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Flooding in Strathclyde

Between 9th and 11th December 1994 west-central Scotland experienced sustained heavy rainfall, resulting in severe flooding in several parts of Strathclyde Region. The warm sector of a frontal system became almost stationary over the area and caused continuous rainfall for over 48 hours in many places. The worst affected rivers were those draining into the Glasgow and Paisley areas, particularly the larger, flatter catchments such as the Kelvin, Black Cart and Clyde. Properties were inundated in six different areas of the city, major transport disruption resulted and three lives were lost.

Rainfall

Summary results from raingauges operated by Clyde River Purification Board (CRPB) over the period are shown in Table 1. Several exceptional daily totals can be seen: the maximum was 165 mm on the 10th at Gleniffer Braes to the south of Paisley. These totals are particularly noteworthy for sites at relatively low altitude.

Accumulations over the two days 10th and 11th December are even more remarkable at some sites, with estimated return periods of over 500 years for Gleniffer Braes, Picketlaw and Mugdock Park. It must, however, be emphasised that return period estimates of this rarity are based on extrapolations from statistical analyses of available records, and they should always be treated with caution.

River flows

Many flow gauging stations across the Strathclyde area recorded new maxima, often by substantial margins, with several stations being flooded out. With extreme conditions having been experienced at so many sites, the estimation of peak flows represents a major and difficult challenge for the CRPB. Only provisional flow data are therefore available thus far, but it can be seen that the event is of major hydrological significance. Data for four of the most seriously affected rivers are given in Table 2: these rivers together drain a large area on the north and south sides of Glasgow.

Because of the sustained nature of the rainfall, the greatest effects were observed on the larger catchments with longer response times. Peak flows from tributaries were able to coincide, and the attenuation afforded by flat floodplain areas was less effective than in many previous events owing to the large volumes of runoff involved. This was particularly true in the case of the River Kelvin, where the recorded peak was at least twice that previously recorded in 46 years of record.

Normally safe areas adjacent to the large floodplain upstream were inundated, including recent residential and commercial developments. Consequently, there has been some controversy over the efficacy of the planning system.

By contrast, the peak recorded at Hawkhead, the lowest station on White Cart Water, exceeded the previous maximum by only a modest margin. Indeed, stations in the upper parts of the White Cart did not record new maxima, despite shorter record lengths,



Figure 1 Flooding in the Strathclyde Region of Scotland

Table 1 Daily rainfall totals (mm) for selected CRPB raingauges, water days 9-11 December 1994. Almost all the rain was received within 48 hours at each gauge.

Gauge	Catchment	OS NGR	Altitude (m)	9th	10th	11th
Dunlop	Annick Water	NS412489	148	16.4	88.0	57.2
Saughall	Irvine	NS598364	222	6.9	80.5	54.3
Leadhills	Clyde	NS888151	384	3.2	65.8	46.5
East Kilbride	Clyde	NS638535	178	9.4	69.0	48.0
Clyde Park SW	Clyde	NS772539	30	3.4	42.2	29.4
Picketlaw	White Cart	NS568515	220	14.0	100.8	57.6
Gleniffer Braes	Black Cart	NS435595	183	22.7	165.4	54.6
Mugdock Park	Allander/Kelvin	NS546779	164	11.9	126.0	53.4
Glenmill	Glazert/Kelvin	NS605794	99	18.1	89.3	57.3
Cumbernauld*	Kelvin	NS783770	85	5.4	99.6	52.6
Inveruglas	Loch Lomond	NS320091	13	36.9	100.4	28.5

* *Operated by Forth RPB*

affected, with backing up from culverts exacerbating the problems in the Ferguslie Park area of Paisley.

Commercial properties were also flooded, particularly in the Rutherglen area of Glasgow. Coastal flooding in the Firth of Clyde in mid-January — the result of storm-force winds combining with a 1.5 m tidal surge and high tides — has subsequently added to the difficulties faced by local authorities in the area.

Advances for the future

Clyde RPB, supported by the Scottish Office, have initiated a project to assess the causes, extent and implications of the flooding. They hope that this will produce a definitive map of flood-prone areas within the Region. Elsewhere in Scotland, it was announced this week (17th January) that the planning authorities in Perth will no longer allow development on flood-prone areas, following the inundation there in January 1993 (see *Circulation* **38**) and the example set by Highland Regional Council a number of years ago. These initiatives serve as important and timely advances in flood hazard management in Scotland.

Table 2 Comparison of December 1994 and previous peak flows. h: stage; Q discharge; n/a not available.

