THE NEWSLETTER OF THE BRITISH HYDROLOGICAL SOCIETY

Circulation

No. 54 May 1997

Low flows: towards a solution

BHS National Meeting
Environment Agency Head Office, Bristol
12 February 1997

Perhaps ironically, those who attended this half-day meeting on low flows had to brave strong winds and rain to get there, but more than 50 members and non-members did. The four papers were presented as elements along the low flow alleviation investigative "chain".

Quantifying low flows at gauged and ungauged sites

The first presentation was by **Andy Young** (Institute of Hydrology) and addressed the accuracy of calculated low flow statistics, such as Q_{95} and flow duration curves, which are tools at the disposal of hydrologists to quantify low river flows. Ideally long natural gauged records could be interrogated to derive flow statistics, but such flow gauges are unfortunately the exception rather than the norm. In the absence of long records, the Institute of Hydrology has developed a methodology, detailed in IH Report 108*, to derive low flow statistics. This uses multiple regression and up to twelve soil classifications, known as HOST groups, to generate low flow statistics. Micro Low Flows, a computerised GIS that includes drainage networks and HOST soil groupings, is used by seven of the eight Environment Agency regions to generate low flow statistics, and the GIS is now being extended to cover Scotland and Northern Ireland. Studies have shown that the HOST methodology estimates Q_{95} best for catchments that receive more than 1000 mm of precipitation annually.

The Institute of Hydrology and Edinburgh Hydropower Systems have recently completed a collaborative study using 90 natural and good quality gauging stations throughout Scotland. Assuming that hydrological years are independent and representative of the annual variability of the underlying population, analysis has been undertaken by constructing random assemblages of hydrometric years. If two years of natural and good quality data are available, the results of this method give a better estimate of mean flow than using traditional catchment-based indices, and a longer flow record will not produce significantly more accurate estimates of mean flow.

* IH Report 108, 1992, *Low flow estimation in the United Kingdom*, A. Gustard, A. Bullock & J.M. Dixon, Institute of Hydrology, £30.00

Defining an ecologically acceptable flow regime

Professor Geoff Petts (University of Birmingham) detailed the importance of understanding a river's flow regime when applying low flow statistics. Ecological diversity is a function of varying flow, for example flushing flows to provide nutrients, bankfull flows to maintain channel form, as well as summer flows to provide a haven for aquatic life. Recent advances in habitat modelling have reinforced the concept that end-of-summer flows are the most important when defining an ecologically acceptable flow regime. A variable flow regime is important to ensure that no one species will dominate a river's ecology.

Where possible, benchmark flows should be defined for wet, average and dry years. If you are able to protect the wet year the river population should survive dry years., Low flow statistics, habitat and geomorphological mapping and computer simulation can all be used to define benchmark flows; local knowledge from residents, anglers and users of a river can provide valuable anecdotal information. These data can be used to target those river reaches that are critical for the success of any improvement scheme. Studies should also examine the influence of channel design, man, compensation releases and biological controls when evaluating an ecological flow regime.

Flow threshold or control lines can be developed to manage the resources in a river. The lines should permit

varying river flows to maintain varied river ecology, and control lines can be placed to prompt when abstraction from the river is allowed or when augmentation releases are required.

Costs and benefits of alleviating low flows

John Samuel (Environment Resources Management Economics) detailed an ongoing study, for the Environment Agency in south-west England, which has examined people's willingness to pay for alleviating low river flows. The study used sentiments set out in the HM Treasury Appraisal document.

Physical impacts of low flows include the volume of water in the river and the fish stocks. Economic impacts of low flows include extra costs imposed on businesses (farms and water companies etc.), reduced value of enjoyment, reduced property values and 'anguish' caused by environmental degradation. Considering economic benefits enables low-flow alleviation projects to be prioritised, so that those with perceived high benefits can be undertaken first.

The study has established focus groups to assess public awareness of low flows and their willingness to pay for improvement schemes. These groups have shown (1) river pollution perceived as the main problem, (2) a low level of awareness of low flows, (3) no awareness of the causes of low river flows, (4) a feeling that low flows should be corrected, and (5) that people would be happy to pay for river improvement.

Field surveys quantified the impact of low flows on informal recreation (river walks and sports), anglers and property prices. Preliminary results have shown a general public willingness to pay for the alleviation of low flows, there is significant damage to property values adjacent to low-flow rivers and that the study methodology can be used in a CBA framework. Benefits were generally enough to justify a wide range of river management options, but not those involving heavy capital expenditure.

Low flow alleviation in practice

Luke de Vial (Wessex Water), **Dr Rob Grew** (Environment Agency) and **Paul Hodge** (Bristol Water) detailed the cause of low flows and a low flow alleviation scheme on the Malmesbury Avon. This river rises 40 km east of Bristol and drains a catchment of 300 km^2, underlain by Great and Inferior Oolite aquifers, which are heavily exploited by Bristol Water and Wessex Water. In recent years the number of complaints of low flow in the Malmesbury Avon has been increasing. Computer modelling of the catchment has shown that public water abstractions from groundwater were reducing river flows by up to 50-60%, and in April 1996 a Memorandum of Understanding was signed by Bristol Water, Wessex Water and the Environment Agency.

Since then all parties have been working together to resolve the low flow problems. Measures involving increases to stream support and changes to abstraction arrangements have undergone field trials. Bristol Water has temporarily reduced their abstraction at Shipton Moyne/Long Newton while Wessex Water has used its stream support boreholes to maintain target flows set by the Agency. Initial results have been promising but further work is required before changes can be implemented on a permanent basis. The Agency will be using its groundwater model to help address the sustainability of increased stream support.

Throughout the study the Agency has taken steps to involve the public. In 1991 it formed a river liaison group comprising eight local bodies, which has raised local awareness of the river by holding open days and exhibitions. It has published regular river bulletins and used local people in studies to assess the impact of abstraction on amenity and angling.

Conclusion

The meeting provided a clear demonstration that the application of appropriate theory and good local knowledge are perhaps the most important elements of effective low-flow alleviation. There is also a great deal of challenging technical work going on from disciplines as diverse as hydrology, ecology and economics, and the papers presented demonstrated that these varied specialities are required in order to identify fully-integrated low-flow alleviation solutions.

Graeme Boyce thanked all those who had attended and contributed to the meeting and especially Paul Sadler for chairing it.

Gordon Robb
SECOR

President's piece

I have just returned from the fifth IAHS Scientific Assembly, which was held in Rabat from 23rd April to 3rd May. It is worth remembering that these assemblies were first proposed by the UK delegation at the 1979 General Assembly of the International Union of Geology and Geophysics (IUGG) in Canberra. With enthusiastic support from the UK hydrological community and the Institute of Hydrology, the first Assembly was held in Exeter in 1982, and it was at that meeting that BHS was conceived and launched.

At Rabat there were six major symposia as well as five workshops. My own interests were in the symposium on "Sustainability of water resources under increasing uncertainty" and the workshop about "Scaling issues in the coupling of hydrological and atmospheric models".

In addition to the excellent scientific programme, attended by some 450 delegates, there were meetings of the IAHS bureau and two plenary meetings for all delegates. In my capacity as a member of the organising committee of the next IUGG General Assembly (to be held in Birmingham in 1999), I attended one of the bureau meetings. This concerned general arrangements for Birmingham, but more particularly, the formulation of the IAHS scientific programme. The programme is the responsibility of Professor Brian Wilkinson, and consists of five major symposia plus a number of workshops. The IAHS proposals, together with those from the other six Associates within IUGG, are to be discussed at a meeting of the IUGG Scientific Programme Committee in Birmingham in mid-September this year. Following the meeting the final programme will be known. I hope BHS will be able to take responsibility for one of the IAHS Symposia. This could perhaps take the place of the BHS biennial Symposium due to be held in 1999.

At the last meeting of the BHS main committee the reports of the three groups set up to consider the way ahead were discussed. As a result of the committee's discussions it is hoped that the content and format of future meetings will meet the perceived wishes of the membership. These three reports will also influence the general direction of future initiatives.

The Salford Symposium is now only four months ahead and it would be good if the attendance & enthusiasm matched the extremely successful Edinburgh meeting in 1995. The AGM will also be held in Salford on Tuesday 16th September, and I would urge members to respond to the request for nominations to the main committee, as well as to propose items for discussion at the AGM. The Society belongs to its members, and a measure of its success is the level of input which individual members make.

M J Hamlin

Long-term PET: is it worth the effort?

Hydrologists in various parts of the country are rushing around trying to produce long-term flow records and to reassess the yield of the country's water resources. Probably the only hydrologists not doing this are those who are waiting for the results! These long-term flow records are required to cover the drought of the early 1930s and to take account of even earlier droughts if possible.

Probably many of the flow records needed will be produced using rainfall/runoff models. Whilst it is obvious that rainfall data will be needed for the whole period of simulation, some people argue that there is no need to calculate potential evaporation (PET) values for the whole period, and that average monthly values will be sufficient. This is what I am examining in more detail in this article.

The data for the examination of this question come from a project I carried out in 1994 and 1995 for the Midland Region of the Environment Agency in conjunction with Acer Environmental. The main aim of this project was to produce a long-term flow record for the Trent basin as far as North Muskham. For this purpose, long-term monthly PET data were calculated, using the Penman formula, for the period 1918 to 1993, taking data from eight climate stations in, or close to, the Trent basin. All of the sites recorded temperature, most of them had sunshine hours and some also had wet bulb depression and wind data. Some of the eight "sites" used data from two nearby stations, which between them had operated for the whole period.

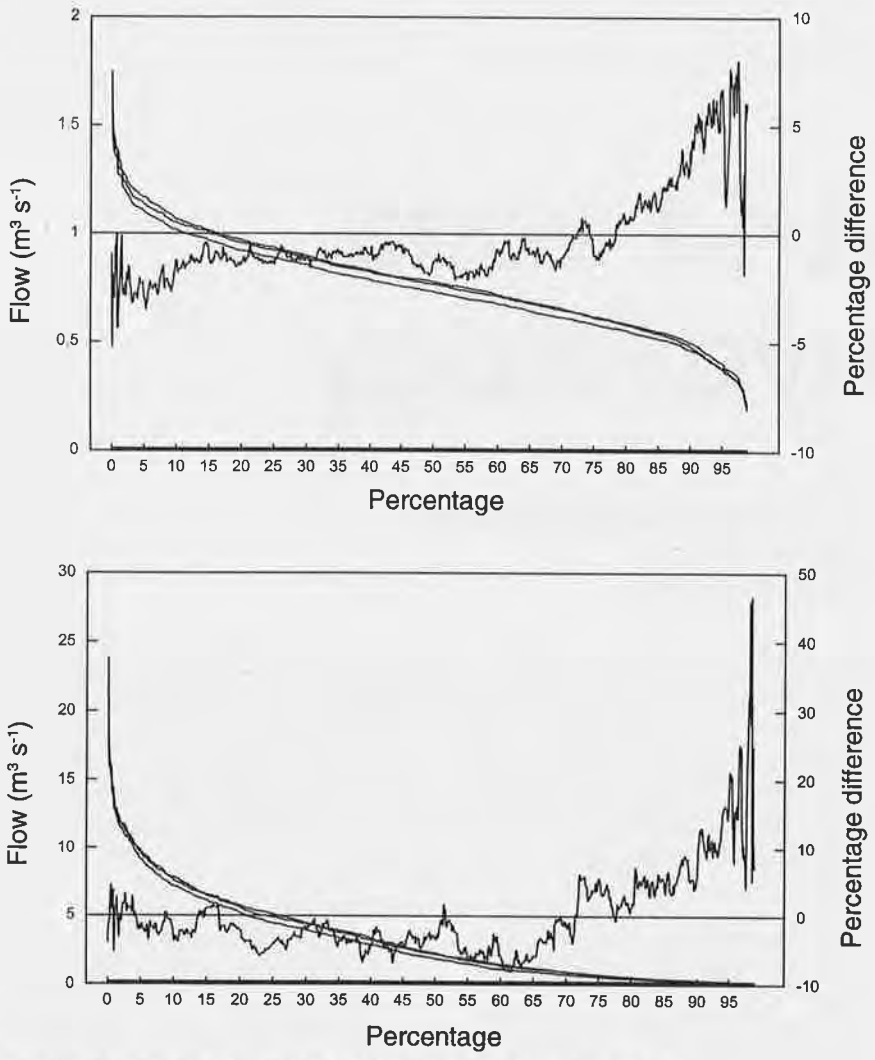
These data were used with daily rainfall, observed flow and artificial influence data to calibrate the HYSIM rainfall/runoff model. To arrive at a value for Colwick, 20 upstream sub-catchments were modelled. The model was initially set up to simulate both natural and artificial components of the hydrology, and was calibrated against the observed flow record over a six-year period. It was then used with the long-term data to produce a naturalised daily flow record from 1918 to 1993, the values for the first two years being discarded, since they would have been influenced by assumptions about initial catchment conditions.

To test the effects of using average, rather than historic, values of PET, three data sets were prepared for two sub-catchments. The first had calculated PET values for each month from 1918 to 1993, the second had twelve monthly average values based on the full 76 years of data, while the third also had twelve average values but based on the last ten years of available data (1984 to 1993). The two catch-ments were the River Wreake at Syston, a flashy clay catchment, and the Dover Beck at Lowdham, a sandstone catchment with significant groundwater.

