satellites); Remote sensing and Water (including water level, peak gauges, stilling wells, current meters, river flow measurement, and water quality).

A concluding chapter presents a broad view of the difficulties in assessing available hydrological information by the Intergovernmental Panel on Climate Change (IPCC). The author points out that the most sophisticated models are not yet able to predict what the real-world climate will do. It is apparent that many past measurements of hydrological variables, as well as measurements being made today, originate from simple mechanical, manual instruments, together with their shortcomings. The author makes a case for an improvement in global hydrological information including land-surface air temperature data, surface instrument networks and other climate variables. Nevertheless, the book has demonstrated that hydrologists are now in a position to measure, with much improved accuracy and geographic coverage, what the climate actually may do in the future, should the necessary investment be made (*investment* being the operative word in this case).

The book benefits from being written in clear, concise English, and to each chapter a useful list of references is given. Since the book was published, British Standards on raingauges may be added to these references and a European Standard on the rainfall pit gauge has just been published, the author being very much involved as the convener of the working group that drafted the standard. Each chapter is provided with excellent black-and-white illustrations in the form of diagrams, graphs and photographs.

I would recommend this book to all engaged in hydrology (or hydrometry) and especially to those studying the subject in universities or colleges.

Reg Herschy
CNS (Chairman BSI/CPI113 CEN 318)

Honour for Jim Dooge

Professor Jim Dooge, one of the six Honorary Members of BHS, was awarded an honorary doctorate by Heriot-Watt University last July.

The citation speech recognised in him three important values that were at the core of the university's aspirations: academic excellence, care for the environment and public service.

Jim Dooge was the keynote speaker at the BHS international conference in Exeter in 1998 and greatly influenced the Exeter Statement. His distinguished career in civil engineering and water resources management was matched by a parallel career in Irish politics: he was Minister of Foreign Affairs in the 1980s.



Prof. Jim Dooge (left) with Lord Mackay, Chancellor of Heriot-Watt University.

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Circulation PLUS

On an acceptable criterion for model rejection

Prof. Keith Beven, University of Lancaster

This is a new pull-out section containing thought-provoking articles. We kick off with two items from universities, by Keith Beven and Howard Wheater's team, but you do not need to be an academic to write for C+. Perhaps you have something to offer on practical hydrology? Please use C+ for items that you want to share with other members, but which might not be appropriate for publication in a formal Journal.

In much of my recent research in different contexts of hydrological prediction, Monte Carlo simulation experiments carried out within the GLUE (Generalised Likelihood Uncertainty Estimation) framework have suggested that there may be many model structures and parameter sets parameter sets that result in acceptable or behavioural simulations of available observational data.

This has been found in rainfall-runoff modelling, flood inundation modelling, flood frequency estimation, land surface parameterisations, geochemical modelling (see Beven *et al.*, 2001, or Beven, 2001, and references therein). One simulation will always be the best that has been found so far, but this "optimal" simulation will not be invariant to a change in objective function or change in calibration data set.

Thus, I have suggested that the idea of an "optimal" model is flawed and should be replaced by a concept of *equifinality* of models in reproducing the data. Equifinality of models, of course, implies uncertainty in predictions and it is this concept that underlies the GLUE approach to modelling, weighting the predictions of each model according to how well that model has performed in the past. Models that have not been acceptable are rejected (given a weight of zero).

One intriguing aspect of this approach to prediction is at what point is a model rejected? This is not really an issue that has been considered much in the past, because of the predominance of optimisation strategies in model calibration. In very many studies *all* but the optimum model are rejected. The best models must, of course, be considered acceptable — even if the results are not really exceptionally good. Acceptability has to take account of the fact that even the most process-based model structures are necessarily approximate and there are always measurement errors for both inputs and outputs that will restrict how well even a perfect model could perform. It is also generally the case that within any model structure there will be parameter sets that give obviously unacceptable results (Nash-Sutcliffe efficiencies of less than 0, for example). But between these two extremes there are models that range from very good to poor. So what should be an acceptable criterion for model rejection?

Statisticians solve this problem by formulating a likelihood function. Properly posed, this will provide an estimate of the probability that a model will predict any particular data point. Integrated over all models, a distribution function for the prediction of any data point is derived. In a Bayesian formulation, this will be based on the posterior distribution function formed by combining a prior probability for the models, with a likelihood function based on the structure of the model residuals. It is accepted that the prior distribution might be defined subjectively (or a noninformative prior distribution might be used), but the likelihood function should properly reflect the information content of the model residuals. This requires making some assumptions about the structure of the model residuals.

Experience with implementing this approach within the GLUE methodology has brought up some interesting points. A typical set of likelihood function assumptions in rainfall-runoff modelling (e.g. that the residuals are multiplicative autocorrelated Gaussian variates) results in response surfaces that are far, far peakier than (say) using the Nash-Sutcliffe efficiency. The implication is that models with good efficiencies (and that visually produce acceptable simulations) have very low likelihood. Only in the region of the parameter space local to the "optimum" model are the likelihoods significantly greater than zero.

This suggests that such a likelihood function is overconditioning the model results. This may be fine if the only interest is in some optimum model, but the consequence seems to be that the prediction distributions are constrained to such an extent that they do not necessarily bracket the observations. This result appears to stems from an overestimation of the information content of the residuals as a result of the errors inherent in both the structure and input data of hydrological models.

There is an implicit assumption within this statistical approach that may not hold for the case of hydrological modelling. That assumption is that the hydrological model component is a true model of the system. We know that this is not the case, even though many models give "acceptable" simulations. Kennedy and O'Hagan (2001) have recently presented an approach to model calibration, based on Bayesian likelihood concepts, in which they introduce an (additive) model inadequacy function. This inadequacy function could be as simple as allowing that there is a model bias: it could be more complex. In hydrological modelling, models are used because by including knowledge of the (nonlinear) dynamics in prediction to other cases, the predictions will be in some sense more rigorous. The model itself is therefore being used as a tool for extrapolation of understanding to predictive situations. The danger is that if either the model structure or the parameter values are incorrect, the predictions may be inaccurate. Thus, adding a model inadequacy function into the likelihood function would seem to be an excellent idea.

However, experience with GLUE simulations suggests that it may be very

difficult to formulate an inadequacy function, especially for models that make predictions in both time and space. In particular, parameter interactions and covariation leading to models that fit the data well can be markedly different in different parts of the parameter space. Model inadequacy functions might also be expected to vary through the "model space" (of model structures and parameter sets) and through time and space for individual models in that space. It would be possible, given sufficient computer time, to estimate an inadequacy function for each of the individual models sampled (or at least the subset of those considered "behavioural" in fitting the data). This was done within the GLUE methodology, for example by Romanowicz *et al.* (1994), who allowed for the simplest case of a mean bias in integrating over a likelihood function for a given set of model parameters.

From the process point of view, since each set of model parameter values may then have its own inadequacy function, inadequacy then becomes an additional model component (but one which may have no clear physical meaning). Depending on the chosen function, the best joint model in calibration may not necessarily be the best physical model (or consequently the best model in prediction under changed hydrological circumstances). If the interest is accuracy in prediction alone (as for example in the case of adding a stochastic error model in operational flood forecasting), then this might be acceptable, but it may be difficult to interpret hydrologically, since the mean residual and any other error parameters then effectively become additional parameters of the model.

A better strategy would seem to be to use a model inadequacy function as a basis for model rejection as well as for improving prediction. There is, however, a complementary difficulty to that of deciding on the acceptability of models noted above. There is no marked threshold at which a model becomes inadequate, only a continuous spectrum of performances from good (or at least the best available) to bad.

One way around this might be the use of multiple criteria for acceptability or inadequacy. Models that are acceptable on one criterion might be rejected on another, thereby refining the uncertainty in prediction. This multicriteria approach is inherent in the Pareto optimal set approach to model calibration (see Gupta *et al.*, 1998; Yapo *et al.*, 1998). All models in the Pareto optimal set are on the Pareto front that defines the trade-off in performance between one criterion and another. Multiple performance criteria can also be used in the GLUE methodology by combining them in different ways to produce a single likelihood measure or prediction weight.

There is, however, a critical difference between the two approaches. In the Pareto optimal set approach, only models on the Pareto front are retained in the optimal set. Unlike GLUE, other models that are very nearly as good (and that might be on the front for a different set of performance criteria or calibration data) are rejected. The rejection is therefore objective, but will not be invariant to change in criteria or dataset. Prediction bounds for the Pareto set can be calculated, but published results suggest that they do not bracket the observations, presumably as a result of model and data errors as well as the choice of criteria used. In this sense therefore this approach is also overconditioned.

So far, therefore, both statistical likelihood functions and Pareto optimal set approaches appear to overcondition the set of retained models, while the GLUE approach requires some (subjective) decision about the threshold of acceptability for model rejection. Neither seems entirely satisfactory, although the results of the GLUE approach appear not to be too sensitive to the choice of a threshold because of the weighting used with the predictions of the retained models (see, for example, Freer *et al.*, 1996). So, to pose the question again, what should be an acceptable criterion for model rejection?