River/Station	Records from	December 1994		Previous maximum		
		h(m)	*Q (m^3s^{-1})*	*h (m)*	*Q (m^3s^{-1})*	*Date*
Clyde at Daldowie	1963	5.9	1100-1300	4.70	803	9/85
Kelvin at Killermont	1960	3.9	≥350	2.25	104	8/61
(previous site)	1948			2.21	175	10/54
Black Cart at Milliken Park	1967	2.0	≥110	1.38	79	1/74
White Cart at Hawkhead	1963	~4.2	n/a	3.65	187	12/66

reflecting the steeper catchment and consequently greater responsiveness to more intense rainfall. This rapid response is illustrated by the successful operation of the White Cart flood warning model by the CRPB.

Flood warnings

The first telemetry alarm was received at 1145 on Saturday 10th December, and at 1505 Strathclyde Police were formally warned that flooding was likely in parts of Cathcart, southern Glasgow. The river initially peaked at 1830, but by 2300 had started to rise again, finally peaking at 0130 on Sunday 11th. The Board's flood warning staff were operational continuously from 0600 on the 10th to 0600 on the 12th; its computer model was run 23 times over the period (with no telemetry failures) and more than 400 telephone calls were made or responded to by flood warning staff (BT shareholders take note!). Despite the exceptionally high flows, data were only lost from six stations due to instruments being flooded; for four of these the data loss was for less than six hours and peak levels are available.

Damage

Damage was widespread across the region, and the total economic cost must run into several tens of millions of pounds. Several bridges were damaged, including one over the Kelvin at Twechar which collapsed with the loss of two lives. At the peak of the floods, major roads were closed across a wide area, but the dislocation of Glasgow's underground rail services is expected to last several months — peak flows in some of the rail tunnels are estimated to have reached 20 m^3s^{-1}.

Flooding of residential areas forced 700 people out of their homes. Kirkintilloch and Paisley were worst

Tony Bennett, Clyde RPB
Andrew Black, IH Scotland

Postgraduate Symposium

The Fifth BHS Postgraduate Symposium will be held at the University of Salford, Manchester from *3rd to 5th April 1995*.

Postgraduate students (current and recent) will be able to present their work and discuss it within their peer group in an informal and friendly environment. As in previous years, presentations on a wide range of hydrological topics are expected.

The experiences of giving a presentation and contributing to the ensuing discussion are usually regarded as extremely valuable by all those who take part. The Symposium programme also includes a hydrological field visit and guest presentations.

Interested postgraduate students/employees should contact Kevin Tilford at the University of Salford without delay. Supervisors/mentors/managers are encouraged to inform their students of the Symposium and support their attendance.

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Tablets of Stone

by David Archer, NRA Northumbria and Yorkshire Region

When Moses descended from Mount Sinai bearing 'tablets of stone' recording the Ten Commandments, he set a metaphorical standard both for the importance of the message and the accuracy of the reporting.

Hydrological 'tablets of stone' bear a less earth-shattering message but some are of considerable antiquity. They take the form of engraved marks often accompanied by a date, in riverside cliffs, walls and bridges, indicating the level reached in historic floods. For example, the 14th century Ferry Gate wall alongside the River Severn near Worcester Cathedral is decorated with 16 flood stones, the earliest dating from 1672.

In Northumbria there are numerous flood stones, from Tweed to Tees, but nowhere more than five marks in one place (Archer 1992). The practice seems to have started after the extraordinary flood of 1771 when the estimated peak discharge was nearly 4000 $m^3 s^{-1}$ on the Tyne and every bridge except one was carried away (Archer, 1993).

The antiquity of the marks and the permanence of their inscription lend a credibility which a closer inspection suggests is not always justified.

Wrong Month

The old Town Hall in the High Street of Yarm on the Lower Tees bears two flood marks, one from 1771 and one from 1881. The 1771 stone stands three metres above the cobbled market place (Figure 1) and the severity of the flood is confirmed by contemporary accounts of damage and loss of life in the town. However, the stone bears the date "17 September 1771" rather than the correct date of 17 November 1771.

Wrong Year

The Boathouse pub at Newburn on the lower Tyne has five marks ranging in date from 1771 to 1856. The marks have no relationship to contemporary river flows, as dredging of the river from the middle of the last century has changed the reach from fluvial to tidal dominance. The flood levels are dated by year only, with the third highest dated 1832. A careful search of local newspapers for 1832 revealed no flood records whatever, but a big flood the previous year appears unrecorded. It seems likely that the stone bears the wrong year date.

Exchange of Month

Further upstream on the Tyne, successive steps to Bywell House in the village of the same name bear flood marks for June 1903 and October 1924. Historical research shows that the floods in fact occurred in October 1903 and June 1924.

It is possible that all these marks are exact replacements for undated contemporaneous level marks and therefore correct levels. But there is certainly room for suspicion that they may be approximations placed from memory long after the event. In the case of Bywell, the marks must have been made well after the later of the two floods and thus at least a quarter of a century after the first.