The results are presented as flow duration curves (three smooth curves using the left-hand scale represent calculated, short-term and long-term PET) and as percentage errors (single fluctuating curve using the right-hand scale). To calculate flow duration and differences the daily values were aggregated to monthly mean flows. For the Dover Beck at Lowdham the two flow duration curves for the calculated and long-term average PET are close together for flows around the mean, but tend to diverge near the extremes. The use of the ten-year period to calculate the PET has introduced a systematic error: 5% for the Dover Beck and 10% for the River Wreake. The plot of differences shows that, the 95% dry flow is overestimated by around 5% when the long-term average PET is used rather than calculated values. For the River Wreake there are similar but more marked differences, with the 95% dry flow overestimated by around 15%.

No re-calibration of the model was done, and it is possible that if the model had been calibrated using average rather than calculated PET values then the different parameter values obtained would have compensated for this to some extent — however one could question the advisability of relying on model calibration to minimise shortcomings in the data.

Against this, it should be noted that the values presented above are based on the flow duration curves derived from each of the flow records ranked separately. A comparison of the differences between the simulated flow records suggests that errors are larger than this graph appears to indicate. The



Flow duration curves: calculated, short-term and long-term PET (three smooth curves) and percentage error (single fluctuating curve) for the Dover Beck at Lowdham (top) and the River Wreake at Syston (bottom)

standard error of estimate of the points on the flow duration curve was 0.013 $m^3 s^{-1}$ for Dover Beck and 0.109 $m^3 s^{-1}$ for the Wreake. The standard errors of estimate, comparing the flow records produced with the two data sets, were 0.038 $m^3 s^{-1}$ and 0.426 $m^3 s^{-1}$ respectively — around three times as large.

In summary:

- Using long-term average PET rather than calculated PET values introduces a bias in the flow duration relationship, with the 95% percentile dry flows overestimated by 5 to 15%;
- Using average PET values based on a short period (ten years in the above test) can introduce a systematic bias to the mean flows;
- Differences in simulated flows produced by the two methods are larger than the differences in the points on the flow duration curve.

The main conclusion from this (admittedly fairly brief) analysis is that when producing long-term flow records there are definite arguments for doing it on the basis of long-term PET data. These arguments are particularly strong in two cases:

- Where resources are being used conjunctively and it is important to know the historically deployable resources in each of the sources being considered;
- Where a catchment has little groundwater, and runoff is much more dependent on immediate weather conditions.

I wish to thank the Environment Agency for permission to use the data and results of a project carried out for them. The views expressed are mine and do not necessarily represent the view of the Environment Agency.

Ron Manley
Cambridge

New Members

We welcome the following members to the Society:

Arch, S.E.	Croydon
Birdsall, K.	Dept of Geography, University of Sheffield
Butterworth, J.A.	Staffordshire
Cargill, A.	Dept of Geography, University of Dundee
Cheesman, J.E.	Dept of Environment & Geology, Manchester Metropolitan Universty
Davies, G.	Hyder Consulting
Gasca-Tucker, D.L.	Jackson Environment Institute
Irvine, B.J.	Dept of Geography, University of Lancaste
Malcolm, R.	Dept of Geography, University of Aberdeen
Marshall, P.C.	Gwent
Mhango, D.H.Z.	Dept of Civil Engineering, University of Strathclyde
Michaelides, K.	Dept of Geography, King's College, London
Nicholson, L.T.	Jarrow, Tyne and Wear
Rebeiro-Hargrave, A.	Dept of Geography, King's College, London
Scarrott, R.M.J.	Sir William Halcrow & Partners, Swindon
Stark D.	Sir Alexander Gibb Ltd
Wainwright, J.	Dept of Geography, King's College, London

Arid zone hydrology

BHS Midlands Section meeting
Loughborough
4 December 1996

***Professor Ian Reid* welcomed a diverse group of approximately fifty academics, consultants and students to this Midlands Section meeting at Loughborough University. During the afternoon we were introduced to four speakers, whose presentations drew on work carried out on three continents and highlighted the scientific and practical challenges of managing water and water-borne sediment in dry areas.**

Dr Steve Twomlow, on behalf of himself and **Dr Patricia Bruneau** from the BBSRC Silsoe Research Institute, outlined current research in East Africa aimed at improving soil management in semi-arid agriculture. Inability to retain seasonal precipitation inputs is the key limitation to productivity in many semi-arid areas.

Their presentation highlighted the socioeconomic constraints on management solutions in regions where an outlay of as little as $25 by the farmers may be untenable. In such an economic setting, simple traditional practices (using existing hand hoes and ploughs for weed control) can be very powerful water conservation tools: applying management techniques developed elsewhere may be less successful. For example, detailed measurements show that tied ridge systems developed in North America to conserve soil (rather than moisture) minimise soil loss but do little to enhance crop yields. Early in the growing season the traditional flat cropping system may be more appropriate, as it retains more wet-season rain through the critical germination period. Producing tied furrows between crop rows after germination may then prove beneficial in reducing soil erosion.

Turning from soil moisture to surface runoff, **Dr John Wainwright** (King's College, London) presented the results of field experiments carried out with **Professor Tony Parsons** (Leicester University) and **Professor Athol Abrahams** (SUNY, Buffalo) at the Walnut Gulch facility in Arizona. They studied the impact of vegetation changes (wrought largely by cattle overgrazing) on surface runoff characteristics and hillslope erosion in the American Southwest. Grasslands have been replaced by shrubby communities: although these provide greater ground cover, they are associated with order-of-magnitude increases in runoff and sediment discharge.

This paradoxical situation stems from the uniform pattern of infiltration and more diffuse overland flow generated on grassed slopes. Shrubs

funnel precipitation into distinct pathways, leading to rapid surface runoff and the development of inter-shrub swales. Flow threads that follow these swales may then reach critical flow depths and generate shear stresses that can mobilise lag pavement particles. Subsequent entrainment of relatively more mobile material beneath the surface elevates sediment yields and leads to rill formation.

The team's efforts are now focused on modelling these processes. A key problem is adequate characterisation of empirical parameter values, including friction factors and infiltration rates. Contrary to other studies, initial work suggests that scaling from the experimental plots is not so problematic.

The third speaker, **Dr Howard Fox** (Derby University), gave a colourful account of work being carried out with **Dr Heather Moore** (also of Derby) on the semi-arid catchment of Oued Massa in southern Morocco. Dam construction for irrigation in the upper part of this basin has led to a sediment deficit and reduced peak flows in the lower channel. Consequent changes in channel morphology and estuarine ecology provide an interesting quandary for the National Park authorities who manage the site, and have attracted the interest of the RSPB, who are part-funding the research. Between infrequent flood events, the subdued flow regime of the lower Massa cannot prevent the development of a river-mouth barrier bar, which impounds a freshwater lagoon in the estuary. This is accompanied by a rise in duck and coot populations, which the Park authorities are keen to encourage. The question then arises of how the estuary can be managed to preserve the freshwater lagoon and prevent its replacement with brackish waters when flood flows periodically breach the barrier bar. Several hard and soft engineering options have been suggested.

Finally **Dr Mark Powell** (University of Leicester) described research into water and sediment yields in the Northern Negev desert, conducted with **Professor Ian Reid** (Loughborough) and **Professor Jonathan Laronne** (Ben Gurion University). Dr Powell pointed out the difficulty of obtaining fluvial field data in an environment where flow events are rare and unpredictable.

The consequent paucity of information about the hydrological and sedimentological behaviour of ephemeral semi-arid streams has implications for water and sediment management. Automated sediment and water sampling instruments are required, and have been installed by the team on the Nahel Eshtemoa in southern Israel in an attempt to improve understanding of the relations between sediment load and wadi hydraulics. Over a four-year period the Birkbeck bed-load samplers, suspended sediment samplers and flow instruments have collected data for nineteen discrete flow events. The stream is hydraulically active for an average of seven days per year and reaches bankfull for only eleven hours per year.

Sediment discharge is very sensitive to excess shear stress, and bedload transport rates are high at even modest (two-thirds bankfull) flows. Thus, even though flow events are rare and short-lived, sediment transport rates are high: the average specific sediment yield is 472 t km^{-2} y^{-1}. Sediment discharge is also highly variable between events: half of the total sediment yield for the period was produced in a single flood, and the three largest floods contributed 85% of the total yield. The team hope that continued monitoring and new ventures will help to answer questions about the role of river bed texture in moderating sediment yields, and will also be of wider management benefit.

Each talk generated questions on the scientific nature of the research projects, their instrumentation and methodology, and the management implications of the results to date. Discussions continued throughout the refreshment breaks and (from eaves-dropping on conversations at the end of the afternoon) it was clear that despite the focus on dryland hydrology, the afternoon had planted seeds in fertile ground.

Stephen Rice
Loughborough University

Water resource management for arid and semi-arid regions

BHS Southern Section meeting
Imperial College, London
22nd January 1997

In the month when President Mubarak of Egypt announced that Egypt was intending to pump six billion gallons of water a day from Lake Nasser to irrigate 500 000 acres of the Western Desert, and Jordan announced that it is pressing forward with plans to link the Red and Dead Seas, it was apt that the BHS Southern Section should have arranged an evening talk on water management in arid and semi-arid regions.

The evening focused on two contrasting regions. **Tim Hannan** addressed the problems of managing irrigation development in an arid environment in Turkmenistan. **Tim Jolley** investigated the problem of sustainable water resource management in the Badia region of Jordan, currently experiencing extreme pressures from municipal and agricultural demands.

Tim Hannan has just returned from Turkmenistan, where he was project manager for Gibb International on a World-Bank-funded project to improve water management of the Karakum canal and its associated irrigated areas. The socioeconomic development of Turkmenistan has depended on irrigation since 2000 BC. During the first century AD came perhaps the two most significant developments: the Muslim Arabs introduced cotton to the region and they developed relatively sophisticated technologies for lifting, storing and transferring water. From then on, the future of Turkmenistan has been inextricably bound to the demand for cotton and the availability of water.

The system was destroyed by Genghis Khan in the 13th century and only after the Russian revolution in 1906 was the irrigation system redeveloped through mechanisation and the introduction of fertilizers. It was the Russians who proposed the Karakum canal, to reduce dependence on the highly seasonal flows from the Kopet Mountains by diverting water from the Amu Darya river (Figure 1).

During the Second World War,

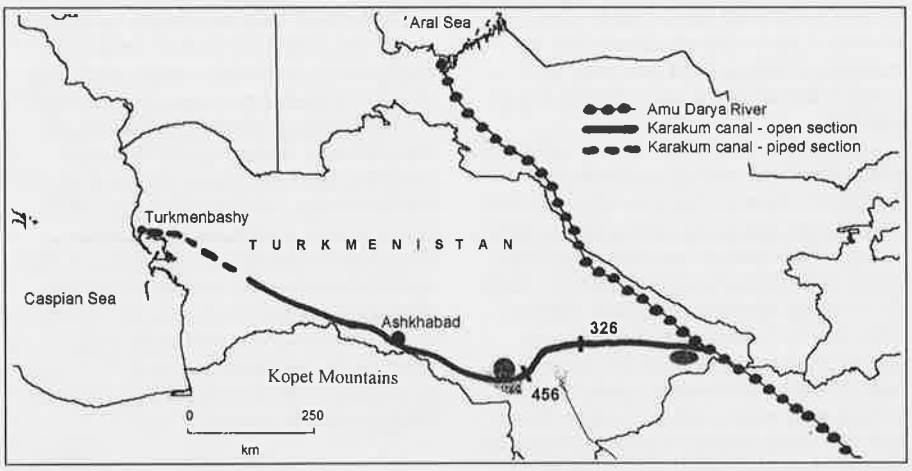


***Figure 1** The Karakum canal, Turkmenistan*

irrigation development stagnated, but it began again during the 1950s with the construction of the Karakum canal. Between 1950 and 1970 the region saw unprecedented development, driven primarily by the Soviet military's demand for cotton and their expansionist policies. The completion of the canal led to the drastic fall in water levels of the Aral sea after 1960 and the subsequent destruction of its ecosystem and the dependent fishing industry. The situation was not helped by the low efficiencies of the canal and the control structures (30 to 35%). In other words about 70% of the water being diverted away from the Aral sea was not reaching its intended destination.

The break-up of the Soviet Union in 1989 has created a number of water management problems. The military demand for cotton has greatly reduced and Turkmenistan, left with 1.5 Mha of cotton, has had to compete within a global market. While Turkmenistan is solely responsible for managing and maintaining the canal, it no longer has the subsidies and technical assistance that were formerly available.

Moreover, the Aral Sea is no longer just a regional problem — it lies within two nations (Kazakhstan and Uzbekistan) and is affected by the water resource management of five nations.

The Turkmenistan Irrigation and Drainage Project, funded by the World Bank and managed by Gibb International, is focused on improving the efficiency of the Karakum canal. There are three components to the project: irrigation and drainage management of secondary, tertiary and farm level distribution systems; the hydraulic operation of the main canal; a feasibility study and detailed design of two new control structures.