It seems that this question is not so easy to answer, but rather raises a number of important issues. The first is whether rejection should depend on the aims of a modelling project or only on some (objective) statistical criteria based on the structure of the model residuals. Certainly, in practice, the criteria of performance are often chosen to be purpose-specific. Some projects will be more interested in models that predict peak flows well, others in the timing of the flood peaks, others only in volumes, others may want to reduce the sum of squared errors or increase the efficiency for the whole hydrograph (though note that statistical theory tells us that ignoring any correlation in the residuals will lead to a bias in the "optimal" parameter values). Clearly a model that is really "behavioural" should "pass" on all of these criteria, so this is a good argument for using a multicriteria approach. The problem that might be encountered is that all the models might fail on one or more criteria. Few studies have been reported of the failure of all models considered when evaluated against observations. Optimisation, or Pareto optimal sets, do not actually take any account of whether the best models are acceptable, only that they are the best avail-able. GLUE can reject all the models considered (see Zak *et al.*, 1999, for a soil geochemical example).

A second point to discuss is how far it is possible to take measurement errors into account in model rejection. A model might be deemed non-behavioural only because of the errors in input or output data, even if the model was, in fact, a good one. In hydrological datasets, even if considerable effort has been put into quality assurance, we know that there are errors in the measurements of both inputs and outputs, partly because of the limitations of the measurement techniques available, partly because of the frequent requirement to extrapolate from point measurements to areal average quantities (rainfall, snow pack water equivalent, potential evapotranspiration, water table levels, etc.). A model might be rejected therefore because it is not possible to produce a behavioural simulation given the data available.

In some cases this is obvious and the data cannot be used in evaluation (see Hornberger *et al.*, 1985, for a good rainfall-runoff modelling example). In other cases it is not so obvious whether the data or the model are at fault (see Freer *et al.*, 1996, for an example of a continuing error in predicted discharges that is due to a timing error in predicting the onset of snowmelt). Most model evaluations take no account of the potential for observational error, or at least do so only implicitly. (This really applies also to statistical likelihood functions that treat all the residual as "measurement error" as if the true model and true inputs were available.)

It would seem, however, that an acceptable criterion for model rejection should try to avoid rejecting models because of inadequacies of the data, rather than of the model itself. The difficulty is to know *when* the data are inadequate. Is it enough to screen the data before evaluating any models? But one way of doing so is to use a model to indicate any inconsistencies in the data, with the potential danger of a consequent circularity of reasoning. The potential for errors in input data suggests that models should be evaluated using different (stochastic) input sequences — if only we knew what the structure of the input errors might be! Any such errors are therefore also likely to continue to be treated implicitly for purely practical reasons.

To summarise, we do not seem to have got very far with finding an acceptable criterion for model rejection. Optimisation methods (including Pareto optimisation), while superficially objective, do appear to reject too many models that might be useful in prediction for other sets of conditions. The differing philosophy of the GLUE approach will retain more models, and is therefore more likely to result in prediction limits that bracket the observations, but requires subjective decisions about rejection thresholds on one or more performance measures. The use of multiple criteria would appear to be a useful strategy,

but may need to take more account of potential data errors to avoid making the "type 2" error of rejecting a model that should be retained. Perhaps in the end it comes down to (subjective) common sense: in the choice of performance (or rejection) measures when statistical likelihood methods do not seem appropriate; in the screening of datasets for obvious errors (trying to avoid the circularity of rejecting the periods of data when the model doesn't work), and in deciding on the threshold of acceptability. From a theoretical point of view, it is arguable that all hydrological models could be rejected as inadequate descriptions of real-world hydrology: it is just that some produce predictions that are thought to be useful in practical applications (at least after some calibration).

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A Matlab toolkit for conceptual rainfall-runoff modelling and the analysis of Monte-Carlo simulations

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Introduction

Rainfall-runoff models are widely used in hydrological practice, but have important limitations. Recent research has clarified these limitations, and powerful new methods of analysis of model performance, identifiability and uncertainty have been developed. This article describes two modelling toolkits, which support the rapid development of tailored model structures and the analysis of performance using a powerful range of Monte-Carlo-based tools.

It is widely recognised that most rainfall-runoff models suffer from the problem of equifinality, in that alternative parameter sets, and even alternative model structures, can give very similar levels of performance, at least as determined by a single criterion of goodness of fit. This may or may not be important for conventional applications to a gauged catchment, but if it is required to attach some physical significance to parameter values, or to look for relationships between optimised parameter values and measurable catchment characteristics, then this ambiguity is a major problem. One approach is to tailor a model structure to a particular task. For example, if regionalisation is a goal, then some degradation of simulation performance may be acceptable if it is associated with improved parameter identifiability. A second, related approach is to improve the information content of the available time-series data by using various performance criteria (see Hoshin Gupta's article on pages 1 and 2 of this edition).

A modelling toolkit has been developed to produce efficient lumped model structures with a high degree of parameter identifiability (Wagener *et al.*, 2001c). The toolkit contains two major components, which are implemented in the Matlab programming environment (Mathworks, 1996). The first is a Rainfall-Runoff Modeling Toolbox (RRMT) with a generic architecture of lumped model elements, which allows alternative model structures to be rapidly constructed and tested. The second component is a Monte-Carlo Analysis Toolbox (MCAT) combining a number of analysis tools to investigate parameter identifiability, model behaviour and prediction uncertainty.

Rainfall-Runoff Modelling Toolbox (RRMT)

The philosophy behind this toolbox is the recognition that no model structure is suitable for all modeling exercises, but that the appropriate model structure is a function of: (1) the modelling objectives (*e.g.* required spatial and temporal discretisation, relevant response modes to be simulated), (2) the characteristics of the hydrological system under investigation (*e.g.* dominant processes, response times of the system), and (3) the available data (*e.g.* possible temporal discretisation).

The implemented system is a generic modelling shell. Its architecture is shown in Figure 1. All model structures are a combination of a rainfall loss model and a routing component. Different options for both model parts are available for selection by the user. Examples of loss model components are Penman-type soil moisture stores (Penman, 1949) and Antecedent Precipitation Index (API) type functions (e.g. Jakeman and Hornberger, 1993). Available routing components are linear and non-linear conceptual reservoirs and transfer-functions (e.g. Young, 1992). However, new components can quickly be added as long as their input and output format conforms to the appropriate specification. Additionally, visual analysis and off-line data processing

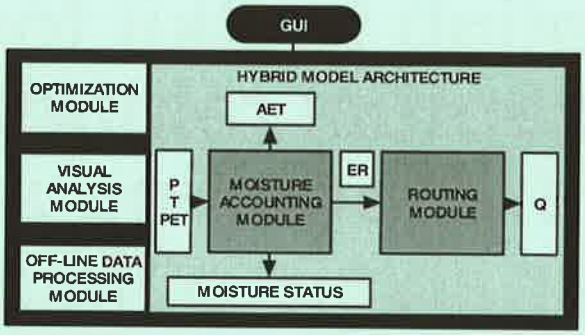


Figure 1 *System architecture of the Rainfall-Runoff Modelling Toolbox (RRMT).*

modules are available for the visualisation of data or model performance, or the calculation of flow duration curves, volumetric fit, *etc.*

Monte-Carlo Analysis Toolbox (MCAT)

The detailed investigation of model behaviour in terms of parameter sensitivity and identifiability, the suitability of a particular model structure, and prediction uncertainty, are increasingly important parts of the modeling task. The understanding of model behaviour and performance gained increases the transparency of the modeling procedure and helps to assess the reliability of modeling results.

The Monte-Carlo Analysis Toolbox (MCAT) combines a number of analysis methods to evaluate the results of Monte-Carlo parameter sampling experiments or model optimisation methods based on population evolution techniques.

Functions contained in the MCAT include an extension of the Regional Sensitivity Analysis (RSA, Spear and Hornberger, 1980) proposed by Freer et al. (1996), various components of the Generalized Likelihood Uncertainty Estimation (GLUE) method (Beven and Binley, 1992), options for the use of multiple-objectives for model assessment (Gupta et al., 1998; see Figure 2), and response surface plots.

The MCAT can be used in conjunction with the RRMT, but also separately to analyse any dynamic mathematical model structure.

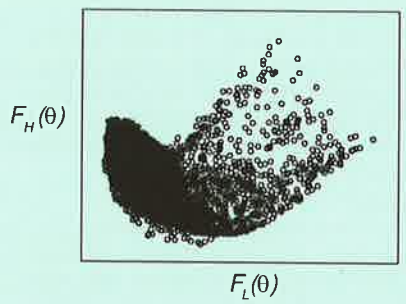


Figure 2 *Monte-Carlo results for a conceptual rainfall-runoff model using two objective functions are shown in a MCAT plot. Both are based on the Root Mean Squared Error (minimum in bottom left corner). F_H only considers periods above a certain threshold (high flows), while F_L only uses values below a certain threshold (slow recession periods). A clear trade-off front between the two measures is visible, showing the inability of the model to simulate both periods with one parameter set.*

Conclusions

Two toolboxes have been implemented in the Matlab programming environment. One (RRMT) for the development and implementation of lumped model structures, of either conceptual or hybrid-conceptual type, and one (MCAT) for the analysis of dynamic mathematical models.