Engraving in tablets of stone, it would seem, gives no more guarantee of veracity than paper and print. As for Moses' stone tablets, one may wonder whether there were any amendments between conception and delivery. What if, for example, the original set said 'now' instead of 'not'!



Figure 1 *Flood marks, Yarm Town Hall*

References

Archer, D. R. 1992. *Land of Singing Waters.* Spreddon Press, Stocksfield.

Archer, N. 1993. Discharge estimate for Britain's greatest flood: River Tyne, 17th November 1771. *Proc. BHS 4th National Hydrology Symp.*, Cardiff, 4.1-4.6.

President's piece

The turn of the year has seen several key events in increasing the profile of the Society.

Firstly, the long awaited BHS Research Strategy has been published. This has been produced by an R&D sub-committee, led by **Frank Law** (IH) and **Howard Wheater** (Imperial College) with members drawn from the research institutes and academic departments. The document is directed at those in a position to fund hydrological research and identifies those key areas where the Society feels resources and energies should be directed in coming years. The review is very timely, bearing in mind the recent restructuring of the funding councils and the reorganisation of the major research institutes.

The second initiative has been the Society's contribution to the House of Lords Select Committee on Sustainable Development (see page ...). Over the years, there has been much debate in Main Committee as to whether it is worth spending time responding to Government consultation documents. One view is that any response is likely to be ignored and a lot of effort is involved to produce a response that is likely to be deposited unread in the library of the Houses of Parliament. A different view acknowledges the time involved but recognises that responding to such documents is one way to get the Society noticed and increase its influence. My own view has drifted between these positions over the years, but I have tended to become more cynical of late as our responses seem to have achieved no more than a polite "thank you" letter.

It was therefore a great surprise and pleasure to find that over the last few months the Society has engaged in correspondence with the House of Lords Select Committee on Sustainable Development. Frank Law kindly produced the Society's original response, when he was serving on the Main Committee. Much to our surprise, the Select Committee picked up on several of the points in our submission and made them the basis of questions to OFWAT, WSA and the NRA. The Committee's particular interest in our submission related to problems of low flow rivers and the historic patterns of over-abstraction of groundwater in parts of the UK. The introduction of

abstraction licences which reflect sustainable levels of exploitation was advocated, together with a requirement to put right the problems associated with historic over-generous abstraction conditions.

Though Frank stepped down from the Main Committee in September, he has continued to act as the link with the Select Committee, whose work is still going on. Such involvement can do the Society nothing but good and I hope will allow us in some small way to influence thoughts at Westminster. If anyone would like to see a copy of the BHS submission, please contact Frank at IH (01491 838800).

Plans are now well under way for the international conference which BHS will hold in 1998. Offers to host the event have been received from several universities. A sub-committee has been set up to recommend to the Main Committee which is most suitable.

John Cole has agreed to help the Main Committee as an External Affairs Officer for a trial period of one year. He will spend of the order of 20 days helping BHS on a project basis. In line with BHS Strategy, the Main Committee is anxious to develop the Society's profile in disseminating information about hydrology to the public, and in particular to school children. **Hilary Smithers** has taken over Main Committee responsibility for this role and John's initial task will be to assist her with the development of a schools pack, which will be compatible with the National Curriculum.

Following **Angela Gurnell**'s election to the Main Committee, she has agreed to take responsibility for the marketing and sale of BHS products. By giving a Main Committee member responsibility for this, we hope we can be much more proactive in marketing BHS goods than has been possible in the past. They provide a significant source of income to the Society, so anyone who has yet to buy a tie or stick pin, or indeed spare copies of BHS publications, should contact Angela without delay! (Details elsewhere in this issue.)

I am delighted to be able to report that we have been able to support three BHS members with travel grants from the Exeter Fund (details elsewhere in this issue). Whilst the Royal Society, when it was custodian of the Fund, did informally ask for BHS advice as to how the money should be distributed, it is much more satisfactory for BHS to be in full control of the Fund.

As we look towards the turn of the century, the Main Committee is looking at how the Society can mark the occasion. **Max Beran** (IH) contacted me with an idea for a Millenium Project and he presented his thoughts to the Main Committee. A working party has been set up to investigate its feasibility, so watch this space when ideas have crystallised further!

Sue Walker

Contingency plans for UK droughts

Hazards Forum seminar Institution of Civil Engineers 4th October 1994

The impact of a drought has implications for water suppliers, regulators, consumers and the environment. The aim of this seminar was to examine droughts in the UK that are more severe than those on which water resource strategies and processing facilities are designed, and to consider how planning for a drought can improve water resource management to cope with the consequences. Approximately 50 delegates attended the seminar, which was chaired by *Alan Simcock* (Department of the Environment) and supported by the British Hydrological Society and the Water Resources Panel of the Institution of Water and Environmental Management.