The poor management of secondary, tertiary and farm level systems has led to extensive waterlogging of soils and consequently high levels of salinity and poor crop yields. The project proposes the development of adequate drainage infrastructure and improved control of water allocation. The difficulty in controlling day-to-day operation of the main canal is the main reason for poor control of water. Tim attributed this to its sheer physical size: the canal is 1100 km long (linked by a 200 km pipeline to the Caspian sea), 250 m wide at its inlet and designed to convey a peak flow of 650 m^3s^{-1}. It is constructed in unconsolidated aeolian sand and therefore maintenance costs are high and transmission efficiencies are low. In fact little attempt is made to control the flow, and the canal operates continuously at maximum flow.

The second element of the project aims to improve the level of control of flows in the main canal. The hydraulic model ISIS was used to develop a one-dimensional hydrodynamic model of the canal, in order to investigate alternative operating strategies. Tim summarised the recommendations of the first phase of this study. Canal conveyance and timing of diversions are crucial to control water distribution; the control of high velocities is essential to minimise maintenance costs and finally, in-channel storage cannot be neglected when operating canals of this scale. The ultimate objective is to use the model together with telemetry to control flows on a day-to-day basis. However, many of the hydraulic controls are in extremely poor condition and have only remained in operation thanks to the dedication and ingenuity of local engineers.

The third component of the project will help to rectify this problem by replacing the control structures at kilometres 326 and 456, at an estimated cost of $60 Million and taking three years to complete. In contrast the completion of the drainage infrastructure would cost $2000 per hectare (a total cost of about $2 billion) and take many more years to complete. To develop an operational system for the main canal will cost less than $3 Million and take about three years to complete.

Tim concluded by reflecting on the future. To allow more water to reach the Aral Sea, diversions must be reduced, but are we prepared to spend the $2 billion needed to improve irrigation efficiency sufficiently? Why do we want to rehabilitate the Aral Sea? Who should pay for it? It was clear from Tim's talk that the economic state of Tukmenistan is so serious that it is unrealistic to expect them to place the future of the Aral Sea before their own economic survival.

A number of questions were asked about the efficiency of the irrigation system, the levels in the Aral sea and research into crops demanding less water than cotton. Tim said that the majority of water was lost from the secondary, tertiary and farm level systems, while perhaps only 10% was lost from the canal itself. Water levels in the Aral Sea are directly attributable to these losses, but consideration must also be given to diversions from the other rivers draining to the sea in neighbouring states. An increase in the irrigation efficiency to 70% could double the yield of cotton, but there may not be a market for it. There are moves to diversify to less-water-intensive crops, but the high salinities and sandy soils are not suitable for many other crops.

Tim Jolley's presentation was on the Badia Research and Development Programme (BDRP) in Jordan, jointly sponsored by the Royal Geographical Society and the Jordanian Government. The BDRP's objective is "the sustainable development of the desertified Badia environment and the improvement of the standard of living of the inhabitants".

This is the Jordanian 'outback', the region east of the Jordan Valley, with Syria to the north, Saudi Arabia to the south and Iraq to the east (Figure 2). It is the transition zone between the Mediterranean climate of the Jordan Valley and the fully arid climate of the desert areas of far-eastern Jordan. Mean annual rainfall is less than 50 mm a^{-1}, 80% of which falls between December and March. Evaporation is over 50 times the mean annual rainfall. Temperature ranges from a mean annual maximum of 35-38°C and a minimum of 2-9°C. It is therefore, by definition, an arid region.

The BDRP area covers about 14% of Jordan, centred on Safawi, a village on the main Amman-Baghdad road. This was a former pumping station on the Baghdad-Haifa oil pipeline, and the BDRP's field centre is in the old oil company buildings. To the northwest of the programme area the land rises to 1100-1200 m on the Jabal Druz and continues to rise into Syria; elevation in the south, along the Saudi Arabian border, is 400 m. The annual rainfall pattern reflects the topography, decreasing from above 200 mm a^{-1} in the north to less than 50 mm a^{-1} in the south (exact figures are not known).

The programme area covers three major basins: the Hammad (east), Wadi Sirhan (south) but mainly the Azraq basin, which also stretches into Syria (Figure 2).

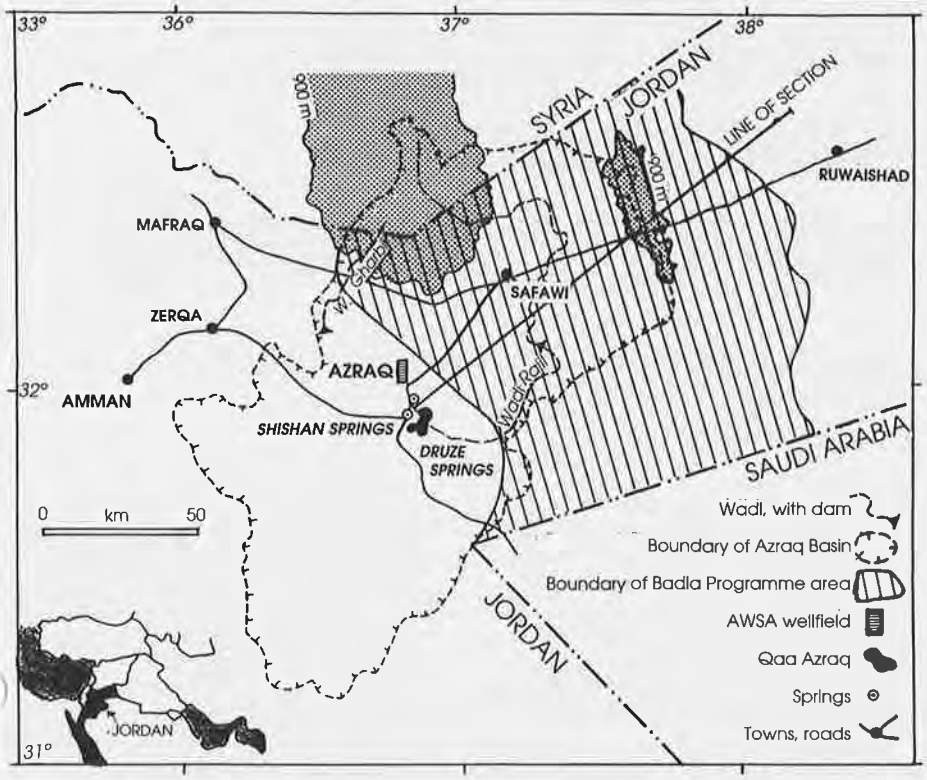


Figure 2 *The Badia Research and Development Programme, Jordan*

Water resources comprise the upper, middle and lower aquifers (Figure 3), seasonal wadi flows and local precipitation. The demands on these resources are domestic use, livestock watering, irrigation and evaporation within the Badia and water supplies for the cities of Amman, Zerqa and Mafraq. Groundwater flow is towards Azraq, once the site of an extensive oasis, but abstraction to supply Amman has made it barely distinguishable from the rest of the desert. A conservation project (funded by the United Nations Development Programme) is pumping water into two small pools in an attempt to regenerate the Azraq oasis.

The quality of groundwater from the upper aquifer is extremely good and can be used for drinking and irrigation but current abstraction rates are unsustainable. Abstraction and natural discharges amount to 58.9-65.1 $Mm^3 a^{-1}$. Several attempts (from the limited data) have estimated recharge at 0-64 $Mm^3 a^{-1}$! The water of the middle aquifer is more saline but is suitable for irrigation. However, it is thought that exploiting this aquifer may induce leakage from the upper aquifer. The water of the lower aquifer, from depths in excess of 1 km, is highly saline and unsuitable for irrigation.

Tim then described the options available to the Programme to meet the challenge of providing 'sufficient water for local needs without aggravating the problems of over abstraction at Azraq'. He suggested that perhaps the Azraq Oasis is damaged beyond repair and attempts at conservation may be pointless. He also questioned the rationale of using valuable groundwater to grow vegetables in the Badia, which cannot compete, in economic terms at least, with those from the Jordan Valley.

Tim identified the lack of hydrological data as the main constraint on quantifying sustainable yields for existing and future water resources. For example, there are only three recording raingauges in the project region (11 000 km^2) and no flow gauging has ever been carried out in the Badia region as a whole. Future work will be aimed at improving the gauging network for rainfall and wadi flows to give an idea of the temporal and spatial characteristics of flows and to begin to quantify recharge and the volumes of water that would be available for surface water harvesting, a technique which has been used to support large communities in the area since as long as 5000 years ago.

The BRDP has identified surface water harvesting as a promising way to enhance the water resources within the Badia without effecting the yield of the upper aquifer. Evidence from hydrogeochemical data and water balance studies has shown that recharge occurs at elevations above 850 m (i.e. in the north of the region). Hence, it is thought that wadi flows at elevations of below 850 m are an untapped resource. The efficiency of surface water harvesting is being investigated by the BDRP; with the aim of holding back some of the wadi flows that currently flow through the region relatively unused for local supply and maybe also to enhance groundwater recharge.

Tim concluded by emphasising the different scales at which water resource sustainability can be addressed. In the case of the Badia, local sustainability may be achieved by developing water harvesting schemes. However, regional water resources would still be unsustainable, because of the imbalance between abstractions and recharge from the upper aquifer. The regional and local scale sustainability depend on national and international policies. For example, abstractions from the upper aquifer could be reduced if additional supplies for Amman were made available. Tim mentioned schemes to link the Red and Dead seas and to transfer water from the Euphrates. Furthermore, in the case of the Badia, local sustainability could be affected by the development of irrigation schemes in the Syrian part of the Azraq basin.

Ron Manley asked why the BRDP was focusing on providing water for

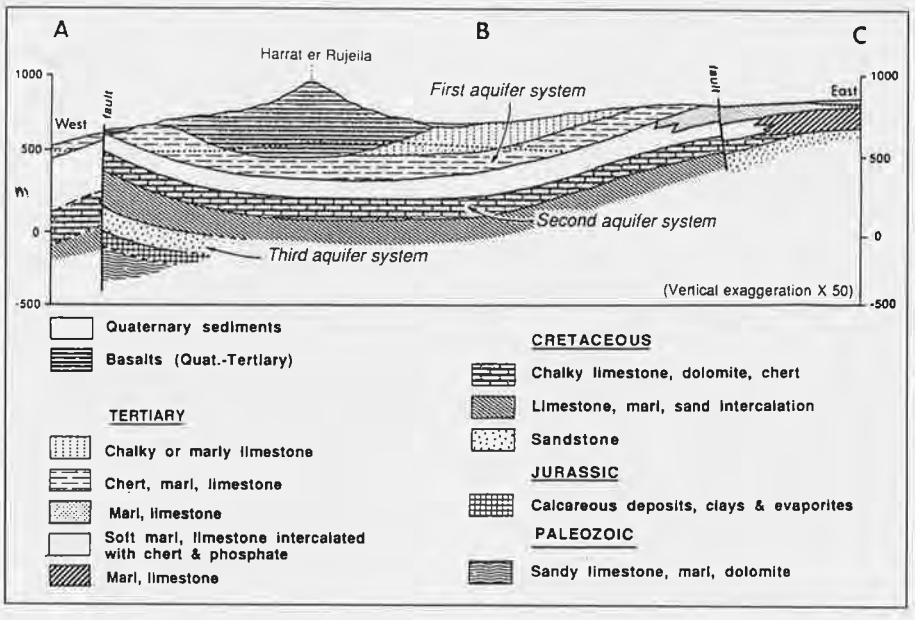


Figure 3 *Cross-section of the main aquifers of the Badia, Jordan*

local domestic use and livestock watering when the most significant users of water were the Water and Sewerage Authority of Amman and irrigators around Azraq. Tim replied that although water supplies to Amman make up 31% and irrigation around Azraq 46% of abstractions from the upper Aquifer, the BDRP has a local focus. These large abstractions cannot be controlled by the programme and it is beyond the scope of the project to include a national analysis. However, he agreed that the water policy in Jordan does need reviewing and that overabstraction at the basin scale need not prevent local development, provided alternative sources can be found, such as the surface water harvesting.

Roger Simpson had been involved in the Azraq Water Conservation Project in the 1980s and to his knowledge the oasis had never extended in recent history beyond the two small ponds shown by Tim. Roger went on to develop the international and political theme of the evening by presenting a brief resume of his recent visit to Iran.

Adrian Butler closed the meeting by thanking the two Tims for their interesting and thought-provoking presentations.

Tim Jolley & Daniel Haynes

Water supply: sustainability, quantity & quality

Scottish Hydraulics Study Group One-day Seminar Edinburgh 21 March 1997

Seventy-five delegates attended this timely seminar which explored some of the latest developments in research, technology and practice for the water supply industry in the UK. The day's programme was organised by the Scottish Hydraulics Study Group, sponsored by CIWEM, and particularly well orchestrated by the Chairman, John Riddell of Strathclyde University.

It began with a keynote address by **Duncan Macdonald**, who admirably introduced many of the ideas to be explored by the speakers and focused attention on the water supply industry in Scotland. The seminar themes were then covered by eight papers, delivered by **Robin Wardlaw, Mark Randall-Smith, John O'Donnell, Brian Gill, Ralph Strafford, Francois Bouchart, Ross Dalgleish** and **Hilary Smithers**. A collection for Water Aid (organised by Hilary Smithers) raised the sum of £105.