Wagener *et al.* (2001c) has a more detailed description of both toolboxes. Applications of RRMT and MCAT can be found in Wagener *et al.* (2001a;c;d), and of MCAT in Camacho (2000, solute transport model), Smith *et al.* (2001, water quality model), and Wagener *et al.* (2001b, solute transport model).

The toolboxes require Matlab version 5 or higher installed on the PC. They are available for download free of charge for non-commercial use from the Imperial College web-site at *http://ewre.cv.ic.ac.uk/hydro/hydropeople.html#Thorsten.*

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Have you found this section interesting? If so, why not send in a contribution for a future edition of C+?

Copy deadline for *Circulation* No. 69 2nd April 2001

Publications

Society publications update

In the past six months, three new BHS Publications have been published. These provide excellent hydrological value for your money, with discounts for members, and offer right up-to-date, authoritative statements on current practice and the latest research in the areas of hydrology covered.

Members will have received the latest issue of the publications order form in their previous *Circulation*. Note that **Occasional Paper 8 is now out of print**, and that every effort will be made to maintain the latest publications availability information on the BHS web pages.

Occasional Paper 12, "***Flood forecasting: What does research offer the practitioner?***", is just in from the printers, containing papers from CEH, Met Office, EA and university hydrologists, presented at the National meeting in Bristol: it represents a major step towards bringing the latest flood research into the practitioner's domain.

Occasional Paper 11, "***Water in the Celtic world: managing resources for the 21st century***", from last year's Inter-Celtic Colloquium, contains some 51 papers covering much of the breadth of contemporary hydrology (e.g. water supply and demand, climatic change, extreme events, processes and ecosystems). Papers are drawn from as far apart as Canada and Portugal, and will help readers tap into current developments in other Celtic lands. The ***7th Symposium Proceedings*** will be of particular value to members who were unable to attend last year's Newcastle symposium. Papers are grouped around integrated water resources, the science base, data and modelling, decision-making and posters.

The prices are: Newcastle and Inter-Celtic volumes £30 (£25 to members); Occasional Paper 12 costs £15 (£10 to members). Orders should be sent with cheques, including £2.50 postage and packing per order. Enquiries are welcome: please contact Neil Macdonald or Andrew Black, Department of Geography, University of Dundee, Dundee DD1 4HN (email n.macdonald@dundee.ac.uk).

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British-Bulgarian volume

G. Gergov and I.G. Littlewood (eds) (2000) *British-Bulgarian Collaboration in Hydrology*, British Council, Sofia, 181pp. ISBN 954-90726-1-4. ***Free copies*** are available while stocks last.

British-Bulgarian Collaboration in Hydrology marks the completion of a British-Council-funded exchange programme led by **Prof. Georgi Gergov** of the National Institute of Meteorology and Hydrology (NIMH), Sofia and **Dr Ian Littlewood** of the Centre for Ecology and Hydrology (CEH), Wallingford. The programme, undertaken in two phases, has been concerned with the exchange of information on hydrometry, hydrology and related data management procedures and processes. The emphasis was on gathering information of assistance to Bulgaria as that country prepares to become a member of the EU (Bulgaria became an Associate member in 1995).

Initially, the programme was concerned primarily with sediment in rivers (Prof. Gergov is Head of the Sediment Transport and Fluvial Processes Division at NIMH), but as the first phase developed the advantages of taking a more general view became obvious. The first phase of the programme was expanded, therefore, to include methods of hydrological monitoring, data management and analysis more generally.

The second phase continued with topics taken up in the first phase, but dealt also with policy and legal aspects of water monitoring and management in the context of 'Bulgaria and an expanding European Union'.

The book comprises articles by key personnel involved in the exchange programme. Authors are from UK and Bulgarian government departments and agencies, universities and research institutes and from the UK private sector. The book is bilingual: there are seven articles by Bulgarian authors, with English summaries, and *vice versa* for nine articles by UK authors. Given the modest level of resources available for preparation and production of its 181 pages, and the self-selected topics dealt with by contributing authors, the book does not attempt to cover the whole spectrum of topics and issues related to hydrology and water resources. However, the sixteen articles do cover a wide range of topics including:

- An overview of Bulgarian government policy on water;
- UK and Bulgarian water legislation;
- International hydrometry standards;
- Organisation of the hydrometry and hydrology functions of the Environment Agency;
- Rainfall-streamflow modelling, with examples for a UK catchment and a Bulgarian catchment;
- The role of CIWEM as a non-governmental organisation (NGO) serving the interests of water and environment management professionals;
- Aspects of the water resources of Bulgarian catchments draining into the Black Sea.

Readers in the UK who would like a *free copy* of the book should contact Ian (see footnote). Readers of abstracts who are particularly interested in any of the Bulgarian articles are also invited to contact Ian: it may be possible to provide a translation through Prof. Gergov. Alternatively, readers can contact authors directly to make further enquiries about a particular topic (email addresses are given with short biographies of the authors).

During the current period of gradual progress in Bulgaria towards adoption of European models of water monitoring and management at river basin scale, and the imminent EU Water Framework Directive, there is vigorous debate in Bulgaria in the context of their continuously evolving Water Law. Prof. Gergov is active in this area and has taken part in radio broadcasts from Sofia using the information he has gathered from the British Council exchange programme, and he is now able to bring the book to the attention of others in Bulgaria. A Bulgarian National Water Association has been formed, with Prof. Gergov as its Vice-President — they would be pleased to hear from anyone in the UK interested in working with Bulgarian hydrologists and water resources professionals, whether in the private or public sector. The book may be a good starting point for BHS members interested in working in the region.

Ian Littlewood

Free copies are available from Dr Ian Littlewood, Centre for Ecology and Hydrology, Wallingford, OX10 8BB (*igl@ceh. ac.uk*). Please send a stamped self-addressed envelope (sae) measuring at least 20cm x 30cm. The book weighs 363 grams: please affix the required value of postage stamps: £1.24 first class or £1.00 second class.

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HSJ contents

The two latest issues of the *Hydrological Sciences Journal* (Vol. **45**, No. 6 and Vol. **45**, No. 6) contain these papers:

Vol. 45 No. 6, December 2000:

Eric Sauquet, Lars Gottschalk & Etienne Leblois: *Mapping average annual runoff: a hierarchical approach applying a stochastic interpolation scheme*

Costanza Di Stefano, Vito Ferro & Salvatore Rizzo: *Assessing soil erosion in a small Sicilian basin by Caesium-137 measurements and a simplified mass balance model*

Magnus Persson, Ronny Berndtsson, Slah Nasri, Jean Albergel, Patrick Zante & Yuki Yumegaki: *Solute transport and water content measurements in clay soils using time domain reflectrometry*

Amin A. Elshorbagy, U. S. Panu & S. P. Simonovic: *Group-based estimation of missing hydrological data: I. Approach and general methodology; II. Application to streamflows*

Pawel M. Rowinski, Wlodzimierz Czernuszenko & Jean-Marc Pretre: *Time-dependent shear velocities in channel routing*

Wan Ruslan Ismail: *The hydrology and sediment yield of the Sungai Air Terjun catchment, Penang Hill, Malaysia*

Jacques Callede, Pascal Kosuth, Jean-Loup Guyot & Valdemar Santos Guimarães: *Discharge determination by acoustic Doppler current profiler (ADCP): a moving bottom error correction method, applied on the River Amazon at Obidos*

Plus book reviews of the *Flood Estimation Handbook*, and *Hydrogeology of Crystalline Rocks* (edited by Ingrid Stober & Kurt Butcher).

Vol. 46 No. 1, February 2001:

Mikdat Kadioðlu & Zekai [a] en: *Monthly precipitation–runoff polygons and mean runoff coefficients*

T.K.S. Abam: *Regional hydrological research perspectives in the Niger Delta*

T.A. Fontaine, J.F. Klassen, T.S. Cruickshank & R.H. Hotchkiss: *Hydrological response to climate change in the Black Hills of South Dakota, USA*

Benina Touaïbia, Abdellah Aïdaoui, Dieter Gomer & Mohamed Achite: *Quantification et variabilité temporelles de l'écoulement solide en zone semi-aride, de l'Algérie du Nord*

Y. S. Yang, R. M. Kalin, Y. Zhang, X. Lin & L. Zou: *Multi-objective optimization for sustainable groundwater resource management in a semiarid catchment*

S. A. Wooldridge, S. W. Franks & J. D. Kalma: *Hydrological implications of the Southern Oscillation: variability of the rainfall–runoff relationship*

C. Loumagne, M. Normand, M. Riffard, A. Weisse, A. Quesny, S. Le Hégarat-Mascle & F. Alem: *Integration of remote sensing data into hydrological models for reservoir management*

Sarfaraz Ahmad & Syed Iqbal Hasnain: *Snow and stream-water chemistry of the Ganga headwater basin, Garhwal Himalaya, India*

Tawatchai Tingsanchali & Chaiyuth Chinnarasri: *Numerical modelling of dam failure due to flow overtopping*

Bellie Sivakumar, Ronny Berndtsson, Jonas Olsson & Kenji Jinno: *Evidence of chaos in the rainfall–runoff process*

Murray C. Peel, Q.J. Wang, Richard M. Vogel & Thomas A. McMahon: *The utility of L-moment ratio diagrams for selecting a regional probability distribution*

Spyros Beltaos & Terry D. Prowse: *Climate impacts on extreme ice jam events in Canadian rivers*

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Members wishing to refer to these or other publications may contact the National Hydro-Sciences library at CEH Wallingford *(tel 01491 692266)*.