Frank Law (Institute of Hydrology) opened by considering the use of rainfall data to identify historic droughts. He suggested a technique that might be used to define a probable worst drought from UK rainfall data. His overview of past drought probability analyses included the tables, developed by Tabony in 1977, which have become the definitive source of drought definitions and allow for rare events out to the 1-in-1000-year level.

Using data for ten representative raingauges in the UK, Frank illustrated how minimum rainfall totals for different durations (up to 60 months) could be used to identify regional and temporal variations in droughts, highlighting how the severe events during the 1970s, 1850s and 1740s were accentuated slightly in known rain-shadow areas. However, there is no definitive list of lowest actual rainfall ever recorded, and much of the rainfall measurements (pre-1960) are not in digital format.

He suggested a method for defining a probable worst drought. By plotting the lowest rainfall totals for different durations using the data from the ten representative rainfall gauges as a proportion of average annual rainfall a lower envelope could be drawn (see Glasspoole, J., 1947, *JIWE*, **1**, 442). That envelope was based on the minimum of the ten cases: none showed great variability. The evidence was for significant rainfall, even in the worst of droughts, once a period of six months or longer is considered. The lower limit of the rainfall envelope could be assumed to approach the worst probable drought and routing that rainfall through representative storage could lead to estimates of the lowest possible flow.

In conclusion, Frank demonstrated the probability of the rarest events having been measured in the past by superimposing the minimum flows for selected long-running gauging stations onto a dimensionless minimum runoff diagram: he noted that, in general, the recorded minimum flows are close to the minima calculated for 1-in-50-year return periods. Further investigations into extreme low flow extreme events were warranted to improve upon the published low flow statistics (*Low Flow Estimation in the United Kingdom*, IH Report No. 108).

In a change of emphasis, **Professor Susan Walker** (NRA North West Region) considered the priorities as water resources came under increasing stress during a drought, and advocated the incorporation of drought management into normal operating policy. She introduced the conflicts inherent in setting priorities from the water supply perspective, the protection of users' requirements and the environment, and went on to highlight the necessity for an early pro-active response in managing a drought to ensure that any action will be acceptable on all sides. The stages involved in drought management were described, including the classification of drought as defined by *BHS Occasional Paper No. 3*. Sue defined options for improving demand management, routine monitoring of supplies and the environment, assessing the consequences of emergency actions (see Figure 1) and introduction of supply augmentation measures and implementing contingency plans.

Options for management included reducing consumption or increasing the available supplies. From a water supply company point of view, the emphasis would be towards increasing supplies,

but the regulators would try to encourage reduced consumption. It was important to incorporate these considerations into the normal operating policy of the water resource to ensure that the maximum number of priorities are met.

Operating principles in north-west England include routine monitoring of rainfall, water storage and environmental conditions, yield assessment for different contingent runoff conditions and comparisons of long-term storage patterns (using the DROUGHTWATCH software). It was important to simulate the impact on yields, costs and environmental measures such as flows (or groundwater levels). Based on this information, contingency plans could be developed and implemented with confidence.

Key factors were the effective integration of drought management procedures into the normal operating policies and providing contingency plans to balance the conflicting requirements of the 'consumers'.

Continuing the theme of reactions to a drought, **Roger Cook** (Consultant) discussed the priorities for water allocation in a wider sense to include the impact of reduced water levels on the environment. He considered the balance between what needs to be taken out to satisfy consumers and what needs to be left in the rivers and aquifers to maintain the environment and satisfy the requirements of interests as diverse as angling, navigation and effluent dilution.

There was the need to determine whether conditions were 'normal' (a result of the decreased rainfall) or a result of human activities which would drive the options for action. He considered the problem of assigning priorities when the water resources are put under pressure. Water Acts and licence conditions, for example, could provide implicit priorities for protecting the individual users (including people, industry and the environment), but the lack of a definitive list means that the priorities will be based on the responsibilities of individual organisations and will, therefore, be subjective — he offered his own version.

Lessons were learned from the 1988-92 drought in the Anglian region, including the need to reflect on the management of the event, its impact and the need to consider ways in which improvements can be made before the next drought. He recognised the increased concern for the environment by pressure groups and individuals, but stressed the importance of collecting environmental information in order to substantiate claims of (perceived) adverse environmental impacts. This had still not been fully addressed. The final lesson was the value of liaison between affected parties at all stages, not least in the early stages to facilitate forward planning.

A short discussion then raised the difficulty of producing realistic control rules for groundwater supplies. Priorities for protecting the environment were explored, and the need for dynamic management of the river environment was stressed.