Further information about this meeting (including bound copies of the Proceedings at £20 each — cheques payable to the Institution of Civil Engineers) is available from Dr Steve Wallis, Department of Civil & Offshore Engineering, Heriot-Watt University, Edinburgh, EH14 4AS (tel 0131 449 5111 x 4430, fax 0131 451 5078, e-mail stevew@civ.hw.ac.uk).

Movement of sediment from hillslopes to estuaries

BHS Midlands Section Meeting University of Birmingham 5 March 1997

This half-day meeting brought together eight speakers on a range of topics under this theme. *Professor Angela Gurnell* organised and chaired the meeting, which was attended by over fifty people.

The first speaker, **Sue Charlesworth** (Coventry University), gave a joint paper with **Joan Lees** entitled "Tracing sediment sources in urban headwater drainage basins using sediment-associated heavy metals and mineral magnetics". Twelve cores from two urban headwater lakes in Coventry (Wyken Slough and Swanswell Pool) were analysed for heavy metals and mineral magnetics to investigate whether mineral magnetics could be used as a surrogate for heavy metals.

Regression and multivariate (PCA) techniques were used, but no relationships between heavy metals and mineral magnetics were found except weak ones. This prompted investigation of sediment sources in the urban environment to establish whether associations between heavy metals and mineral magnetics were present in these sediment sources and if so why they were absent in the lake sediments. The main urban particulate sources (collectively referred to as street dust) include the atmosphere, soils, vehicles and the surrounding roads and pavements. Particle size of bulk street dust appears to be important, since the fraction <63 mm exhibited no relationships between heavy metals and mineral magnetics, while the dust <2 mm did show an association. The lack of correspondence between heavy metals and mineral magnetics in the urban lake sediments was suggested to be the result of modification of the source sediments during transit (a conceptual model for this was presented), of biogenic and authigenic minerals and diagenetic processes following deposition.

The issues of scale in hydrology were raised by **Steven Wade** (Kings College, London) in his thought-provoking joint paper with **Ian Foster** and **Serwan Baban** (Coventry University) on "The impact of scale on nutrient transfers in Midland England catchments". They discussed the impacts of nitrogen, phosphorus and sediment transport on drinking water quality, eutrophication and channel navigation, respectively. Two examples from the Midlands (Bourne Brook, which drains into the headwaters of the River Trent, and the upper River Avon) highlighted the importance of understanding

catchment nutrient transfers. The effects of basin scale on nutrient transfer were investigated based on analyses of a secondary national data archive, although certain difficulties were noted.

Damian Lawler (Birmingham University) encompassed the work of three former research students, **Louise Bull** (now at the University of Leeds), **Neil Harris** and **John Couperthwaite**, in a paper on "Bank erosion rates and hydraulics in the Upper Severn". Bank erosion is a possible key source of sediment and hence an important component of the fluvial sediment flux.

Monitoring problems resulted from the episodic nature of bank erosion and the difficulties in attributing these aperiodic events to specific points in time. The photo-electric erosion pin (PEEP) monitors the extent of exposure of a series of photosensitive sensors buried in the river bank and provides an automatic continuous monitoring technique which overcomes the sampling problems. Results from PEEPs in the Upper Severn show that bank erosion occurs in response to bank hydrology and sedimentology (influencing erodability), cantilever failure and progressive entrainment processes, as well as fluid entrainment.

These mechanisms may account for the temporal separation (lag) between the peak in flow hydraulics and bank erosion. Automatic continuous monitoring techniques could improve our understanding of geomorphological processes.

Joan Lees presented a paper with Ian Foster on "Changes in sediment yields and sources in headwater drainage basins of the Ouse (Yorkshire) and Tweed catchments over the past 100 years". This research forms part of the RACS (Rivers Atmospheres Coasts Study) protocol of LOIS (Land Ocean Interactions Study). Sediment core data (mineral magnetics and radio-nuclides) were obtained from three upland sites (Elleron Lake, Boltby Reservoir and Newburgh Priory Pond) to elucidate temporal variation in catchment sediment sources and yields. Historical maps were used to identify land use changes over the last 100 years.

Sediment yield rates ranged from 0.10-0.20 cm a^{-1} at Elleron Lake, 0.1-0.35 cm a^{-1} at Boltby Reservoir, but were relatively constant at Newburgh Priory Pond. Sediment sources were identified as woodland and pasture topsoil erosion plus channel bank material at Elleron Lake, forest topsoil erosion related to the afforestation at Boltby Reservoir and channel bank sediment at Newburgh Priory Pond. These in-channel sediment contributions will be analysed in relation to precipitation records and historical channel change to corroborate the sediment core evidence.

Following the tea-break came Ian Foster's paper on "Sediment transfers and budgets in the catchments of Slapton Ley and the Old Mill reservoir, Devon: a multi-tracer approach". Ian concentrated on identifying sediment sources and sinks to calculate sediment budgets. The two catchments have similar lithologies and land uses (a landscape mosaic of small fields) with headwaters in a deeply incised plateau, but they produce contrasting sediment yields and budgets. Caesium-137 was used to date and cross-match lake and reservoir core records from the two catchments; while mineral magnetics were used to source sediments.

Sediment yield for Old Mill was relatively high (90 t km^2 a^{-1}) for an arable system, and in comparison with Slapton Ley (20 t km^2 a^{-1}). This probably relates to an increase in cattle and expansion of arable land use with removal of sediment-trapping hedgerow boundaries in the Old Mill catchment, and floodplain storage in the Slapton Ley catchment. Catchment sediment sources were variable, with obvious implications for development of mixing models. The effects of particle size, modification during transport and diagenetic processes on mineral magnetics were also evaluated.

Geoff Petts (University of Birmingham) presented a paper entitled "Storage of fine sediments in river bed gravels", which considered the stream bed interface within which groundwater and river water interact. This hyporheic zone, extending up to several kilometres away from the river in some instances, is ecologically important (for spawning and as a refuge for invertebrates) and acts as a filter for fine sediment. Nevertheless it is difficult to characterise the role and storage of sediment at this interface because of the dynamic nature of river beds and qualitative nature of much research into siltation.

Data were presented from a ten-year study in south-west England using freeze-coring techniques to sample bed material (since traditional grab samples may lose >90 % of sediment <2mm). The results illustrated the variability of bed siltation in space and time over riffles, and revealed the complexity of fine sediment transport and deposition processes: individual riffles have differing affects on sediment trapping and storage. Siltation patterns could therefore be used as a basis to define a typology for riffles.

Angela Gurnell (University of Birmingham) moved downstream to consider "River channel adjustment to flow regulation across the fluvial-tidal transition". Historical maps, aerial photographs and detailed cross-sections were analysed to investigate spatial and temporal variation in channel geometry for 18 km of the River Dee meanders (on the Welsh border) over about the last 100 years. This section of river is affected by fluvial and tidal processes and the backwater created upstream of Chester Weir.

All the sets of evidence surprisingly showed that channel width decreases while channel depth increases downstream. This channel narrowing occurred earlier upstream and then propagated downstream, especially since the 1960s, in relation to the onset of flow regulation. Aerial photographs suggest that channel shrinkage has been accelerated by an increase in shrub and tree cover where farmers have allowed the natural vegetation to colonise the depositional areas. Spatial patterns in deposition were investigated by looking at the extent of within-channel depositional bars; the transition zone from fluvial to tidal influences seemed to stand out as a very extensive area of deposition. Deposition occurred on both stream banks within this and the downstream reaches (as opposed to either the left or the right bank further upstream), with cycles of bank erosion and deposition. Detailed surveys of the cross-section found three steps in the profile at which the width to depth ratio reached a local minimum. These three levels become less distinct in a downstream direction as the banks gradually steepen and the channel becomes narrower, and are associated with sediment deposition on the banks as a result of interactions between river flows and tidal overtopping of Chester Weir.

The final paper by **John West** (University of Birmingham) moved even further downstream to consider "Cohesive sediment transport in estuaries", focusing on the turbidity maxima at the point of interaction between saline sea water and freshwater from rivers.

This region of high suspended solids impacts upon photosynthesis and concentrates pollutants. Although the turbidity maxima may be modelled either one- or two-dimensionally, these models represent complex processes in a much simplified manner, which limits their predictive capability. John therefore went on to discuss in clear terms the numerous transport mechanisms moving sediment landwards (flow asymmetry, solute and suspended sediment induced turbulence suppression, gravitational flow, inter-tidal zone storage and flocculation), seawards (influenced by channel slope and fluvial advection) and the potential effect of waves. These processes were well illustrated using example from the Firth of Forth, Humber, Severn, Tamar and Trent estuaries.

Finally Geoff Petts summed up the general issues raised, thanked the speakers for the variety of their talks and thanked Angela Gurnell for organising the afternoon. The discussion then adjourned to the University's Staff House bar.

David M. Hannah
University of Birmingham

Wild rivers

Scottish Hydrological Group Meeting
Glasgow University
21 November 1996

The title of this joint meeting of the Scottish Hydrological Group (SHG) and the Scottish Hydraulics Study Group (SHSG) was taken from the recent WWF Scotland (World Wildlife Fund for Nature) Wild Rivers Initiative. This aims to encourage restoration of natural features to Scottish rivers — features that have been steadily eroded by human attempts (often futile or counter-productive) to control or engineer rivers. *Paul Jowitt*, Chairman of the SHG, introduced the speakers to an audience of 66, who later contributed to the lively discussion.

Elizabeth Leighton (WWF Scotland) introduced the theme of the Wild Rivers Initiative (WRI), which aimed to change river management by encouraging soft (environmentally friendly) rather than hard engineering solutions for flood defence. She addressed four main points, illustrating them with slides.

1. Why is it in the river engineer's interest to adopt such alternatives?
Extra (and perhaps unexpected) benefits could accrue from the soft approach: an example from the Netherlands showed ecological benefits; traditional attempts to prevent flooding had backfired on the Mississippi and there was now a new approach, working with (rather than against) the river, which was consistent with the aim to reduce flood damage rather than preventing any flooding at all, and in Scotland schemes are now being required ... "to have regard to conserving natural heritage".

2. What can be achieved?
The two main ideas were: (a) promoting land-use change to modify river edge activity, to address the cause rather than the symptoms: e.g. by not developing river corridors for housing and industry, flood plain inundation could be a viable way of reducing peak flood levels downstream; (b) taking notice of state-of-the-art research in techniques for better river management (examples were discussed later by Dr Pender).

3. When is it justified to use these alternatives?
It might not always be possible or viable to abandon traditional hard engineering solutions. Criteria needed to be defined in terms of safety, ecology and economics in order to assess the costs and benefits of new and traditional techniques.

4.What is the role of the Wild Rivers Initiative?
(a) to encourage more environmentally friendly river engineering, and (b) to work with others to restore natural features to Scottish rivers. This would be achieved by influencing legislative policy, identifying case studies and setting up demonstration sites so that proven benefits could be disseminated.

In conclusion, the use of environmentally friendly engineering solutions could give all-round benefits: for rivers, the natural environment and river engineers themselves.

Garry Pender (Dept. of Civil Engineering, Glasgow University) began by stating that river engineering needs to predict how rivers will behave, which requires knowledge of hydrology, hydraulics and sediment transport. The move towards environmentally friendly hydraulics grew from the 1989 Water Act and the requirement for the National Rivers Authority to promote conservation.

Attempts to encourage rivers to return to their natural or "wild" state could involve restoration (complete structural change), rehabilitation (partial structural change) or enhancement (local environmental improvements). Whichever of these was adopted, it was necessary to think about the "overall hydraulic problem" and the processes occurring in the natural environment.

Indeed, it was becoming clear that proper management of rivers needed additional scientific input, because sediment transport and habitat provision were not purely hydraulic phenomena. It was Garry's view that workable solutions required an inter-disciplinary approach, and the river engineer's role was as a coordinator, who needed to exploit the extra knowledge of, for example, botanists, biologists, geomorphologists and landscape architects.

Garry went on to review the work of the inter-disciplinary Glasgow University River Rehabilitation Group, with projects on the hydraulics of two-stage channels, fish habitat improvement schemes, the influence of fine sediment infiltration on fish spawning, river confluence re-alignments, meander cut-offs and graded sediment transport.

He stated that "environmental works do not necessarily equal fish": this reinforced his earlier ideas and neatly summarised the need to recognise how flora and fauna exploit the habitats provided by rivers, their sediments and flood plains, because by understanding these processes a better hydraulic solution could be found.

Garry's final theme was the difficulty and inaccuracies of predicting sediment transport. One obvious weakness of all traditional sediment transport formulae was the use of single-size sediment. Recent work at Glasgow University on graded sediment transport, using a hiding function, was making progress in improving predictive tools, but there was still a long way to go.

Summing up, he said that successful river rehabilitation works required an interdisciplinary approach, research into sediment transport and a database of post-implementation performance. At the end of the day, the river engineer needs to get it right!

Discussion

Trevor Hoey (Glasgow University) wanted to know how guidelines could be developed to help practitioners decide on the best approach to river engineering works. This seemed to floor both speakers! But clearly there were not enough data available to prepare such guidelines. **Alastair Moir** (Environmental Consultant) said that the objectives of river engineering works had changed markedly during his career — for example, after the war food production had outweighed any environmental concerns. He added that we could work with rivers to get them to do the job for us, and the speakers concurred, noting that society's perspectives have changed and there were now more powerful techniques at our disposal, including multiple-objective decision making.