BHS international strategy

The international profile of the Society to date has involved:

- Maintenance of links with international associations, societies and programmes, including the International Association of Hydrological Sciences (IAHS – via the UK subcommittee of BHS and the Royal Society), the Hydrological Sciences Section of the European Geophysical Society (EGS), and other national hydrological societies worldwide. The Society also has full membership of UNESCO's International Hydrological Programme (IHP) Committee for the UK.
- Extending BHS membership to hydrologists living outside UK: currently ~8% (64 out of 789) live overseas.
- Organisation of the First International BHS Conference in July 1998.

It is suggested that the international profile of BHS might be developed further by the following means:

1) BHS should continue to organise International meetings. In view of the large workload involved, a 6-year cycle of such events is considered appropriate. Given potential links with AGU and EGS, it might be that some of these meetings could be joint ventures. On some occasions, the venue would be in the UK; on others it might be overseas. The next International meeting should be scheduled for 2004. This timing avoids the main cycle of IAHS/IUGG international events, but there is a need to avoid a clash with the International Geographical Union International Conference, which comes to Glasgow in mid-August 2004. It is suggested that BHS does not hold a National Symposium in the same year as an International meeting, but topics for the latter should be carefully selected to appeal to both UK and overseas participants.

2) BHS should attempt to develop a memorandum of understanding with IWRA by which the Society would represent IWRA in Britain, and thereby gain an influence in this growth area of the water management world.

3) BHS should seek to play a role in building links with like-minded NGOs in other countries. In particular, reaching out to Europe should be part of BHS policy. Promoting contact between UK hydrologists and especially those in the 'pre-accession' countries to the EU, convening joint meetings with other European hydrologists and developing a mutual affiliation with The European Network of Experimental and Representative Basins (ERB) are suggested as mechanisms for developing this outreach.

4) Membership of BHS among non-UK hydrologists should be further encouraged. More should be done to advertise BHS at meetings outside the UK, as a way of encouraging new members from abroad. Members sponsored by BHS to attend overseas meetings could be asked to take a lightweight poster presentation, which advertises the Society.

Bruce Webb
BHS International sub-committee

Scottish "Floods" meeting

Scottish Hydrological Group meeting
Perth
27 October 2000

Hydrological meetings on flooding topics in Scotland almost always bring together a large audience, and this meeting, with speakers on four topics, was no exception. During 2000, the worst flooding for perhaps 80 years had hit Edinburgh and north-east Scotland, while a wealth of research effort has provided much scope and need for the hydrologist to keep up to date.

Drew Aitken and **Nigel Goody** (SEPA) led off the afternoon with an account of the April 2000 floods. In urban catchments in Edinburgh, 750 homes were flooded, Murrayfield stadium and Edinburgh Airport were hit, and some £25m of damage was caused. Peak flows in the Almond catchment were estimated to have return periods of ~100 years. Rainfall durations in the north-east were considerably longer than in Edinburgh, with totals of up to 130mm over 60 hours in the Don catchment. Both speakers described the difficulties of real-time forecasting, when urban flow constrictions (caused, for example, by debris) affected flow patterns in Edinburgh, and when radar-based forecasts failed to identify rainfall generated by the tail of the

weather system. In Edinburgh in particular, the event had overwhelmed the council's sandbagging capabilities, and raised many questions for the city's flood emergency plan. Consultants were being appointed to investigate the problems and possible solutions.

Alistair Cargill (Babtie Group) presented some of the results of his recently-completed doctoral research at Dundee University, identifying heterogeneity within flood series and using that recognition to improve flood risk estimates. He demonstrated the considerable variation around the UK in flood seasonality, the synoptic conditions associated with large floods and the significance of snowmelt. He argued that the assumptions underlying flood risk estimation invalidated results obtained from series that are heterogeneous, and demonstrated the results of analyses using single components drawn from various flood series. Showing some foresight perhaps, one of his illustration sites was the River Ouse at York!

Paul Webster (Hydro-Logic Ltd) presented research that he and colleagues had been conducting at the University of Birmingham. His main focus was the exploration of return periods of floods and their causative rainfall, based around the parameters of the unit hydrograph method in the *Flood Studies Report*. Using a sample of catchments, he found that the percentage runoff parameter was often underestimated for low values, and overestimated for high values, yet with little apparent detriment in the overall performance of the method. The reason for this perhaps surprising behaviour was suggested to lie in the role of catchment wetness, allowing high return period floods to be generated from lower return period storms. The results of applying a stochastic rainfall generator to a deterministic simulation model for the Wye catchment were used to confirm this understanding.

Finally, **Ann Calver** (CEH Wallingford) presented a paper on flood frequency estimation using continuous simulation, based on ongoing collaborative work at Wallingford, which is generating considerable interest in addressing flood frequency estimation under climate change. This type of work is being recognised as a new generation in flood estimation. Important characteristics include: no separation of flood and base flow components; no specified relationship between rainfall and flood return periods; the integral representation of antecedent conditions, and the availability of flow duration curves. One important feature is its capacity for spatial generalisation, allowing it to be applied at sites with no flow records. Ann presented this type of work as being in its early stages, but offering exciting potential for the future.

A considerable breadth of topics was raised in discussion of the four papers. **Alan Werritty** (Dundee University) was asked to sum up at the end of the meeting, and identified five themes emerging from the papers and the discussion:

1. Difficulties in real-time flood forecasting and warning – difficulties with the precision and reliability of meteorological forecasts persist, and flood forecasting systems are not available for all the river reaches where they may be needed. There is a clear demand for better information for warning groups.
2. Synoptic meteorology and flood generating processes were recurring themes, and were felt to be important in relation to assessing return periods.
3. Improvements in flood risk estimation continue to be warranted – the FEH, continuous simulation modelling and component separation each offered important new opportunities for the future. The greatest concern will be the success of these methods in coping with future climatic changes, although other aspects, such as flood volume, may be warranted in some situations.
4. Climate change itself was a recurring theme throughout the meeting, and the importance of downscaling from the current GCM work was identified as vitally important.
5. Communicating flood risk estimation with the users of such information (government, Flood Appraisal Groups, insurers) was clearly important now, and would continue to be in the future: much effort could – and should – be put into education, both for organisations and individuals.

Andrew Black
University of Dundee

Postgraduate symposium heads north of the border

The annual BHS Postgraduate Symposium will be organised this year by Dundee and Aberdeen Universities, and held in Dundee on *5-6 September 2001*. It is open to all current and recent postgraduate students in hydrology, as well as to younger members of the society working in hydrology.

Papers will be presented and discussed over the two main days (Wednesday and Thursday). Guest speakers will also be participating in the meeting. A field excursion may be organised for *Friday 7 September*, possibly including visits to Perth's new flood defences, hydro-power schemes in the Grampian Mountains and some new experimental catchments – all depending on demand.

Papers will be welcome from all participants on any aspect of hydrology. Topics that are particularly encouraged are hydro-ecology, water quality, anthropogenic and climatic impacts on hydrology, and flood hydrology.

If you are a current or recent postgraduate student in hydrology, or a young practising hydrologist, we strongly encourage you to attend and we assure you of a warm welcome in Dundee. The BHS postgraduate symposium exists to benefit participants through meeting together and discussing their work, and it always provides an enjoyable social gathering! Costs will be kept to a minimum.

If you are interested in attending, please get in touch by email now so that we can send you further information, and begin to assess likely numbers. Please also let us know of any suggestions for new activities to include in the programme.

Andrew Black, University of Dundee
(a.z.black@dundee.ac.uk)
Chris Soulsby, University of Aberdeen
(c.soulsby@abdn.ac.uk)

News from members

Peter Midgley MBE

Very many congratulations to **Peter Midgley**, who received an MBE in the New Year honours list. Peter has played a leading role in Southern regional management for the Environment Agency for many years: most recently he has been responsible for managing some of the worst flooding problems in the south, including Chichester. He is currently a member of BHS national and Southern section committees. This is a well-earned recognition of Peter's substantial and effective contribution to Hydrology, and it is very good to see the work of a practising hydrologist recognised in this way.