Rick Brassington (Southern Science Ltd) described in his talk the use of emergency boreholes as a possible solution to failing surface water resources. He discussed some of the advantages of using boreholes, in particular the financial advantage of small-scale implementation (one at a time), localised in the region where supplies were required. In choosing to follow this route, the factors which should be considerations in siting the boreholes include thickness and storage capacity of the aquifer, depth to the water, distribution of existing wells, relationship with surface water and the quality of water retrieved.

He presented possible implementation options: the siting of new wells, deepening existing wells and lowering the pump within a well. Influential factors in drought spells are the availability of pumping/drilling rigs, the loss of supply during any deepening activity and whether the efficiency of the borehole would be compromised by moving the pump. However, he stressed the need for operators to monitor water levels and undertake step tests to check borehole output trends. The need for licences limited the speed at which such new resources could be developed.

Use of groundwater augmentation of river flow should be a short-term option. Long-term operation of a borehole would increase the available supplies in a river initially, but over time would reduce the springs that would normally sustain the river flows. He supported the need to have all these options assessed and planned well beforehand as emergency options would take time to put in place and it was therefore unlikely that such actions could be taken in time to be effective during a drought.

The final speaker, **Steve Winston** (Cornwall Emergency Planning Department), set out the response of the County Council to hazards in general, concentrating on an example of a drought in the Bude area, which reaffirmed the value of planning and cooperation. The Council developed a framework for coping with any type of hazard — he described the stages useful detail. Stage one was to set up a crisis management team to coordinate a response in consultation with the District Council, Devon County Council, the utilities (water, gas, electricity), local hospitals, emergency services and 27 parish and town councils, thus ensuring that a comprehensive local response could be provided and coordinated. The team was responsible for identifying key sectors of the community and undertook local research (e.g. where best to site a standpipe in any community).

Stage two ascertained local area information, population details, set up a community resource register (who uses what and how often) and local public protection awareness schemes. Stage three was the development of the response in a crisis to include activating the emergency committee, obtaining the facts and identifying the problem, ensuring that people are aware of their role and that of others. At all stages, the key was to ensure that the responsibilities were outlined, understood and agreed and a record kept of all activities. He advocated the benefit of having a committee of elected representatives which gave credibility to decisions and increased acceptance because the community felt that actions were not being imposed.

Based on the scheme, the County Council developed an action pack which put forward guidelines for reacting to an emergency (key questions to ask, where to get information, etc.) which can be applied to hazards of any kind but which had proved particularly useful in the Bude drought.

The discussion which followed

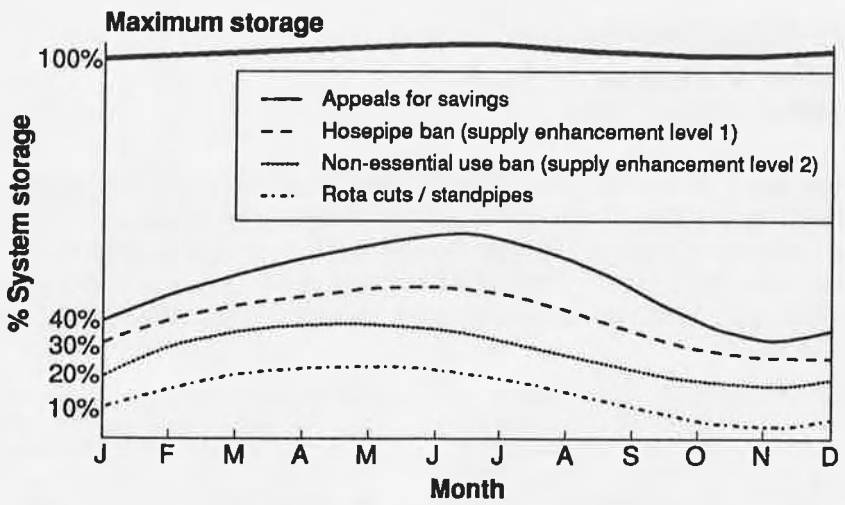


Figure 1 *Example of a drought management policy (from NRA North West Region)*

considered the importance of research and education, public awareness and the need for change in attitudes and perhaps policy for the effective management of droughts.

Chris Binnie (WS Atkins) inquired whether there was any evidence to identify critical periods of groundwater storage. Frank Law made reference to two small-scale studies of a limestone aquifer for which the critical period was estimated to be in the order of 3½ years, but information relating to the distribution of critical periods was not generally available. **Mike Price** (University of Reading) added that, in the absence of recharge, the critical period for useable chalk storage would be equivalent to two years.