Anne McCall (North Lanarkshire Council) asked how landscape architects could take on board all the ideas raised here. She was referred to examples of the "greening of river channels" and advised to visit demonstration sites. **Hassan Jasem** (Cardonald College) said that we could not always leave nature to go its own way: for example, uncontrolled channel migration would be threatening in some places (the Euphrates was an example). The speakers agreed that a balanced approach was required, and the dangers of extremes must be avoided.

Alan Werritty (Dundee University) asked if it was possible to design engineering works correctly, in view of the uncertainties involved — wouldn't schemes inevitably be over designed? Garry replied that some small-scale

works can be designed with confidence, but more monitoring of existing schemes was needed to assess design techniques.

Graham McInally (Babtie Group) agreed that post-implementation monitoring (PIM) was needed, but was not clear on the best way of disseminating the information gained. Schemes on the catchment scale in Scotland were often hampered by the difficulty of getting landowners and land users to agree. On the other hand, small-scale developments would be expensive if environmentally friendly solutions were implemented. This raised again the need for design guidelines and where they should come from.

Elizabeth thought that the Scottish Office should provide the focus, rather than Scottish Natural Heritage (SNH) or WWF, but Garry thought that much of the data could be provided by SNH, WWF and similar organisations, and he said that there were some published examples of PIM.

Alastair Cargill (Dundee University) suggested (principally to representatives of the Scottish Office) that, since Scotland has a large number of rivers which could be restored, there would need to be a coordinated and properly financed programme. **Alan Burdekin** (Scottish Office) responded that there were no funds at present, but he also doubted whether the public was in favour of the nation's rivers being returned to the wild. Elizabeth Leighton disagreed with that, and also noted that water quality improvements were often an added benefit of environmentally-friendly flood defence, which could be used as a focus for allocating spending. Graham McInally reminded the meeting that the Scottish Office were generally supportive of river engineering work, for example on the River Tay.

Paul Jowitt (Heriot-Watt University) said that we had a complex problem on our hands: he wondered whether a scheme could be designed to "wear in" in the same way as old schemes eventually "wear out". In particular, would clients be content with a scheme that would develop into a satisfactory solution over a number of years, by exploiting fluvial processes? Garry thought this was an interesting idea, but it was essential that any scheme survived the first flood, so the initial scheme would need to have most of the attributes of the fully developed one. Alastair Moir added that some of schemes he had worked on were still in place, while others had long since succumbed to the river. It was important to learn from previous experience, and monitoring would help prevent errors being repeated.

Alan Burdekin was concerned that replacing engineered sections of rivers with more natural features might raise upstream water levels, and even lead to prosecution under the 1930 Water Act. Garry thought that this could probably be designed out of most river rehabilitation schemes. Elizabeth took a wider view, looking at multiple objectives, where it could be argued that a large number of benefits would outweigh a few disadvantages.

Ronnie Falconer (Babtie Group) offered a consulting engineer's viewpoint. He thought financing of PIM should be built in from the start, which implied that the client would pay. He agreed that the extra benefits of environmentally friendly solutions (e.g. water quality improvements) were important, and that a balance was needed between flood protection and environmental improvements.

Trevor Hoey wound up the valuable and illuminating discussion, and handed over to Paul Jowitt to thank the speakers for an enjoyable meeting, raising a wide range of views.

Andrew Black
University of Dundee

Flood risk assessment

Scottish Hydrological Group Meeting
Strathclyde University
14 January 1997

A record attendance of eighty-two gathered to hear *Dr James Curran*, Head of Science for the Scottish Environment Protection Agency (SEPA), speak on Flood Risk Assessment (FRA).

At the outset, Dr Curran stressed that he was going to present SEPA's evolving ideas about FRA — these were not adopted policies — and he began with an overview of the role of hydrology within SEPA.

Before SEPA was formed in April 1996 there was no obligation on local authorities or private developers to seek FRAs — this was now considered a mistake. The recently published National Planning Policy Guideline document NPPG-7 states that developers should liaise with SEPA on FRA.

When SEPA came into being, it gained new duties and powers to assess flood risk: the 1995 Environment Act gave SEPA "the function of assessing as far as it considers it appropriate risk of flooding in any area of Scotland", where SEPA interprets "function" as a "discretionary duty". There will also be new flooding-related duties for local authorities, mainly related to maintenance of waterways, arising from the Paisley floods in 1994, which were largely caused by blocked culverts. There is therefore some confusion between the duties of local authorities and those of SEPA, and this is why SEPA must develop a policy on FRA.

What is SEPA trying to address in its policy? One of the major points is the legal implications of any action they take. For example, if an FRA produced by SEPA shows a particular piece of land to be at high risk from flooding, the price of that land will tumble, and the question arises whether SEPA will be liable for claims from its owners. Legal advice has stated that this is not the case, since SEPA will be doing its duty, so long as it is responding to requests for information.

One of SEPA's main aims is to gather as much information as possible about historical flooding events, including coastal flooding. Much of this comes from the former RPBs and concerns individual events, making it difficult to determine return periods. All these data will be put into a GIS, annotated with its reliability, since often the data are anecdotal. Clearly, one-off historical data cannot be relied upon solely, and SEPA needs to be more strategic. A potential model is the mapping project carried out by MAFF and the Institute of Hydrology (IH) in England and Wales. This maps areas flooded by 100-year events, distinguishing urban and non-urban areas. The mapping is not entirely accurate, relying on a DTM created by interpolation from OS contours. IH have recently completed a similar DTM map of the Scottish mainland. NPPG-7 states that local authorities should set up flood appraisal groups to assess this kind of information, and SEPA is willing to help with this.

SEPA have also considered new techniques, in particular aerial surveillance. They have agreed contracts to obtain stereoscopic aerial photographs of floods, from which height contours can be deduced quite cheaply. There is evidence that, for example, torrential rainfall events are more common now than in the 1960s,

and the DoE has therefore recommended a change in design codes and standards for FRA for new construction.

Finally, Dr Curran described the research and development programmes that SEPA are designing for FRA. These will look at some specific topics: a general assessment of networks to enable optimization; funding of a Flood Estimation Handbook for Scotland; potential collaborations to study satellite monitoring of snow cover and melting, and assessments of the usefulness of satellite imagery (particularly radar) in delineating flood envelopes. The work will focus on cost and benefit assessments and on sustainability.

This was a critical time for SEPA: Dr Curran hoped that a draft copy of their FRA proposals would be going out for public comment in the next few months, and he invited criticism and comments from the experts in the audience.

The discussion was opened by **Dr John Riddell** (University of Strathclyde): he thought SEPA should be taking a more active role, as the government had suggested, whereas they seemed just to be going to take data. The new local authorities had little knowledge about floods, and there seemed to be a gap between expectations and reality. Dr Curran said that SEPA faced big problems finding resources. It could do strategic work, but often had insufficient data. SEPA was willing to provide raw data or some basic interpretation, but could not say what should or should not be done. There was a possible knowledge gap, which might be plugged by Flood Assessment Groups within the local authorities, bringing in anyone they liked.

Alastair Moir (Scottish Office, retired) pointed out that SEPA could not allow or prohibit any development — this was the responsibility of the local planning committee, and flooding had always been regarded as a local matter.

David Nicholson (Babtie Group) wondered how SEPA viewed the concept of river basin management, as against local authority region management. Dr Curran said that catchment management was a good idea if a significant issue was at hand, and it was there in bodies such as the Firth Forums, but as a matter of course SEPA would rather avoid it.

Dr Andrew Black (University of Dundee) thought that soil mapping might delineate the edge of flooding areas — patterns of sediment deposition could give some clues as to flooding patterns. **Dick Johnson** (Institute of Hydrology) asked whether flood duration had been considered at all. Dr Curran said it was of secondary concern so far as damage costs were concerned and was not generally used in the equations.

Professor Alan Werritty (University of Dundee) referred to MAFF-funded models in England and Wales that did use duration in the cost equations. There must be a lot of historical flood data around in various hands that would prove very useful. In the short term, might it be possible to set up some kind of a mutual database? James Curran hoped SEPA could try to rake in data from local authorities and consultants, although commercial confidentiality would be a factor. Modelling, as has been carried out by IH, was also a possibility.

Yusuf Kaya (Babtie Group) asked whether the NPPG-7 statement that planning permission should not be given on flood plains would lead to green, very wide flood plains. James Curran's view was that it was not that restrictive: if it were it would pose a real problem in Tayside.

Richard Hackett (Edinburgh Hydro Systems) hoped that SEPA would provide confidence intervals associated with its flood data: Dr Curran agreed that SEPA certainly had a duty to attach 'health warnings' to the data it provided.

The evening was wound up by **Ronnie Falconer**, the new Chairman of the Scottish Hydrological Group, who led the audience in thanking Dr Curran for his interesting presentation.

Andrew Folkard
University of Strathclyde

Flood forecasting and modelling

BHS National Meeting
University of Exeter
13 November 1996

This meeting was planned to promote the activities of the Society in the South West Region. There were four presentations in the School of Engineering during the afternoon, which was chaired by *Dragan Savic.*

The first paper "MOFFS — A Management Overview of Flood Forecasting Systems" was presented by **Allan Lambert** (Consultant and past President). Allan described the origins and philosophy of the MOFF system and its historical development as a practical tool to assess flood forecasting systems.

The Typhoon Operation Experiment (TOPEX, 1979-1984) involved the World Meteorological Organisation (WMO) and the Tropical Storm committees, who wanted to develop a simple system to describe, monitor and assess the facilities and performance of individual Flood Forecasting systems for management purposes. Annual reports were compiled comparing the facilities and performance of individual systems, but the resources involved in the production and analysis of the reports proved too onerous and a simpler points system was developed based on the STIRIF system. Points are awarded for the components of the existing flood forecasting system (maximum) and for the required performance of the system (minimum) for individual flood events. The maximum and minimum scores are compared to produce a deficit score, which allows managers to focus and prioritise resources to improve the system. MOFFS has been applied in areas covered by the Tropical Storm committees throughout the world, including the Pacific Basin, Thailand and the USA. MOFFS has been published as WMO Technical Report No. 715 (1995) and is also available as a spreadsheet.

Tim Wood (Environment Agency) asked about the application of the system to the UK and Europe. Allan said that MOFFS had not been applied in Europe, but there was no reason why it could not be in future.

Roger Austin (Institute of Hydrology) asked how MOFFS could handle the improvement in technology over time. The system did not specifically address this issue, and Allan felt it was more likely that the minimum required performance of the system would change over time.

Professor Keith Beven (University of Lancaster) presented the second paper on "Real-time forecasting of flood inundation with uncertainty". He described the problems associated with the calibration of distributed environmental models using multi-parameter optimisation methods and alternative Monte Carlo simulation methods.

Traditional multi-parameter

optimisation searches for a single set of parameters which can be used for a variety of system responses. Experience of environmental modelling has shown that parameter surfaces can be relatively flat, and so it is possible to calibrate parameter sets for individual events, making it difficult to select an optimum set for real time event modelling.

Monte Carlo methods do not try to determine an optimum set of parameters, but generate a large number of model runs using randomly selected parameter values. The results are compared to the recorded result and are allocated a goodness of fit (GOF). The GOF values are used to update the model parameters and predictions within real time and investigate the model performance for a range of forecast periods. Two examples using Monte Carlo methods were presented: the River Culm in Devon and the River Imera in Sicily.

Richard Horrocks (Environment Agency) asked how suitable these techniques were for operational catchment-scale flood forecasting? Keith commented that these techniques were suitable for modern parallel PC systems and were close to be being able to be used for operational flood forecasting with current technology.

The third paper, "WRIP2 – real-time forecasting using genetic algorithms for parameter optimisation", was presented in two parts: **Graeme Boyce** (Environment Agency) discussed the calibration process and then **Limin Zhang** (University of Salford) discussed the mathematics of the algorithms.

The transfer function models within WRIP require calibration for individual catchments and need only rainfall and runoff data. The transfer function is a linear, time-invariant model, which can be modified by adjusting three parameters: volume, shape and lag. The Environment Agency (South West Region) is evaluating the performance of existing transfer models for flood warning, and developing further models. A methodology for systematic adjustment of the volume, shape and lag parameters is being developed, which could include relating the parameters to Soil Moisture Deficit or other variables. This may extend the flexibility of a linear model to model a non-linear process.

It is important to develop a methodology for assessing the performance of these models in supporting the flood warning system. Key indicators are peak level prediction and hydrograph shape and how these relate to the criteria levels. This allows the timing and level predictions of the model to be assessed. The performance objectives vary according to the characteristics of the catchment and the nature of the flood risk. Where the difference in level between criteria bands is large or where there is a slow rate of rise of the hydrograph, a larger error in the level or timing prediction may be acceptable. Results were presented showing peak predicted and recorded level and criteria levels for both calibration and verification events at Pen Mill, Great Somerford, Ashford Mill and Hamoon gauging stations. At Pen Mill and Great Somerford the models provide a practical, accurate (in terms of criteria band) tool for flood warning operations. The results at Ashford Mill and Hamoon are poorer: non-linearities in the runoff generation and routing effects on larger catchments are possible sources of error.