BHS Committee news

Young members are now represented on the Main Committee by **Samantha**

Green (South West Section Regional Representative). Sam will be happy to hear from any younger members who wish to express a view on any aspect of the Society. You may contact her at South West Water in Exeter *(tel 01392 443774, fax 01392 443231 email Sagreen@South-west-water.co.uk)*

We are also delighted to welcome back **Dr Hilary Smithers** as a co-opted member representing CIWEM. Hilary has previously been a member of the Main Committee, and served as Hon. Secretary: her experience will again be of great value to the Society.

UK Committee for IAHS

Dr Denis Peach has replaced **Professor Stephen Foster** as the UK National Correspondent for the IAHS International Commission on Groundwater. Dr Peach is at the British Geological Survey, Maclean Building, Crowmarsh Gifford, Wallingford, Oxfordshire, OX10 8BB *(tel 01491 692270, fax 01491 692345, email dwpe@bgs.ac.uk).*

News from CEH Wallingford

Duncan Reed — who led the team that produced the *Flood Estimation Handbook* — thanks all BHS members who helped to make the project possible. He has now resigned from CEH Wallingford and is taking a career break until April/May. He can be contacted by email at: *duncanreed@dwrconsult.demon.co.uk.*

Dr Ann Calver has been appointed to take over from Duncan as Head of the Risks and Hydrological Extremes Division. Ann has worked at IH/CEH for 15 years, lately as head of the Catchment Systems Modelling Section. Her earlier career was in university research and the private consulting sector. She specialises in hydrological modelling, including continuous simulation for flood frequency estimation.

Runoff generation and implications for river basin modelling

Observations from the Freiburg Workshop October 2000

A BHS travel grant allowed *Thorsten Wagener* to attend this workshop organised by the University of Freiburg, Germany. This was a successful attempt to bring together experimental and modelling hydrologists to discuss the state of the art and future directions in process understanding and rainfall-runoff modelling. This article on the objectives of conceptual rainfall-runoff model calibration describes one of the many interesting discussions that took place during and around the workshop.

Most rainfall-runoff model structures used today can be classified as conceptual. This means that their structure is defined before any modelling is undertaken, and model parameters have to be derived from calibration against one or more observed output variables, e.g. streamflow.

Calibration can be performed either manually (using a trial-and-error approach), or automatically (using a search algorithm). Manual calibration can yield very good results, but is time-consuming, usually requires enormous experience with a specific model structure, and becomes very difficult when many interacting parameters are involved. Automatic calibration was introduced to overcome these problems and to allow for the investigation of uncertainty in the derived parameters. The development of search algorithms has led from local search methods to global, population evolution approaches, capable of finding a solution to this complex optimisation problem (*e.g.* Duan *et al.*, 1992). The task of these algorithms is generally to minimise (or maximise) a user-defined objective function (OF), usually some aggregated measure of the model residuals' size.

However, automatic calibration has still not replaced manual calibration, despite a decade of research into global search algorithms. The hydrograph produced as a result of traditional automatic calibration procedures is often biased to fit a specific aspect of the catchment response. The development of more sophisticated objective functions (Sorooshian and Dracup, 1980) to produce a more balanced performance could only partially solve this problem.

The selection of an OF unavoidably leads to the loss (perhaps better expressed as the neglect) of certain information available in the residuals. Selecting a measure like the Nash-Sutcliffe Efficiency (NSE, Nash and Sutcliffe, 1970), for example, results in a preference to fit high flows, while the use of log transformed data with the same measure tends to improve predictions during low flow periods. This information loss also contributes to the problem that only a small number of model parameters are identifiable from time series of streamflow alone (Beven and Binley, 1992). This implies, amongst other things, that it is difficult to select the parameter set that is most representative for the catchment at hand. This is a major problem in attempts to regionalise model parameters (*e.g.* Dunne *et al.*, 2000) or to predict future catchment behaviour resulting from land-use or climate change.

Such problems cannot be solved through improved search algorithms. Rather, they are inherent in the calibration procedure. Looking at the requirements for a successful manual calibration, we see that the approach is generally quite different from that of minimising a single objective function, as in automatic calibration. Some examples of requirements defined by the US National Weather Service (NWS) for the calibration of the Sacramento model structure are given here (NWS, 2000):

1 *Proper calibration of a conceptual model should result in parameters that cause model components to mimic processes they are designed to represent. This requires the ability to isolate effects of each parameter.*
2 *Each parameter is designed to represent a specific portion of the hydrograph under certain moisture conditions.*
3 *Concentrate on having each parameter serve its primary function rather than overall goodness of fit.*

The result of manual and automatic calibration will therefore also often be different. It seems that one problem in automatic calibration may be that we are asking the algorithm to solve the wrong problem, *e.g.* to maximise a NSE value: what is wrong is not the solution, but the question. A lot of research effort over the last two years has gone into solving this problem, starting with a paper by Gupta *et al.* (1998).

One task for the future is to translate the strengths of manual calibration practice into an automatic calibration procedure. Seibert and McDonnell (2000) showed how aspect [3] can be addressed by including soft data – *i.e.* expert knowledge – into the calibration procedure by defining fuzzy measures of model performance. They started with a uniform random sampling procedure, producing a large variety of parameter sets yielding similar NSE values. By including field knowledge

about the hydrological processes taking place in the catchment, they were able to decrease the uncertainty in the parameters considerably. They also found that the most suitable parameter set was not the one producing the top NSE values.

Wagener *et al.* (2000) showed that information about the performance of different parameter values and about structural inadequacies of the model is lost through the aggregation of the model residuals. It can be shown that the discriminative power of calibration procedures can be increased when these losses are reduced. This can be done, for example, by using a dynamic approach to parameter estimation (Wagener *et al.*, 2000) or by defining multiple measures of performance based on different catchment response modes (*e.g.* Boyle *et al.*, 2000; Wagener *et al.*, 2001).

Our approach to the calibration of conceptual rainfall-runoff model structures needs rethinking. One reason for the problem outlined here might be that dynamic conceptual model structures are treated like simple regression models – a point **Hoshin Gupta** emphasised in his Penman Lecture at Newcastle *(see page 1)*. The main challenge therefore does not seem to be the development of improved algorithms (although that is still important), but a change in objectives and requirements for automatic calibration procedures, leading away from simple fitting exercises to procedures that include an understanding of the nature of the model structures we use.

A special issue of *Hydrological Processes* containing selected papers will appear in autumn 2001.

Thorsten Wagener
Imperial College, London

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Cryptosporidium and giardia: protozoa in our water supply

BHS Southern Section meeting
6 December 2000
Imperial College, London

Following a brief introduction and welcome from the chair by **Julian Smith** (Arup Water), **Gordon Nichols** (Communicable Disease Surveillance Centre, Public Health Laboratory Service) started the meeting off with a presentation on "Human Giardiasis".

This was a well-constructed, fluid presentation, interlaced with a variety of photos and figures – and at one point even a painting. Gordon gave an overview of the effects and routes of transmission of human Giardiasis: the symptoms include diarrhoea, abdominal cramps, bloating, nausea and vomiting. As a member of the audience who had suffered from the illness pointed out, its symptoms are similar to those of many other illnesses, and it may not be immediately or easily diagnosed.

Giardiasis is contracted by only small infective doses. Following an incubation of 3 days to 6 weeks, it may last between 4 to 6 weeks (although there are chronic incidences). However, unlike Cryptosporidiosis, it is treatable by one of a number of drugs. Its incidence is slightly greater than that of Cryptosporidiosis, and much greater than illnesses from protozoa such as Cyclospora, Toxoplasma or Sarcocysts (all of them still quite rare in the UK). There is also a worldwide occurrence of Giardia, although a number of species may exist infecting different hosts (such as rodents and birds). Giardia duodenalis is synonymous with G. lamblia and G. intestinalis and is the main human pathogen.

Oval in shape and about 10μm long, Giardia cysts remain viable in cool water for up to two months, although they survive only a few days at body temperature. They show some resistance to water treatment disinfectants such as chlorine, but are much less resistant than Cryptosporidia. They are detected in water by immunofluorescence and tested for viability by staining. The main causes of Giardiasis are still unclear, and genetic typing will be important in future to identify the routes of transmission and epidemiology. The major food-related cause of the illness appears to be related to a lack of hygiene (mothers preparing food after changing babies' nappies). The foods involved were mostly those eaten without further heating following preparation by a food handler: those most likely to transmit viable oocysts included home-canned salmon, salads, sliced raw vegetables and ice.

Between 4500 and 7000 cases of Giardiasis are reported each year in England and Wales. The number seems to be declining, but differences between laboratories and testing procedures may influence the results. Interestingly, Giardiasis is not a notifiable illness and the reporting of laboratory results was not mandatory.

When examining the geographical prevalence of Giardiasis, certain areas (e.g. central London) were particularly affected. However, amusement arose when it was explained that this high rate was due to the presence of the London School of Hygiene and Tropical Medicine. Most of the geographical variation is probably due to varying surveillance procedures and relative efficiencies of health authorities, not infection rates.