John Lawson (Halcrow) pointed out that, despite any good intentions about contingencies, planning would always be undertaken during a crisis, and he wondered whether this situation could be improved through a change in attitude, alongside studies of the effects of events with more serious return periods. **Andy Bunch** (East Surrey Water) expressed concern that time and money should not be wasted in planning for a more extreme event if the difference in storage was not found to be significant. The solution would be to identify further the impacts of more severe droughts and so enable the water organisations to make forward investment decisions as well as contingency plans.

A question from **Alan Gustard** (Institute of Hydrology) started a discussion about the priorities and responsibilities for research funding. He commented on the imbalance (experienced over many years by the Institute) between funding for flood research and drought research, and asked whether existing funding for drought research was seen to be adequate by those within the industry.

From an NRA perspective, Professor Walker replied that she would prefer to see investment in investigating the environmental impact of droughts, which is currently less well understood than the associated hydrology. However, John Lawson pointed out that an understanding of the hydrology of drought can control future investment and **Rod Armstrong** (Southern Water) recommended sound justification for any speculative reservoir capacity because of its high cost.

Ben Piper (GU Projects) raised the issue of who should have the responsibility for such research, to which Frank Law suggested that strategic research should be funded by the Department of the Environment and contracted out to other organisations — he recommended that water utilities become more involved as well. Alan Simcock agreed to promote the need for greater cooperation in the investigation of droughts at the next *Foundation for Water Research* Forum. Sue Walker expressed the need for information to be shared between suppliers and regulators in order to maintain integrated basin management.

The possible influence of synoptic-scale physical processes on a drought was brought up by **John Hall** (Binnie & Partners). Frank Law noted that weather maps are not used for retrospective analysis because they are not in digital format. Sue Walker pointed out that, in practice, no proven techniques were available to make use of this type of information on an operational basis.

Neil Whiter (South West Water) described additional advantages of incremental borehole developments, especially where surface water resources were fully utilised. However it was important to manage the surpluses in a controlled way, thus sharing the risk of failure. Rick Brassington confirmed that yield from boreholes was limited by the physical storage and Frank Law provided an example from Hull which indicated that yield dropped by a half at the height of the 1989-92 drought.

The issue of public perception of priorities for water management was discussed. John Lawson inferred that the environment was given a higher priority than security of supply, but Alan Simcock questioned whether individuals understood some of the terms to provide an informed response. **Peter Herbertson** (NRA Southern Region) added that an OFWAT survey was also undertaken which revealed that the public would prefer to see water in the rivers and protection from flooding. Again, the value of the public's response was questioned, being influenced by personal experiences and very local. Their answers also depended on what question was asked.

John Lawson asked whether drought management practice from other countries could be transferred to the UK. Alan Simcock replied that this was a reasonable assumption in principle, but individual countries would have unique problems in terms of the physical characteristics, the legal framework and the attitudes of society which would restrict wholesale transplanting of technology. As to whether the minimum acceptable flow provisions of the Water Acts would be reappraised by the new Environment Agency, Alan Simcock felt that this was not a possibility because of the known difficulties of the concept and of estimating appropriate values, but the Deregulation Bill currently under discussion in the Commons might provide a means to simplify the regulatory system.

The discussions were concluded by **Professor Peter Wolf** (Pell Frischmann), who acknowledged the activities and achievements of the Forum and expressed his appreciation of those who had contributed to a successful event.

Karen M Irving
Institute of Hydrology

Urban hydrology & water quality management

BHS Southern Section Meeting
Imperial College, London
19th October 1994

For the first meeting of their 1993/94 programme, the Southern Section welcomed about 45 people to Imperial College to hear two papers on urban hydrology, focusing first on the quantity of stormwater runoff which the Brighton sewer system has to deal with, and then on the quality and pollution potential of highway drainage.

A 5 km tunnel is currently being constructed 30 m under the seafront at Brighton as part of Southern Water's Operation Seaclean, in response to the EC Bathing Water Directive. Brighton's sewers were constructed in the Victorian era, and have become a popular tourist attraction, with guided tours available in the summer months. However, Victorian sewers have their drawbacks when it comes to meeting EC directives. The main interceptor

sewer along the seafront surcharges and overflows into short sea outfalls during heavy rainfall events. The new tunnel, which will be 6 m in diameter, is designed to provide detention storage capacity, so that after a storm event, the sewage can be pumped back into the existing interceptor sewer at a controlled rate, for treatment and discharge to sea through a long outfall.

At the start of the project it was decided that the system should be designed to cope with a 50-year-return-period storm, with no spills. This is both unusual and ambitious: stormwater detention storage systems are commonly designed for 10-year return periods at most. The first paper of the evening, given jointly by **Martin Francis** and **Richard Long** (both of Acer Consultants Ltd), concentrated on the hydrological aspects of the design of the tunnel system, which had the target of eliminating Combined Sewer Overflow (CSO) in any 50-year storm.