Transfer function models relate the flow to previous flow and rainfall values. Models are calibrated using a least squares method. Initial experience using transfer function models at Great Somerford gauging station showed good results for up to two time steps ahead but not for greater. This was felt to be because the model mainly identified the relationship between the flow values and not between flow and rainfall. Transfer functions have been developed with a fast and a slow component to the response and have been applied to the River Hodder catchment. Advances to transfer function modelling include the use of genetic algorithms which calibrate the model by selecting parameter values iteratively based on the results of previous parameter values.

On larger catchments channel routing effects are important in predicting the hydrograph which are not modelled by transfer functions. The Bristol Avon catchment has been modelled by a multiple input single output (MISO) model, which divides the catchment into tributary catchments. The tributaries are modelled using transfer functions and linear reservoir cascades, which are then combined to give a hydrograph at Bath.

Tim Harrison (Environment Agency) asked whether, and at what advance time, warnings would be issued to EA staff or the public based on forecast levels. Graeme said that warnings were not currently based on predicted levels.

The final paper "Economic benefits of flood warning and flood forecasting: review of research and assessment techniques" was presented by **Ken Taylor** (Entec Ltd). Ken described the progress of the Environment Agency R&D Project WSC 001: Phase 1 comprised a literature review to identify assessment techniques and to select case studies for use in Phase 2. The literature detailed flood warning systems on many varied catchments and coastal situations, with four possible outcomes:

Warning issued — no flood
Warning issued — flood
No warning issued — no flood
No warning issued — flood

Research so far showed that the public would prefer too many warnings rather than too few. Evaluating the benefits of flood warning is inherently difficult, as not all recipients will be able to act on that warning. The literature review has highlighted that the tangible damages are well researched and methodologies are published, but that intangible damages are very difficult to assess. Factors affecting the evaluation of tangible benefits are

Accuracy of forecast;
False/unofficial warning;
Dissemination;
Awareness of recipient.

The effects of stress and ill health have been researched well in qualitative terms but not quantitatively. Intangible damages can be estimated by methods such as Contingent Valuation Method and Willingness to Pay. Flood forecasting can potentially reduce damages by 50% and this has to be compared to the resources required to run the service.

Roger Quinn
Environment Agency South West

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Development and practical applications of frequency analysis

BHS Pennines Section Meeting
Lancaster University
19 February 1997

***Keith Beven* (Lancaster University) opened the meeting, which was well timed with research now going on at IH into developing the Flood Estimation Handbook (to supersede the Flood Studies Report) and recent applications of continuous simulation techniques to flood frequency analysis.**

The first presentation was entitled 'Use of a simulation approach to explore variations in flood frequency curves', by **A. M. Hashemi** and **Prof. Enda O'Connell** (University of Newcastle). The work aims to understand the factors that contribute to variability in catchment flood frequencies. Rainfall data were used to generate characteristic rainfall statistics. A Neyman Scott Rectangular Pulse (NSRP) model was used to drive the ARNO rainfall-runoff model through stochastically-generated rainfall inputs for a 'synthetic' catchment with a representative parameterisation. From the parameterisations of these coupled models, the variability in generated flood frequency curves was explored.

Potential sources of variations included rainfall characteristics, soil moisture and stream network geometry. Annual maximum flow, when standardised by the annual mean flow, was particularly sensitive to the number of cells per storm, indicating a strong control by the interaction of rainfall and soil moisture. Flood frequency characteristics were also sensitive to evapotranspiration and maximum surface soil moisture storage, showing significant control on the variations of catchment response. Drainage network also significantly influenced the flood frequency curves. Enda finished by restating the importance of rainfall and climate for variations in flood frequency curves, and he outlined future work on real catchments.

Jonathon Tawn (Lancaster University) asked about the difficulty of identifying the number of cells per storm from intensity. Enda replied that the study was to evaluate the sensitivity of flood frequency curves, but recognised the need for correlation between number of cells and intensity, as well as seasonal dependencies. A full analysis of the variance would be achieved soon through a factorial experiment.

Duncan Reed (Institute of Hydrology) then presented an update on the research going into the preparation of the Flood Estimation Handbook. There were several new themes such as regionalisation, and methods developed since the Flood Studies Report. A key objective was to develop techniques for easy access and use of the Flood Estimation Handbook, to be based on the maximum exploitation of data and information.

Emphasis was placed on uncertainty, a theme that underlay a number of the presentations at the meeting. This was exemplified by flooding at Kenwyn near Truro, where two devastating floods occurred in 1988. Before these events, the flood frequency characteristics of the site indicated that the 1988 floods were 1-in-100-year events, but incorporating them into the flood frequency analysis meant that the floods were in fact of the order of 1-in-5 or 1-in-10-year events. Duncan quoted Bobby Robson (former England football squad coach): 'We didn't underestimate them — they were just better than we thought'.

The adequacy of data in terms of absolute values and availability of sufficiently long and representative periods was a factor limiting the accuracy of flood frequency estimates. Comparing the number of sites/records used in this research, compared to those used to compile the Flood Studies Report, showed an increase by a factor of at least 2 or 3 for most hydrological variables. There were new techniques for regionalising flood frequency characteristics. The Flood Studies Report had regionalised responses according to hydrometric-geographical areas. Discharge statistics could be used, but a danger of over-conditioning could lead to false confidence in the predictions when extrapolated to ungauged sites. New methods included analysis of the seasonal distribution of the Peaks Over Threshold (POT): by plotting the distributions of POT on a circle, representing a yearly cycle, and weighting each event, the 'centre of gravity' of the circle gave mean annual timing, and the strength of the seasonality of POT events. When plotted according to location, marked groupings were immediately obvious. This technique was also usd for rainfall statistics and flood irregularity. There was coherence for the rainfall and discharges, but not for the irregularity, except in the east of the UK. Areas could be classified by novel analyses like this.

The rest of the talk focused on other new techniques, such as using the median of the annual maximum flood to yield more robust estimates, since maxima-maxima gave greater gauging errors. Duncan advocated greater use of POT to detect non-stationarity effectively, to provide better estimates of index floods and to differentiate between flood regimes. Digital spatial information was also very useful: urban/suburban land-use classifications, HOST soil classifications and Digital Terrain Analyses could all contribute to improved estimates of flood regimes.

The use of information is changing, and this will free users to make sensible evaluations of problems. The incorporation of new types of data in different ways will require an evaluation of its utility. The Flood Estimation Handbook would provide easy access to more reliable techniques for the practical estimation of flood frequency designs.

Enda O'Connell asked about problems of estimation for ungauged catchments. Duncan replied that for the UK there would be few problems regarding representative rainfall records, and discharges could be related to catchment information. The geographical position of an ungauged catchment relative to classified catchments could give strong argument for assigning the dominant class to the ungauged catchment. Returning to uncertainty, it was clear that some areas exhibiting ambivalent characteristics need not belong wholly to an individual classification, and some probabilistic weighting could be assigned to represent membership of a number of classes.

The next presentation, 'Flood frequency estimation by continuous rainfall-runoff modelling', was by **Rob Lamb** (Institute of Hydrology). Two conceptual models were being calibrated using hourly rainfall and flow data from 41 catchments in the UK. It was hoped that the model

parameters might be related to catchment characteristics, enabling the method to be applied to ungauged catchments using synthetic long rainfall series. The 41 chosen catchments were well distributed around the UK to represent a number of HOST soil classes. In this way, it was hoped that HOST data might be used in estimating parameters for ungauged catchments. The study so far has concentrated on data collation and 'cleaning', using techniques to achieve continuous time series on an hourly time-step.

For one application of the technique to the Wye catchment at Plynlimon, two simple physically-based models have been used: the Probability Distributed Model (PDM), and the Time Area Topographic Extension (TATE) model. Two years of rain and flow data were used for the calibration of the models, and 14 years of rainfall data were then used to generate simulated flow series. Flood frequency curves derived from the model outputs were plotted against the observed data-derived frequency curve. Good agreement was achieved for both models with respect to the observed data-derived curve at the lower return periods, but there was some divergence at the extremes.

In an application to an urban catchment (the Rea at Calthorpe Park) the flood frequency curve from the PDM was consistently biased but had good form, while the TATE-derived curve performed significantly better with respect to that derived from the observed flow data. In a final application to the Findhorn, both models gave excellent agreement to the observed flood frequency curve.

In conclusion, Rob addressed the adequacy of the continuous simulations. He noted that whilst the derived flood frequency curves gave good agreement, the models were not necessarily representing the discharge record exactly. By visualising the largest three peaks per year for the 'observed' data, and the PDM and TATE simulation data, the magnitudes were broadly reproduced. However, when the timing of the storms was viewed, it was obvious that the time distribution of large events was not simulated correctly. This, it was stated, reflected the problems of traditional calibration techniques, and limitations of the models used.

Keith Beven asked about adopting an hourly time-step for all 41 catchments, pointing out that the instantaneous peak discharge is a key requirement in flood estimation, and that the hourly time-step might be less appropriate for smaller catchments. Rob replied that most of the catchments were of a sufficient size that an hourly time step seemed appropriate, but the decision to model at this time step had been largely pragmatic.

Enda O'Connell asked about the optimisation techniques used in the calibration. A simplex algorithm had been used, but was sometimes found to be unsatisfactory in terms of the identified parameter sets. Manual calibration had been performed to augment simplex-derived calibrations, and Monte Carlo techniques would also be performed soon. Given the long hourly time series, it was likely that the selection of an appropriate objective function is of equal importance when defining a reliable calibration. It was not thought that the method of optimising a given function was the key constraint on the calibration process used.

The next paper, 'Uncertainty in simulated flood frequency characteristics', was presented by **Keith Beven** (Lancaster University) and **Sarka Blazkova** (TG Masaryk Water Research Institute, Prague). Keith began by noting that it was ten years since the first application of TOPMODEL to predict flood frequency predictions, and that its recent focus had been towards data-sparse catchments. Developing the uncertainty theme, he asked whether it was possible to achieve flood frequency analysis by continuous simulation when there is a lack of data. As noted by Rob Lamb, robust calibration was difficult enough with many years of data. To incorporate the uncertainty associated with model parameterisations, the Generalised Uncertainty Likelihood Estimation methodology was used.

Sarka Balzkova then presented a simple stochastic rainfall model incorporating two types of rainfall — frontal and convective — which was used to drive TOPMODEL in application to a small upland catchment in the Czech Republic. Flood frequency curves were plotted from 13 000 simulations of a 68-year period. The range of curves showed that *a priori* parameter estimates gave wide uncertainty in flood frequency estimates. To constrain this uncertainty, possible model parameterisations were conditioned against low flows, and a number of them were rejected as unrepresentative. Although the flood frequency curves were significantly constrained, they were still very wide towards the extremes. Analysis of model peaks for 1000-year simulations showed similar uncertainty, and some improvement was achieved after constraint. Confidence limits were then derived, providing some probabilistic measure of the uncertainty of estimating flood frequency curves.

David Cameron (Lancaster University) outlined a similar application of uncertainty techniques to the identification of flood frequency characteristics in a presentation entitled 'Flood frequency estimation by continuous simulation for the River Wye'. Results indicated significant uncertainty when TOPMODEL was applied to the Wye catchment at Plynlimon. Different realisations of 1000-year simulations were achieved for the catchment with random parameterisations of both the rainfall model and TOPMODEL. The frequency curves from the model output of each simulation were compared to the available 21 years of flow data through the annual maximum flood. The derived frequency curves were highly variable in terms of their gradients prior to conditioning against the available data. After constraint, by assessing the sum of the absolute errors against the measured data-derived frequency curve, a number of realisations were rejected. The retained parameterisations displayed significantly less variability in terms of the derived frequency curves, showing that adding pertinent data could significantly reduce the uncertainty. Future directions of research included assessing the acceptability of the multiple calibrations of TOPMODEL parameters according to the reproduction of the available discharge time series, application to other catchments and evaluating potential changes on the flood frequency curves from land-use and climatic changes.

The last paper was by **Jonathon Tawn** (Lancaster University) on 'Estimating extremes for spatially and temporally aggregated rainfall'. He demonstrated how dependence models from extreme value methods could address a variety of problems in estimating the frequency of extreme rainfall. Problems exist with the spatial aggregation of extreme rainfall frequencies. Data at a network of sites are likely to be unrepresentative of a region. He identified limitations of current approaches by presenting classical limits distributions, and ran through typical procedures to estimate the frequency of extreme rainfalls, which require that spatial measures of rainfall are independently distributed, enabling the Generalised Extreme Value (GEV) to be applied. The location, scale and shape parameters of this function are estimated and return levels are derived.

If we are interested in different spatial locations, GEV parameters are fitted for each data set. This is easy but potentially inconsistent (because of different sampling and/or distribution), is inefficient, and does not permit estimation at a new site. Moreover, it does not enable either spatial or temporal analysis of the structure of the rainstorm. Problems of temporal aggregation and discretisation were also addressed. Extremes of D-hour rainfall are required for a range of D: separate extremal analyses are possible for various values of D, but may lead to inconsistencies if the ordering of aggregated data is not accounted for. Extreme 24-hour rain-falls are also of interest, but measured data are usually

from a particular 24-hour period. Simulating idealised rainfall processes by extracting extremal features from a long record is easy, consistent and can answer complex questions, but it suffers from problems: for example, the extremes of the true process are not permitted to differ from the norm, and no appreciation of the model uncertainty can be carried forward into the final uncertainty. Jonathon concluded that dependence plays a key role in the extreme rainfall frequencies, and that information must be carefully exploited in terms of spatial covariates, historical data and ordering, leading to the potential to exploit the structure of the data.