A large temporal variation was also apparent, with annual peaks in late summer and autumn. This was most likely to be due to infected people returning from foreign holidays. Travel abroad had been identified as a major factor in the incidence of Giardiasis, which in turn also influenced the analysis for the illness. Apart from a peak associated with very young children, the average age ranged from the early twenty to mid-thirty-year-olds, probably because more of this age group frequently travelled abroad.

A case control study conducted by the PHLS in Southwest England of non-

travel related incidences had revealed an incidence rate of five Giardiasis cases per 100,000 population, and an increased risk associated with swimming in pools and fresh water, and watersports, particularly when the head was immersed. Correlation was also made between incidence and drinking tapwater, although work was currently under way to establish whether this was genuine or not.

Following a lively discussion, **Emily Whitehead** (British Geological Survey) took the stage to give another very informative and polished presentation, on "Groundwater contamination by Cryptosporidium: transport and risk".

Emily referred to BGS's involvement in Cryptosporidia Expert Groups. She described the similarities between Cryptosporidia and Giardia. Both of them are pathogenic protozoa that infect both animals and humans at low doses. Transmission routes, symptoms and duration are similar in ordinarily healthy individuals. The main concern with Cryptosporidia, however, was with immuno-depressed individuals, such as those on medication following transplant surgery, or suffering from HIV-related illnesses. The drug combination administered to HIV sufferers does have some effect, but there is no truly effective treatment for cryptosporidiosis, which can be life-threatening in such vulnerable individuals.

In the absence of effective treatment, the best way to protect public health was to prevent Cryptosporidia getting into water, a major transmission route.

Groundwaters are an important water source, providing 30% of potable water supplies in England and Wales — and up to 80% in some regions. Such sources were, until recently, thought to be reasonably secure from Cryptosporidia contamination. Cryptosporidia oocysts are about 4μm to 6μm in diameter, slightly smaller than Giardia, and can be filtered from groundwaters by aquifer materials. There are other attenuation processes, but none is effective in all situations.

Cryptosporidia is also very resistant to physico-chemical changes, including some desiccation, and can remain viable for up to three months in moist soil, and even longer in clear water. Subsurface conditions are therefore very favourable to maintaining their viability. Groundwaters have also traditionally received minimal treatment before distribution, and as Cryptosporidia is relatively resistant to disinfectants such as chlorine, there is a good chance of it remaining viable in the potable water supply. Filtration is possibly the best treatment barrier, but has to be very efficient to trap the small oocysts.

A clear link was shown between groundwater sources and Cryptosporidia in 1997 in North London. An Expert Group was then set up which recommended that the water utilities assess the risk of cryptosporidia in all water sources. Of the 1481 water sources evaluated, 335 were at risk from cryptosporidia. Of these, over half (171 sources) were groundwaters. Emily described how legislation then came into force requiring continuous monitoring of all sites at significant risk although, at present, there are no standard methods of assessing this risk. A general approach that could be used, however, was to assess the risks in a catchment from the cryptosporidia sources, its transmission routes and the receptor boreholes and wells.

As both people and animals may be infected, the sources of cryptosporidia are both rural and urban, with primary sources of oocysts from infected cattle, runoff from farms and farm waste stores, municipal wastewater discharges and leaking sewers. Consequently, cryptosporidia is relatively ubiquitous in the environment.

Transport of oocysts in the environment to an aquifer depends on the soil thickness, and the presence of bypass pathways, such as open sinks and solution holes in karst environments, or engineered objects such as slurry pits or septic tanks. Rivers flowing over permeable gravels also transport cryptosporidia rapidly into aquifers with minimum attenuation. Leaking sewer pipes can be an accidental source of cryptosporidia below the soil layer.

Studies on nitrates during the 1980s revealed that transport of contaminants through the unsaturated layers of aquifers is very slow. The risk of contamination thus increases after heavy rainfall or when bypass flows occur along cracks and fissures, which dramatically shorten the time taken for water to be transmitted into and through an aquifer. Most of the groundwater supplies in England and Wales have porosities dominated by cracks and fissures: of the most important aquifer types, only greensands have a predominance of intergranular primary porosity. Due to its large relative size, cryptosporidia is unable to pass through intergranular pores and relies upon cracks and fissures for transmission through an aquifer.

The construction of the receptor boreholes and wells also affected the risk of cryptosporidia reaching the water supply. The main construction factor was adits: built to increase water yields, they resembled large fissures, and dramatically reduced water transmission times.

Emily concluded by summarising various measures that can be taken to manage and reduce the risk of cryptosporidia contamination. She pointed out that the risks may change, and they needed reviewing regularly.

Attendance was a little less than normal, but this meeting had a friendly, informal feeling and people present showed considerable interest, joining in a lengthy and wide-ranging final discussion, with questions to both presenters. This was an informative and thoroughly enjoyable meeting, with two excellent presentations.

Steve Lambert
Imperial College

Travel grants

Travel grants are available to help members whose travel expenses are not met by an employer to attend scientific meetings. The amount will depend on the nature and location of the meeting and the case put forward.

Grants are mainly intended to help younger members, but are open to all. Successful applicants will be expected to write a short report for *Circulation*.

The Exeter Fund, looked after by BHS, also pays grants, specifically to help British hydrologists to participate in IAHS activities.

Anyone wishing to apply for a BHS travel grant should contact the Hon. Treasurer, **Terry Evans**, 107 Ely Road, Littleport, Ely, Cambridgeshire, CB6 1HJ *(Tel. 01353 862723, email TEEVANS100@AOL.com).*

Elizabethan hydrology?

Past-President **Frank Law** has come across a tantalising reference to a 16th century hydrological survey:

S. D. Coates wrote a booklet, published by the Monmouth Borough Museums Service in 1992, entitled 'The water powered industries of the Lower Wye Valley', which is still on sale. It says (on page 9), " ... in the winter and spring of 1565-66 a survey of various rivers in the Kingdom was made by the Government to investigate sites suitable for the establishment of a modern water-powered wire-making industry and a site on the Angidy river at Tintern was selected."

The booklet includes coverage of this Wye tributary site and very many

others used since in that valley.

No reference is given to the original document title, and despite efforts I cannot trace it in the British Library's excellent electronic catalogue. This survey predates anything else like it by about 360 years! I would be most grateful if anyone who knows of its existence could contact me. It deserves to be better known, and the author(s) given posthumous honour by our Society. I wonder what technology they used for site comparisons.

Frank M. Law

BHS 'Champions' needed to recruit new members

The BHS Committee sees advantages in increasing membership of the Society, and is devising a strategy to achieve this. One thread of the strategy is to seek 'champions' within workplaces, whose role will be to encourage colleagues to join the Society by extolling the benefits of membership. We are currently developing materials that could be used to assist this 'sales drive', but we are also looking for volunteers who could perform this key role of achieving membership growth within their workplace.

If you are willing to carry out this vital co-ordinating role, or if you would just like to know more about what is involved, please contact **Steve Parsons** at Mott Macdonald in Cambridge *(email: sbp@mm-camb.mottmac.com)*.

FORTHCOMING EVENTS

Meetings

BHS East Midlands Meeting
HOLISTIC HYDROLOGY: LOOKING AT THE BIGGER PICTURE
28 March 2001
Loughborough, UK

This meeting is free to BHS members and non-members. The four talks will be: *Impacts of quarry discharge upon a raised bog ecosystem* (Dr Jill Labadz, Nottingham Trent University); *Prospects for seasonal river flow forecasting in the UK* (Dr Rob Wilby, University of Derby); *Wetland water fluxes: integration of fieldwork and modelling results* (Dr Chris Bradley, University of Birmingham), and *Hydro-ecological variability within a ground-water-dominated river* (Dr Paul Wood, Loughborough University).

A poster presentation will take place on themes that integrate hydrology with geomorphology, climatology, ecology, water resource management and other disciplines (postgraduate students are especially welcome to present posters).

To confirm an interest in attending, and anyone wishing to present a poster, please contact Dr Paul Wood at Loughborough University *(Tel: 01509 223012, Fax: 01509 223930, Email: p.j.wood@lboro.ac.uk)*.

River Restoration Centre
ANNUAL NETWORK CONFERENCE
23–24 April 2001
Coventry, UK

This annual conference aims to bring together people from all sectors with an interest in river restoration – planners, river managers, conservation, fisheries, biology, recreation officers, researchers, landscape architects, river engineering product suppliers, consultants, etc.. Through its Annual Conference, RRC will strive to maintain the momentum of sharing experiences and networking begun at the first Conference in 2000.

There will be two half-days of presentations and discussion (*Monday p.m.* and *Tuesday a.m.*). On Tuesday afternoon there will be visits to two local rehabilitation projects. A third site visit can be made available on Monday morning, depending on numbers. A Geomorphology Workshop will follow at the same venue on *25 April*.