Rainfall analysis & antecedent conditions

One of the key issues in the hydrological study was deciding what rainfall and antecedent conditions should be used. Options included: annual time-series rainfall (often used for CSO spill calculations, but not applicable with the performance criterion in excess of one year); real rainfall records (site specific), and the Wallingford rainfall generator (which generates synthetic design storms for any return period). It was recognised that the selection of suitable antecedent conditions would be of critical importance. Uncertainties can be reduced by using long-term real rainfall records, but when studying a 50-year return period, at least 100 years of hourly rainfall data are required. This would have been difficult to find and expensive, the oldest data would be only daily totals, and simulation runs through a Wallrus model would take a long time, because of the sheer quantity of data.

As there were clear advantages to be gained from retaining the existing detailed and verified Wallrus model of the Brighton sewer system (as opposed to using a much-simplified calibrated catchment model), it was decided to use the Wallingford rainfall generator in combination with limited amounts of real rainfall data. The most significant events from twenty years of local hourly rainfall data were used to calibrate the Wallingford rainfall generator and derive local antecedent conditions applicable to long return period events. The amount of runoff produced by a rain storm can be affected dramatically by the wetness of the catchment before the storm.

Using the standard equation for percentage runoff from the Wallingford Procedure, there was found to be a 17% increase in runoff using a typical high value of UCWI (140), as opposed to a typical low value (65). Earlier work analysing time-series had already revealed that many summer storms had values of UCWI much higher than the average summer values. In view of the major cost implications of providing large detention storage volumes, the rainfall analysis considered in some detail the depth of rain in the storms in the long rainfall record, to see if they showed that standard synthetic storms were incorrect. The actual antecedent conditions were also examined for each of the large storms in the record.

Recorded *v* Synthetic Storms

To cut a long story short, the 20 years of hourly rainfall data were analysed for storm durations of 1, 2, 4, 8, 16, and 32 hours, and the total depth of rain calculated starting at every clock hour of the record. Local maxima were identified, and adjusted (using correction factors from the Flood Studies Report) for the effect of significant storms being split between two or more clock hours. The hundred largest maxima were sorted, and their return periods calculated (again using FSR guidelines). Next, synthetic storms of comparable return period and duration to the recorded events were generated by the Wallingford rainfall generator, and the depths were compared (see Figure 1).

The comparison shows reasonable agreement for short durations and return periods, but for return periods greater than 5 years, and durations of over 16 hours, the historical data show significantly smaller values than the synthetic standard storms.

In the end, the standard storms were used without adjustment for return periods up to the required 50 years, as it was felt that the statistical difference was insufficient to prove that the standard storms were incorrect, given that the addition of just one large duration storm to the observed data would probably be enough to remove the difference.

The 60 heaviest storms closest to the critical duration were then analysed, and it was found that there was no tendency for larger storms to have drier or wetter antecedent conditions, allowing for seasonal variations. All that remained was to carry out a simulation of the appropriate design event, using the calibrated Wallingford rainfall generator, and then to start digging!

Questions flowed thick and fast, under the guiding hand of meeting chairman **David Butler**, with many wanting to know about how the detention storage system will work in practice. The Wallrus model is being used to develop control rules for the pumps which feed stormwater from the tunnel back into the interceptor sewer, and real-time flow sensors will be incorporated in the downstream interceptor sewer, to optimise the tunnel emptying time.

Highway drainage

Professor Bryan Ellis (NERC Swindon) gave the second paper of the evening, with the emphasis shifting from urban runoff quantity to its quality. His paper was entitled "Highway discharge quality: pollution potential and treat-