Enda O'Connell asked about the pros and cons of the statistical analysis considering the required parameterisation of the various assumed functions of the dependence models. Jonathon pointed out that idealised rainfall processes contained imbedded assumed distributions requiring parameterisation.

Duncan Reed (Institute of Hydrology) mentioned recent investigations of the spatial dependencies of rainfall, and the problem of discretisation, and thought that Jonathon had moved research in this area on significantly. The meeting was closed by Professor Keith Beven, who noted the many new themes being actively pursued in the area of frequency estimation. He warmly thanked all who had attended this interesting and informative meeting, and concluded by thanking all the speakers.

Stewart Franks
Lancaster University

IHP documents at IH

The following documents have been received by the UK IHP Committee. They are lodged with the Institute of Hydrology library, from where they may be borrowed (or you may visit if you prefer). Please contact the Librarian (Tel. 01491 692266).

Environmental and socio-economic consequences of water resources development and management: Proceedings of the Moscow Symposium (15-20 May 1995), ed. G.V. Voropaev and N.A. Zaitseva, IHP-V Technical Documents in Hydrology No. 3.

Past, present and future of postgraduate education in hydrology: Proceedings of the Prague Workshop (29-31 August 1994), ed. H. Salz, IHP-V Technical Documents in Hydrology No. 4.

Fresh groundwater lens recharge, Bonriki, Kiribati: Preliminary Report, I. White, IHP-V Technical Documents in Hydrology No. 5.

Groundwater pollution by sanitation on tropical islands, P. Dillon, IHP-V Technical Documents in Hydrology No. 6.

Ecohydrology: a new paradigm for the sustainable use of aquatic resources, ed. M. Zalewski, G.A. Janauer, G. Jolankai, IHP-V Technical Documents in Hydrology No. 7.

Water resources in the OSS countries evaluation, use and management, International Hydrological Programme, May 1995.

World water: is there enough?

A 22-page booklet just published by WMO and UNESCO draws attention to the urgent need to assess world water resources in order to meet the increasing demand for water information. This is vital for sustainable development, to ensure that human activities in the 21st century will not be limited by shortage of water.

The world's water — is there enough? is WMO publication No. 857, ISBN 92-63-10857-9.

BOOKS

Geomicrobiology text

Ground Water Microbiology and Geochemistry. Francis H. Chapelle. John Wiley & Sons, New York, 1993, 424pp, £48.95, hardback, ISBN 0-471-52951-6.

Both geochemistry and geophysics are sufficiently well-established fields to warrant undergraduate and graduate courses in universities (and moreover to have established journals and texts). However, the exciting and fledgling field of geomicrobiology, as it seems to be becoming known (at least in the UK) is still in the making, with a rash of postdoctoral research positions being offered and moves towards establishing a professorial chair, but as yet few established texts deal with the realm of subsurface microbiology as opposed to soil microbiology (e.g. *Groundwater Pollution Microbiology*, G. Bitton and C. P. Gerba (Eds), 1984, John Wiley).

Again, specialist texts covering groundwater chemistry have traditionally concentrated on inorganic hydrogeochemical processes affecting natural water quality in aquifers. More recently the emphasis has shifted to describing their organic and pollutant geochemistry too, but although the role subsurface microbiology may play, e.g. in mitigating groundwater contaminants (organic and inorganic), is readily acknowledged, their exact roles and identities are not made explicit.

Chapelle's book is therefore timely, as it attempts coherently to combine classical microbiology and hydrogeology, bridging the gap between applied environmental microbiology and applied groundwater geochemistry, both areas in which he is expert. The meeting point of these areas (stressed throughout the book) is in their controlling influences on groundwater quality.

The book is in three parts. After a concise overview of the histories of geology and microbiology and their integration in groundwater studies (Chapter 1), the rest of Part I lays a groundwork in basic microbiology and microbial ecology. Chapter 2 discusses microbial classification systematics. Chapters 3 and 4 cover bacterial growth (including culture techniques) and geochemically important metabolic pathways. Chapter 5 discusses bacterial genetics, and application of DNA technology in identifying bacteria and for engineering genetically modified organisms (GMOs): apart from the ethical questions of releasing GMOs, there has been generally poor survival of such laboratory-adapted microorganisms in the environment. Chapter 6 rounds off the microbiology groundwork by discussing the general microbial ecology of groundwater systems, including discussion of microbial population interactions and competition.

Parts II and III then attempt to link the microbiology with the geochemistry of both pristine and contaminated aquifer systems.

Part II deals with "natural" biogeochemical cycling. Chapter 7 leads in by describing the microbial distribution and diversity with respect to hydrological conditions in the unsaturated versus saturated zones, the latter classified further on the basis of Toth's zonation of aquifers into local, intermediate and regional groundwater flow systems. Chapter 8 gives an excellent discussion of the techniques and problems of aseptic microbiological sampling in these environments. Chapter 9 thoroughly covers the biogeochemical cycling of oxygen, carbon, nitrogen, iron and sulphur. Chapter 10 concisely introduces the

techniques of geochemical modelling as an aid to identifying the important geochemical process (biotic and abiotic) operating within aquifer systems. However, here there remains some mismatch in linking essentially (thermodynamic) equilibrium reaction models as discussed in this latter chapter with the earlier description of microbial growth (and nutrient uptake) as a kinetic process (Chapter 2). Although in combination with groundwater dating techniques geochemical techniques can be used to estimate integrated past/present microbial metabolic rates as described clearly here, there is little prescriptive power to this approach for simulating future trends. It is a pity then that there is no discussion of numerical modelling of solute transport and fate in aquifers (such as is published regularly in journals such as *Water Resources Research*), especially since Part III then deals with the adaptation of the microbial system to, and biodegradation of, aquifer contaminants.

The final set of chapters describes the degradation pathways of selected groups of important contaminants. Chapter 11 leads in with a useful discussion of adaptation of microbial systems to aquifer pollution by xenobiotic (i.e. foreign) contaminants. The concept of there being recalcitrant or "non-biodegradable" compounds might be better put in the context of lead-in "lag times" for microbial systems to acclimatise to their presence. Standard biodegradation tests in industry may be on the timescale of only months, but in certain circumstances acclimatisation can take much longer before a biodegradative capacity arises. However, again I would stress that the coupling between the dynamics of the flow system and kinetics of the biodegradation processes is not addressed in this book. In the final two chapters (12 and 13), Chapelle looks at the biodegradation pathways of two very important classes of aquifer contaminants which have received high profile as groundwater quality issues during the 1980s and 1990s: petroleum hydrocarbons (e.g. Benzene, Toluene, Ethylbenzene, Xylene — BTEX), and halogenated organic compounds (e.g. chlorinated pesticides, chlorinated solvents). In these latter chapters there is also some further discussion about the potential for in-situ bioremediation, e.g. through biostimulation of the microbial environment. However, there are problems of getting the nutrients to microbial sites of remediation to consider and Chapelle rightly points out that the technical and economic practicality of these strategies needs to be carefully considered in each case.

There are some 248 references, with citations up to 1992 and spanning most of the important journals from the relevant scientific and engineering disciplines. The illustrations (black and white and shades of grey) are excellent, although I hesitate to praise too much lest I am banded with those "visually orientated geoscientists" to whom (according to the jacket) they are thought to particularly appeal. It is a pity that the jacket illustration and spine are themselves not more exciting so that the book would be more visually appealing on the shelf! I am irritated by a few basic proofreading mistakes that crop up regularly: bacterial growth kinetics are referred to as being described by monad kinetics (instead of Monod), and the correct spelling is Michaelis-Menten (enzyme kinetics).

Nevertheless, this is an excellent introduction to the realm of subsurface microbiology and groundwater quality studies as an integrated discipline. Indeed it scores over e.g. Bitton and Gerba precisely in presenting an integrated account. Overall, the book amply achieves its stated objective of bringing microbiology to geoscientists and generally vice versa, and achieves it in a clear and coherent manner. Its price does however relegate it to the personal shelves of specialist graduate researchers at least, but I would heartily recommend a copy for all libraries catering for courses in water quality, geohydrology, geo- or environmental microbiology, and other relevant science and engineering courses. My only sustained criticism, albeit outside the present stated objectives of the book, is that predictive and prescriptive coupled flow and biogeochemical reaction models (including microbial degradation processes) for the transport/fate of aquifer contaminants are becoming available (e.g. the BIOPLUME series) and deserve to be included in this integrated picture. Contaminant hydrogeology coupled with pollutant (bio)geochemical modelling is becoming an important tool in assessing groundwater quality issues.

Trevor Elliot
Water Resource Systems Research Unit
University of Newcastle upon Tyne

Solute modelling in catchments

Solute modelling in catchment systems, S. T. Trudgill (Ed.), John Wiley and Sons, Chichester, 1995, 473pp

The publication in 1986 of '*Solute Processes*', edited by Steve Trudgill, provided an invaluable text for research and teaching. A decade later the same editor has assembled a star cast of hydrologists to produce an equally valuable text focusing on modelling solutes at the catchment scale. The emphasis is on model description, calibration and applications, together with field results and details of model performance.

The first chapter (Ball and Trudgill) reviews developments in solute modelling in the last decades. For anyone new to this subject two excellent reference tables detail the major processes, inputs and outputs for 24 different solute models. The bulk of the chapter provides half-page-plus summaries of the key elements and applications of these models. They are categorised under five general headings: acidification models — episodic or long term; transport models — nutrients and pollutants; field-scale models; river water quality models, and catchment scale models. In summarising the models available to date it provides an excellent background to later chapters that describe both new models and recent advances with more familiar models. This chapter went straight onto my MSc and BSc reading lists.

Wafvinge provides an uncommonly useful review of the basic principles of frequently used models. In asking the question, "Is the current set of equations, used in the model to represent a process, sufficient to reproduce the patterns and variability in the observations?", he makes clear the need to link field observations to model procedures. He points out that somewhere in most models' development is funding directed at answering a water quality management problem, and this will have influenced the model design.

The main text is divided into four headings: ecosystem processes, hydrological and hydrochemical processes, weathering and soils, and solute models. Newson's concluding chapter addresses water quality management: the issues, strategies and scientific challenges for catchment scale solute modelling in managed catchments.

I will highlight a few of the excellent chapters in this text to give a feel for its range:

- Tracing nitrates across small agricultural catchments with the MONITOR model (Whelan *et al.*);
- Incorporating biological and ecological processes in modelling regolith weathering (Velbel);
- The use of isotope tracers to glean knowledge of residence and travel times in soils and river flows (Unnikrishna *et al.*);
- Modelling sulphate deposition and its impact on acidification (Wheater and Beck);
- The role of modelling to forecast solute behaviour in response to environmental change and changing anthropogenic conditions with the MAGIC model (Whitehead);
- Revisiting the Birkenes catchment, with the emphasis on integrating field work and modelling and the use of EMMA in forecasting (Seip *et al.*);
- The use of SHETRAN for tracking sediments and contaminant

pollutants at the catchment scale (Ewen).

Although this is a research-level text, which some final year students may find inaccessible, I shall still recommend the opening and closing chapters and those on SHETRAN, Nitrates and the MAGIC model to my students.

Finally, with the publishers announcing that this book printed on acid-free paper, with two trees planted for each used in its production, we can be sure solutes will continue to cycle through new forests.

Pauline Kneale
University of Leeds

Riparian landscape ecology

Riparian landscapes, G. P. Malanson, Cambridge University Press, 1993, 296pp

The author's stated aim is to review the diverse literature in geography and ecology on riparian ecology, and to introduce a landscape ecology perspective to the subject. The text focuses on patterns of riparian vegetation and their relationship with geomorphological features and hydrological processes. In particular the author shows how river erosion and deposition cycles impact on forest dynamics.

The book is well structured, with good scene-setting introductions to each chapter, but very limited in illustration. Chapter 1 gives a background introduction to landscape ecology and the physical geography of riparian areas. Relevant links between hydrological, geomorphological and ecological principles are established, and theoretical links are explored. Chapter 2 summarises the role of human activities in changing riparian processes. The wealth of examples used at this point to describe how human impact can lead to habitat damage or destruction is typical of the style of the book The third chapter describes seven types of river landscape in detail and shows how the different landscapes impact on river-side processes. Detailed processes within the individual landscapes and the influence of dynamic vegetation change are explored in later chapters. The emphasis is on the movements of energy, biomass and water within and between systems, the need to make the link between in-channel and over-bank ecological processes, and flood processes, seeing the whole as a continuum.

Geomorphological events are identified as having an impact on flows of genetic information in the ecological system. The difficulty of measuring dispersal, diffusion and migration of species is explored. Essentially landscape change affects population distributions in the channel and on the banks. When a river floods with major associated erosion or deposition the vegetation change may be catastrophic. Where channel migration is active there is a more regular pattern to change in the vegetation. Ecological impacts are felt at the local population scale, in community structures, and in spatial patterns of vegetation across the whole landscape.

In the final chapter Malanson considers the potential role for GIS and simulation modelling in advancing understanding of riparian environments. Modelling needs to link the hydrological, ecological and geomorphological processes to simulate spatial patterns and the biotic and abiotic flows through the system. If such models incorporated management information, conservation issues might be addressed.