The Keynote Speaker will be **Baroness Young**, Chief Executive of the Environment Agency. Conference themes will be finalised in February once all summaries have been received. Likely areas include urban watercourse rehabilitation, landscape and planning, river restoration and fisheries, and river restoration case studies.

RRC was established in 1998 as a UK Centre committed to a proactive role in river management and restoration. Further information is available from RRC, Silsoe Campus, Silsoe, Beds, MK45 4DT *(email rrc@cranfield.ac.uk)*.

A new River Restoration mailing list has just been set up in JISCMAIL (the national academic mailing list), to act as a discussion forum for academics and practitioners in the field. Because it is new, there are few members, so feel free to join, and pass the message on to any other interested parties.

To join the list, send the message "join river-restoration FIRSTNAME LASTNAME" to *jiscmail@jiscmail.ac.uk*, or you can use the LISTSERV web interface – http://www.jiscmail.ac.uk/lists/river-restoration.html .

First Announcement
IGU Study Group conference
ENVIRONMENTAL CHANGE AND WATER SUSTAINABILITY
2 – 6 July 2001
Zaragoza, Spain

The International Geographical Union Study Group on Water Sustainability (formerly Environmental Change and Extreme Hydrological Events) is holding this five-day conference at the Instituto Pirenaico de Ecologia in Zaragoza, Spain.

The conference is calling for papers focusing on four major themes:
- Water management and sustainability
- The impact of reservoirs on water sustainability
- The effects of land-use changes on floods and low flows
- Sediment transport and water sustainability

The Conference is particularly concerned with changes in water quality and quantity, and hydrological régime in relation to environmental and human changes (climate change, land-use changes, increasing population, etc.). Water is a strategic resource, and the future health, livelihood and development of many people and countries in the world will depend on the way we manage both water and the environment. Water quality and quantity are very sensitive to changes in plant cover, farming systems and patterns of industrialisation. The main question is: How can we manage both the environment and water resources in order to ensure human development and sustainability? Fieldtrips to the Pyrenees and the Ebro basin are included.

Further details from: **Dr Tony Jones** at Aberystwyth (email jaj@aber.ac.uk).

Call for contributions
BHS National Meeting
CONTINUOUS RIVER FLOW SIMULATION: METHODS, APPLICATIONS & UNCERTAINTIES
5 July 2001
CEH, Wallingford, Oxfordshire

There have been recent advances in the development, application and delivery (to end-users) of catchment-scale continuous river flow simulation models and packages for a variety of applications. Uncertainties in model structures, model parameters and estimated flows are key issues. This full-day national BHS meeting will provide an opportunity for anyone developing and applying continuous flow simulation modelling to present their work to an interested audience in a semi-formal atmosphere, and to receive useful feedback. The programme will cover a range of modelling approaches and applications.

Please contact **Ian Littlewood** or **Rob Lamb** if you are interested in making a presentation at this meeting, giving a half-page (maximum) outline of your work. Each speaker selected will provide a short paper, which will be made available to those who attend the meeting. There may also be a post-meeting publication. This meeting may count towards CPD, but delegates must check this individually. Details of the programme, with registration forms, will be published in, or included with, the May 2001 issue of *Circulation*.

Contact: Ian Littlewood *(tel 01491 692385, fax 01491 692424, email igl@ceh.ac.uk)* or Rob Lamb *(tel. 01491 692402, fax 01491 692424, email rla@ceh.ac.uk).*

Call for abstracts
WWRP international conference on QUANTITATIVE PRECIPITATION FORECASTING (QPF)
2-6 September 2002
Reading, UK

Being able to predict precipitation accurately, in terms of both location and timing, benefits almost all of our global society and industrial sectors. Precipitation is responsible for many high-impact events, notably flooding, and the ability to have advanced warning enables us to provide valuable services, e.g. to agriculture, aviation, hydrologists and emergency response teams. Many advances in computational and modelling techniques are beginning to lead to significant improvements in QPF. It is timely to bring together supplier and user communities to share and review these achievements and to provide a focus for future developments in this field.

The Programme Committee (on behalf of WMO's World Weather Research Programme (WWRP) and the Royal Meteorological Society), is pleased to announce this international conference and to call for contributions.

A wide range of QPF-related issues will be covered, from measurement and forecasting of precipitation through to the application and benefits of quantitative information on precipitation fields, concluding by identifying gaps in current knowledge and key future areas of work. Abstracts are invited under these six topic headings:

- Socio-economic impacts and environmental stresses of precipitation events
- Precipitation measurement, estimation and associated issues from observing systems
- Nowcasting, including deterministic, conceptual and probabilistic methods
- NWP-based forecasting methods, including precipitation assimilation, resolution issues, post processing and ensemble methodologies
- Prediction techniques and predictability of extended range of seasonal forecasting
- Applications of QPF and demonstration of potential benefits to user communities

The deadline for receipt of abstracts is **28 February 2002.** Information about the Royal Meteorological Society can be obtained from *http://www.royal-met-soc.org.uk* or by email: *execsec@royal-met-soc.org.uk.*

Copy deadline for *Circulation* No. 69 2nd April 2001

Diary

22nd February 2001
Scottish Hydrological Group + SHSG
"Millennium Link – Forth-Clyde Canal: hydraulic & hydrological aspects"
Venue: Edinburgh
Time: 18.30
Contact: Dr Kate Heal, Inst. of Ecology & Resource Management, University of Edinburgh *(tel 0131 650 5420, fax 0131 662 0478, email Kate.Heal@ed.ac.uk)*

14th March 2001
Scottish Hydrological Group AGM
"Advances in low flow estimation"
Venue: Edinburgh University
Time: 18.30
Contact: Dr Kate Heal *(see above)*

5th April 2001
Scottish Hydrological Group meeting
"The Loch Lomond Water Supply Scheme, 30 years on"
Venue: Ross Priory
Time: 14.00
Contact: Dr Kate Heal *(see above)*

11th April 2001
BHS Southern Section meeting
"The Autumn floods of 2000 — initial reactions for the south-east"
Venue: Dept of Civil & Environmental Engineering, Imperial College, London.
Time: 17.30 p.m. (tea at 17.00)
Contact: Dr Adrian Butler, Dept of Civil & Env. Engineering, Imperial College, London SW7 2BU *(Tel 0207 594 6122, Fax 0207 594 6124, email a.butler@ic.ac.uk)*

2nd May 2001
BHS South West Section
"Urban hydrology"
Venue: University of Exeter
Time: 14.00
Contact: Sam Green *(tel 01392 443774, fax 01392 443231 email Sagreen@South-west-water.co.uk)*

16th May 2001
BHS National Meeting
"Hydro-ecology of managed rivers"
Venue: Birmingham University *(all day)*
Contact: Dr Chris Bradley *(tel 0121 693 2888, fax 0121 693 2889, email C.Bradley@bham.ac.uk)*

23rd May 2001
BHS Pennines Hydrological Group AGM
"Hydrodynamical methods"
Venue: Yorkshire Museum, York
Time: 13.00 for 13.30
Contact: Chris Kilsby *(tel 0191 222 5614, fax 0191 222 6669, email c.g.kilsby@ncl.ac.uk)*

13th June 2001
BHS Southern Section meeting
"Windsor & Maidenhead flood prevention scheme — presentation and site visit"
Venue: Environment Agency offices, 110-114 High Street, Maidenhead.
Time: 14:00
Contact: Dr Adrian Butler *(see above)*

18th–21st June 2001
Groundwater Quality 2001 (IAHS)
Venue: Sheffield University
Contact: Prof. David Lerner *(tel 0114 222 5743, fax 0114 222 5701, email gq2001@sheffield.ac.uk)*

5th July 2001
BHS National Meeting
"Continuous river flow simulation: methods, applications & uncertainties"
Venue: CEH Wallingford
Contact: Dr Ian Littlewood *(tel 01491 692385, fax 01491 692424, email igl@ceh.ac.uk)*

18th–27th July 2001
6th Scientific Assembly of the IAHS
Venue: Maastricht, The Netherlands
Contact: IAHS office *(tel +31 43 3619192, fax +31 43 3619020, email Cal.conferenceagency@ wxs.nl, website www.cig.ensmp.fr/~iahs/)*

Circulation supplement

Biogeochemical modelling of natural and enhanced remediation of groundwater

Scottish Hydrological Group meeting
22 November 2000
University of Edinburgh

This evening meeting of the SHG heard Professor Andrew Barry (School of Civil and Environmental Engineering and Director of the Contaminated Land Assessment and Remediation Research Centre, University of Edinburgh) describe his recent work with Henning Prommer.

In this interesting talk, **Andrew Barry** described developments in detailed geochemical modelling, which are being applied to further understanding and to make predictions about natural remediation of contaminated groundwater. Remediation of contaminated groundwater by natural attenuation involves leaving the groundwater alone and monitoring the contamination. Modelling is required for this type of remediation because hydrogeological and chemical data are expensive and also to maximise the use of the limited data available.