The text is aimed at graduates and researchers, so it assumes a knowledge of ecological principles. However its clear layout and the useful chapter summary and conclusion paragraphs would make it useful reading for undergraduates looking into riparian ecology, and might tempt them to look at the whole text. *Riparian Landscapes* is part of the 'Cambridge Studies in Ecology Series' and therefore ecological in approach, although the emphasis is heavily on riparian flora. There is limited mention of faunal activity and impacts. I would have liked to see more illustrations in the text, perhaps at the expense of some of the 57 pages of references, which take up 20% of the book. Nearly all the examples come from the author's personal experience (from Iowa, Montana and Utah, USA), and although they are excellently described, their global appeal will be limited: a wider use of examples and case studies would have been useful. But overall, *Riparian Landscapes* gives a comprehensive perspective on the dynamics of ecology and landscape response along rivers.

Pauline Kneale
University of Leeds

Travel grants

A BHS subcommittee (the President, the Hon. Treasurer, Dr David Collins and Dr Jim McCulloch) administers the interest from the Exeter Fund and awards travel grants to members.

Grants of up to £150 are available towards the cost of attending meetings. Please provide details of the meeting, why you want to attend, the costs of attending and other sources of finance. Successful applicants are expected to produce a short report.

Any enquiries should be made to the Hon. Treasurer, Dr Richard Harpin *(tel/fax 01793 812479).*

Wanted! nominations to the BHS committee

There will be vacancies on the BHS Committee for three ordinary members and the Hon. Treasurer. We thank **Richard Harpin,** who has served the Society so well as its Hon. Treasurer for the past two years, **Angela Gurnell, Richard Davis** and **Laura Baird** for all the work they have done for the Society as members of the main committee.

A nomination form is enclosed for their replacements. Please reread the President's piece on page three and consider putting a name forward (yours or a colleague's). The committee meets four times a year in London.

The British Soil-Water Physics Group

Lester Simmonds at the Department of Soil Science at Reading is taking over as coordinator of the British Soil-Water Physics Group; he will be aided by **Glyn Bengough** at the Scottish Crop Research Institute, Dundee.

This group was formed in 1980 by **Edward Youngs** (then at Rothamsted Experimental Station) and **John Bell** at the Institute of Hydrology in an attempt to bring together workers from various disciplines concerned with soil-water physics. Since the opening meeting at Rothamsted the group has met about twice a year for discussion meetings, workshops and the occasional field visit. Meetings are planned to be informal and each is organised by the scientist who elects to host it.

The next meeting is to be held on *28th May* at Imperial College, London in conjunction with the British Hydrological Society. The topic is "Macropore flows in soils — the state of the art" and details are on the Diary page.

Anyone new wishing to be put on the mailing list of the British Soil-Water Physics Group is invited to get in touch with Lester Simmonds, Department of Soil Science, University of Reading, Whiteknights, P.O. Box 233, Reading RG6 6DW, tel. 0118 931 6557, fax 0118 931 6660, e-mail asssimmo@reading.ac.uk

Occasional Paper No. 7 — Palaeohydrology

Palaeohydrology is defined as 'the study of science of the waters of the earth, their composition, distribution and movement from the beginning of the first rainfall to the beginning of continuous records'. The need to study palaeohydrology has arisen because there are many situations where we require a longer sequence of hydrological records than is available from the period of continuous measurement.

BHS Occasional Paper No. 7 is entitled *Palaeohydrology: context, components and application* and was produced following the BHS national meeting on palaeohydrology in *December 1995*. It aims to provide an introduction to the methods of studying palaeohydrology and the applications of palaeohydrological data.

Chapters include:

- Definition and development of palaeohydrology
- River flow andgroundwater level records — the instrumented era
- Peatlands, palaeoclimates, palaeohydrology
- Palaeohydrogeology: unravelling the evolution and past dynamics of aquifer systems
- Palaeohydrology and archaeology with special reference to the Middle Trent
- Building the foundation for long-term hydrological research: the role of the database

Occasional paper No. 7 (ISBN 0 948540 77 X) is edited by Julia Branson of the GeoData Institute, University of Southampton (Tel. +44 (0)1703 592719, Fax +44 (0)1703 592849, E-mail j.branson@soton.ac.uk). The price is £15 (£10 to BHS members) + £2 p&p. To order, please send a cheque, payable to *British Hydrological Society*, to Professor Angela Gurnell, School of Geography, University of Birmingham, Edgbaston, Birmingham, B15 2TT.

FORTHCOMING EVENTS

Courses

International Hydrology Postgraduate Courses at Galway, Ireland

The international postgraduate (MSc and Higher Diploma) course in hydrology at University College, Galway welcomes applications. It is a practical course, run by the Department of Engineering Hydrology, and the Irish Government's bilateral aid programme offers fellowships to enable students from less developed countries to participate.

To apply or for further information, please contact Dr Kieran M. O'Connor *(Tel +353 91 750341, Fax +353 91 524913, e-mail Kieran.Oconnor@UCG.ie)*

One-week workshop on WADI HYDROLOGY 21-25 July 1997 Imperial College London

Sponsored by UNESCO, this five-day workshop is part of Imperial College"s programme of professional development. It will be of interest to hydrologists and water managers working in arid regions. Registration *before 20 June* costs £840. A leaflet and registration form is being mailed with this issue.

Meetings

Workshop on ECO-HYDROLOGY: PLANTS AND WATER IN TERRESTRIAL AND AQUATIC ECOSYSTEMS 18-19 October 1997 University of Sheffield, UK

This workshop aims to improve our understanding of hydrological processes in ecosystems, the links between these processes and plant growth/ survival, and the relationship between plants and patterns of water movement /storage in ecosystems.

A dozen international and UK speakers have been invited to present state-of-the-art papers on water-plant relations. On the second day of the meeting there will be an optional fieldtrip to a remnant raised mire at Thorne Moors to look at mire rehabilitation and conservation.

The scientific papers and workshop discussions will be forerunners to a forthcoming edited text on eco-hydrology.

To register, or for more details, please contact Dr Andrew Baird, Department of Geography, University of Sheffield, Sheffield, S10 2TN *(tel. 0114 222 7949, fax 0114 279 7912, e-mail A.Baird@sheffield.ac.uk).*

BHS National Meeting DEALING WITH DROUGHT: CURRENT ISSUES 10 July 1997 ICE, London

The objective of this national meeting is to present and discuss topical issues relating to drought management. The programme has not been finalised, and suggestions are still welcome. It is intended to hold a second meeting later in the year (or early next) to discuss resource/demand balances.

Contact: Dr Hilary Smithers, Environment Agency North West Region *(Tel 01925 653999)*

ICID Conference and Workshop WATER – AN ECONOMIC GOOD? 9-10 September 1997 SUSTAINABLE IRRIGATION IN DROUGHT PRONE AREAS 11-12 September 1997 Oxford

The 18th European Regional Conference of the International Commission on Irrigation and Drainage (ICID) will consider to what extent water is an economic good. Irrigation accounts for 70-80% of water use worldwide and drainage is a key factor with a value in removing excess water.

Registration for the conference costs £220 (£160 for young professionals, defined as under 35). Accommodation costs range from £40 to £130 per night. There are three study tours afterwards.

The workshop costs £100, but is free to those registered for the conference. It will look at measures to combat the socio-economic and environmental impacts of drought, which arise from a complex interaction between natural phenomena and agriculture/irrigation.

For further information, please contact the ICID Committee, 1 Great

George Street, London SW1P 3AA. To register contact Oxford Conference Management, 10b Littlegate Street, Oxford OX1 1QT *(Fax 01865 794695)*

WATERSHED MANAGEMENT: MOVING FROM THEORY TO IMPLEMENTATION
Denver, Colorado, USA
3-6 May, 1998

This conference will build on the exciting 1996 conference sponsored by the Water Environment Federation (WEF), US EPA and other federal agencies. It will cover the latest information on implementing watershed planning, protection, restoration and education.

There will be oral presentations, interactive discussions, posters, exhibits and tours. Abstracts are invited, to be submitted by **16 June 1997**. Authors will be notified by mid-September and must prepare a manuscript by 9 January 1998 for inclusion in the Conference Proceedings. State whether for oral or poster presentation, software demonstration, or workshop discussion format. Send it to Technical Programs – Abstracts, Water Environment Federation, 601 Wythe Street, Alexandria, VA 22314, Australia.

International Association of Hydrogeologists XVII Congress
GROUNDWATER IN THE URBAN ENVIRONMENT
21-27 September 1997
University of Nottingham

This congress will look at urbanisation and groundwater in developed and developing countries to draw lessons for the sustainable use of the ground for water supply and waste disposal within managed urban environments. The registration fee is about £320 (if paid by **30 June 1997**), £385 after that.

Full details may be obtained from Prof. J D Mather, Geology Dept., Royal Holloway & Bedford New College *(Tel: 0784 443625 Fax: 0784 471780).*

Copy deadline for *Circulation* No. 55 11th July 1997

International Symposiumon
EMERGING TRENDS IN HYDROLOGY
25-27 September 1997
Roorkee, India

The deadline for direct submission of full-length papers has been extended to **31 May 1997**. Publication in the proceedings depends on peer review.

To register, or for more details, please contact Professor D. C. Singhal, Organising Secretary, International Symposium on Emerging Trends in Hydrology-1997, Department of Hydrology, University of Roorkee, Roorkee 247667, India *Tel. +091 1332 72349 ext 336 or 65391 (office), fax +091 1332 73560, e-mail hydro@rurkiu.ernet.in*

International Congress on Modelling and Simulation (MODSIM 97)
Special Session on
PROCESS INTERACTIONS IN THE NATURAL ENVIRONMENT
Hobart, Tasmania
8-11 December 1997

While progress has been made in modelling environmental processes (infiltration, surface runoff generation, evaporation and solute transport), to understand the workings of the natural environment better we need knowledge of interactions between processes at different spatial and temporal scales.

Presentations are invited on a combination of modelling and field measurement approaches to understanding process interactions, with emphasis on environmental management.

Other hydrological sessions are on land-surface-atmosphere interactions, surface hydrological models, groundwater flow and transport modelling.

Please mail (or fax) your abstract (300 words, in triplicate) by **31 May 1997** to the International Congress Secretariat (MODSIM 97), CSIRO, P.O. Box 1538, Hobart, Tasmania 7001 Australia, Fax +61 3 6232 5000 and send a copy to Tim Green at CSIRO Land & Water, P.O. Wembley, WA 6014 W. Australia (e-mail T.Green@per.dwr.csiro.au).

Final papers, plus registration, are due by 15 August 1997. As well as the congress proceedings, some papers will be published in international journals.

Further information is available by email (MODSIM97@ml.csiro.au) or on Web site: http://www.ml.csiro.au/modsim97.

Diary

21st May 1997
BHS Pennines Group **AGM**
"Flood defence modelling"
Venue: University of Salford
Contact: Dr K A Tilford, Dept. of Civil Eng., University of Salford, M5 4WT
(Tel: 0161 7455000, Fax: 0161 7455060, E-mail k.a.tilford@civils.salford.ac.uk)

28th May 1997
BHS National meeting — jointly with the British Soil Water Physics Group
"Macropore flow in soils"
Time: 2.00 p.m. - 5.00 p.m.
Venue: Room 141, Dept of Civil Engineering, Imperial College, London SW7
Contact: Dr A P Butler, Dept of Civil Engineering, Imperial College, London SW7 2BU *(Tel: 0171 594 6122)*

10th July 1997
BHS National meeting
"Dealing with drought: current issues"
Venue: ICE, 1 Great George St, London
Contact: Dr Hilary Smithers, Environment Agency North West Region *(Tel 01925 653999)*

9th September 1996
Welsh Hydrological Group **AGM**
"Environmental and hydrological aspects of the Wentloog Levels flood protection works"
Contact: Dr Rob Drayton, 208 Fidlas Road, Llanishen, Cardiff CF4 5NA
(Tel 01222 754879, Fax 01222 754879)

15th - 18th September 1997
Sixth National Hydrology Symposium & **BHS AGM** *(11.00 on 16th September)*
Venue: University of Salford
Contact: Dr K A Tilford *(address above)*
** Second circular enclosed with this issue **

21st - 27th September 1997
IAH XVII Congress
"Groundwater in the urban environment"
Venue: University of Nottingham
Contact: *see Meetings*

18th - 19th October 1997
BHS National Workshop/Conference
"Ecohydrology"
Venue: University of Sheffield
Contact: Dr Andrew Baird, Dept of Geography, University of Sheffield,
(Tel 0114 222 7949, Fax 0114 279 7912, E-mail A.Baird@Sheffield.ac.uk)

Circulation is the quarterly newsletter of the British Hydrological Society. It is issued free to members, but is also available on an annual subscription of £20. Enquiries about membership should be made to Richard Howard, Institution of Civil Engineers, 1-7 Great George Street, London SW1P 3AA. Tel 0171 665 2234, Email howard_r@ice.org.uk. Please address all other correspondence to the Editor, John Griffin, Institute of Hydrology, Wallingford, OX10 8BB. Tel 01491 692395. Fax: 01491 692424. Email b.h.s@ua.nwl.ac.uk.

Circulation is produced by the Institute of Hydrology and indexed in *Geosystems' Hydrotitles & GeoArchive.*