Another advantage of a detailed modelling approach is the design of better experiments. Many investigations of groundwater remediation use laboratory column experiments to study the adsorption of contaminants on media. However the results have little relevance to field situations, because adsorption is affected by many factors, e.g. pH. The detailed modelling approach, developed by Barry and **Prommer,** is PHT3D, a multi-component flow, chemical equilibrium and kinetic model, formed by coupling the groundwater flow model, MODFLOW, with the geochemical equilibrium model, PHREEQE, and kinetic chemical reaction models. PHT3D is being used to investigate remediation options for groundwater contaminated with the organic solvent TCE at a site in Belfast.

The preferred remediation option is a vertical reactive barrier of iron oxide (FeO), which treats groundwater flowing out of the site. However, the efficiency of the reactive barrier is expected to decrease with time due to clogging with iron precipitates. PHT3D is being used to model how changes in the mineralogy of the barrier will affect its porosity. Future developments of this integrated flow and geochemical approach to groundwater remediation will be improvements in computational efficiency and assembling a suite of validated examples.

Kate Heal
Institute of Ecology & Resource Management
University of Edinburgh

Review

Encyclopedia of Geochemistry
Edited by Clare P. Marshall and Rhodes W. Fairbridge, Kluwer, £40.

The Encyclopedia of Geochemistry is a new addition to the Kluwer Encyclopedia of Earth Sciences Series. The book attempts to cover the whole field of geochemistry, which has broadened significantly over recent years, not least in the area of low temperature geochemistry and human impacts, which are of interest to hydrologists. At the same time hydrologists are interested in the basic chemical/geological framework of the earth system and the reactions, which control water quality. The book is billed as "a reference text so that an expert in one field (of geochemistry) can look up information in other fields, or a non-geochemist can investigate a topic that is of interest."

As a text appearing at the start of the 21st century it can be regarded as a useful record and summary of the science of geochemistry to that time (see section on the history of geochemistry for example). In its very concept however, it treats the "parts" of geochemistry and does not really do justice to the whole: most of the advances in the science of geochemistry now concentrate on integration and earth system science, and Gaia theory for example is not covered (even dismissed) in this volume.

Thus the coverage of the Encyclopedia is strong in the classical fields of geochemistry such as petroleum, mineral genesis, hydrothermal systems. The length of each topic is inevitably limited although there is good cross-referencing to other parts of the volume. Areas of interest to hydrologists receive variable coverage: chemical kinetics are covered in three pages; colloids, complexes and equilibrium receive one page each, although geochemical thermodynamics receives six pages. Water (fresh) only receives one page! The Debye-Huckel equation however receives two pages, as does low temperature geochemistry. Taking one of these examples — low temperature geochemistry — we find that it encompasses the range from 0–300°C and from 1–1000 bars pressure! The section only has three subdivisions: isotopes and isotope fractionations, thermodynamic modelling and kinetic considerations. The hydrologist used to working with fresh water systems mainly in the 0–25°C range would therefore not find this reference helpful. Nevertheless, cross-references to other areas are given that may take one to areas of lower temperature interest such as oxidation-reduction *and* Eh-pH relationships.

The Encyclopedia is a good source of information on the range of absolute dating techniques used and which the editors cite as "geochemistry's greatest gift to humankind". Similarly the same holds true for most of the material dealing with stable isotopes of interest to hydrologists – carbon, hydrogen, oxygen, sulphur. There is however no reference of the applications in hydrogeology of noble gases.

An area well covered is that on the geochemistry of the elements, although the nature of the coverage is highly variable and of limited value to the hydrological reader. This is to some extent a result of the varied authorship of the chapters as well as the limits imposed on length, although some greater editorial control on the content of chapters could perhaps have been exercised. Thus boron (and its isotopes) is well covered but Cl and Br of some importance in water resources are only

briefly referred to. Similarly the coverage of strontium (and especially strontium isotopes) contains next to nothing for the hydrologist, despite the wealth of application to studies of hydrogeochemical processes.

In conclusion, the encyclopedia falls short of being a useful reference for the hydrologist or hydrogeologist and others working in the field of water quality, although it does meet its goal of providing insight into classical geochemical topics for the newcomer. Those chapters that are written by specialists with experience in hydrochemistry are inevitably of most value (Eh-pH relationships, isotopic fractionation, for example).

I would recommend the Encyclopedia for purchase by major libraries seeking coverage of the spectrum of the earth sciences, and this volume provides a geochemical companion to the *Encyclopedia of Hydrology and Water Resources* (eds Herschy and Fairbridge) already published. It does not replace in any way the up to date knowledge in low-temperature geochemistry, isotope applications and pollution, which has been well covered in several excellent texts in recent years.

W M Edmunds
British Geological Survey, Wallingford

A curriculum contribution to hydrological work experience

Do you want to work with student centred case materials that get students working in teams, and applying a range of personal and interpersonal skills such as team working, information handling, problem identification, creative problem-solving, negotiation and action-planning?

You might like to check out these case studies, which have been used with undergraduates and masters students. The cases were developed with the Environment Agency:

- 'Seatons' is about a chemical factory dealing with pollution issues. No chemistry is needed and this also works well with the general public and as a staff training exercise.
- 'Flood Defence' – two cases based on the River Lavant, Chichester floods.
- 'Flood Warning' – two cases about planning a flood warning regime.

Each case can be run in a 2-3 hour slot with appropriate briefing, or can be given to students in advance and then presented a week or two later. I use the four flood defence and flood warning cases as the assessments for a ten-credit university hydrology module.

You can download the tutor's notes and student's notes for all these cases from the university web site at ***http://www.geog.leeds.ac.uk/courses/other/casestudies/***.

The cases sponsored by the Environment Agency can also be found at ***http://www.environment-agency.gov.uk/education/studies/case.htm***.

The flood warning and flood defence cases are splendidly topical.

There are some more cases worth looking at on the Leeds University web site at ***http://context.tlsu.leeds.ac.uk/index.asp*** .

Pauline Kneale
University of Leeds
pauline@geog.leeds.ac.uk

Honour for Keith Beven

Congratulations to Professor Keith Beven, who is to be given the honour of receiving the John Dalton medal of the European Geophysical Society for "distinguished research in Hydrology reviewed as an earth science". This is only the fourth time the award has been made.

The previous recipients were Jim Dooge, Peter Eagleson and Ghislain de Marsily. It will be presented at the EGS General Assembly awards ceremony in Nice on 25th March.

Meetings

Fifth International Symposium on HYDROLOGICAL APPLICATIONS OF WEATHER RADAR
19 - 22 November 2001
Heian-Kaikan, Kyoto, Japan

The topics of this symposium are:

- Rainfall estimation and prediction using radar data
- Distributed hydrological modelling
- Hydroclimatic studies based on radar data
- Contributions of radar data to water management
- Emerging radar technologies and their hydrological applications
- Space-borne radar
- Operational experience in radar hydrology
- Coupling meteorological and hydrological models assimilating radar data
- Radar hydrology in urban areas
- Scale issues that radar observation can solve
- Advanced microwave technology for hydrological and meteorological observation
- Application for forecasting of dangerous hydrologic phenomena

The deadline for submitting an extended abstract is 7 May 2001. The registration form will be sent in June and decisions on acceptance of papers will be made in mid-June: the deadline for submitting a 6-page paper is then the end of September 2001.

Full-length papers will be reviewed for publication after the symposium as a special issue of *"Hydrological Processes"* through the normal editorial process of the Japan Society of Hydrology and Water Resources.

Further details are on the website: http://eie.gee. kyoto-u.ac.jp/users/nakakita/radarconf/5thconf.html, or contact Dr Dawei Han, Dept of Civil Engineering, University of Bristol, Bristol BS8 1TR *(Tel 0117 928 9738, Fax 0117 928 7783, Email d.han@bristol.ac.uk).*

Call for papers
Fifth international Workshop on APPLICATIONS OF REMOTE SENSING IN HYDROLOGY
October 2-5, 2001
Montpellier, France

The workshop will emphasise themes of remote sensing for characterising the hydro-environment (with emphasis on semi-arid, humid, cold regions); new sensors, and application of remote sensing to hydrological modelling.

To submit an abstract or register as a participant, please see the web site: http://hydrors2001.teledetection.fr/.

Abstracts are due by **30 April 2001**. If you participated in the last workshop at Santa Fe in 1998, you will be sent the proceedings. Copies may also be obtained from Brenda Doell, Publications Officer, NWRI/NHRC, Saskatoon (Brenda.doell@ec.gc.ca).

Contact for information: Raoul Granger *(Email raoul.granger@ec.gc.ca, tel (306) 975 5758, fax (306) 975 5143).*

Soil erosion

Autumn 2000 was one of the wettest on record, resulting in erosion of some spectacular gully systems in eastern England. For photos, go to http://www.silsoe.cranfield.ac.uk/iwe/erosion/Aut2000/erosion_in_beds.htm. Further information: j.quinton@cranfield.ac.uk.