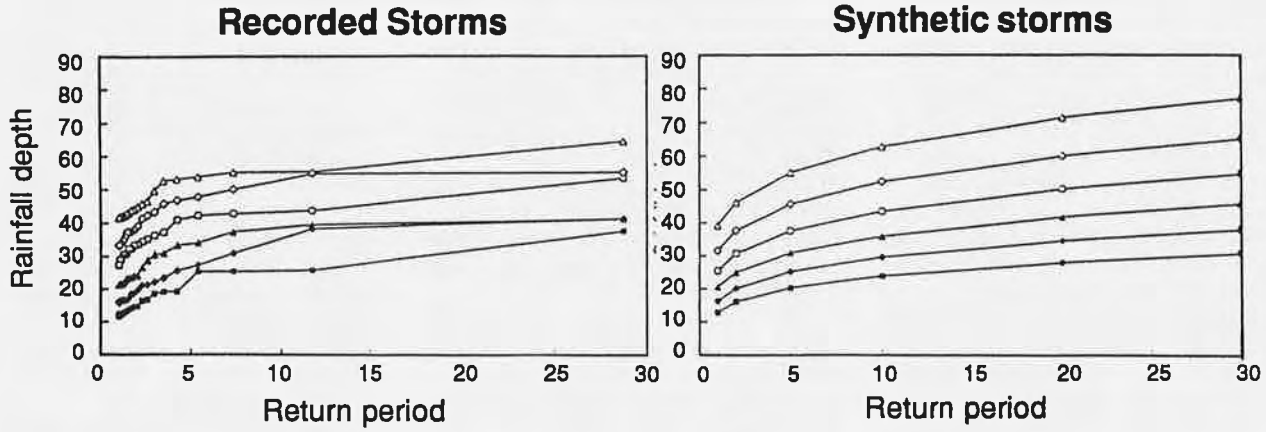


Figure 1 *Comparison between recorded and synthetic storms of six durations — (top to bottom: 32, 16, 8, 4, 2 and 1 hour) (after Long & Francis, October 1994)*

ment". With an estimated 360,000 km of highways in the UK, carrying about 25 million vehicles (rising to 40 million by the turn of the century), significant amounts of contaminants are being washed off the surface to receiving waters, both surface and ground. Four major pollutant groups were identified as being significant in terms of pollution potential:

1 *Solids:* by far the most significant in overall loading terms, causing turbidity and reduced oxygen potential, and also carrying other toxic materials.
2 *Metals*: although lead has the highest public profile of the trace metals, emissions have declined by about 40-50% since the introduction of unleaded petrol. Zinc and cadmium, from tyre and vehicle body wear, are now serious problems.
3 *Hydrocarbons:* some 20-30 mg/l total oils are present in typical motorway discharges, increasing to 200-400 mg/l during intense storms: they are all highly toxic.
4 *Pesticides:* used for weed control on grassed verges, embankments, and motorway hard shoulders: a range of toxic compounds have been found in highway runoff in concentrations one or two orders of magnitude higher than the level permitted for public water supply abstraction.

Chloride (from winter salting), and bacteria (from some residential highway drainage) can also cause local pollution problems. Typical pollutant loadings based on average daily traffic density were presented, as a useful guide for those who wish to evaluate the potential water quality impacts of highway discharges to surface waters.

Relatively few impact studies are available, and the risk of pollution from highway runoff has to be balanced against the benefits of strategic recharge to aquifers. For example, the 52 000 km of highways on the Chalk of south-east England provide some 200 Million m^3 per year.

M25 Case Study

Approaches and devices available for the control and reduction of pollution from highways include gully chambers, filter drains, infiltration systems, soakaways, oil interceptors and wetland systems. Some of these were described briefly, but the rest of Bryan's talk was largely occupied by a case study of a section of the M25. A 7.2 ha stretch in Surrey has been studied in some detail. It is equipped with a kerb gully system, with a French drain connection to a balancing pond, before discharge to a local stream. The system was obviously failing in its task, as high-value organic vegetables on the adjacent land, and fish in an ornamental pond, had been destroyed several times by flooding and contamination. The study provided evidence for a legal challenge to the Department of Transport by the landowner, for causing uncontrolled pollution.

The balancing pond, although somewhat over-designed in the sense that a 1-in-200-year event would only fill it to 80%, was never intended to supply pollution control. It is estimated that 30 m^3 of sediment is accumulating annually, and the main problem is the flushing of low-volume storms through the pond and its channel leading to septicity, with cadmium and zinc consistently above the recommended levels. With respect to hydrocarbons, levels were as high as 55 892 mg/kg total oils at the balancing pond outlet, and several pictures were shown of thick oily coatings in the outlet channel, which illustrated the problem far more dramatically than words and numbers.

This study made an ideal test case, as all the pollution was traceable back to the motorway, and there were direct and measurable ecological (and economical) impacts. Remedial works were designed, consisting of 11 m^3 of detention storage, complete with a floating oil boom. A broad-crested weir then leads into a larger holding basin designed to provide three hours retention time for an annual storm. With the original stream having to be diverted as well, the remedial works and compensation set the DoT back about £0.5 million.

Implications

The eyes of all the consultants in the audience lit up at this, especially when it was added that there are at least 6,500 such balancing ponds within a 30-mile radius of London. However, Bryan was quick to point out that although a test case, this study does not by any means represent a landmark legal precedent. The main problem in most other cases is proving a direct link between the highway drainage and an identifiable environmental impact, and much stamina, not to mention financial backing, would be required to see a case to its conclusion. Again the questions flooded in from the floor, many concentrating on what the DoT may or may not have learned from the case. The NRA and the DoT are now in serious discussion, examining the criteria, assessing the implications for groundwater pollution, and clarifying responsibilities for maintenance of highway drainage systems. It is hoped that manuals will be produced in due course, and that suitable criteria will be written into road construction contracts from now on.

The members dispersed with much to think about, determined no doubt to visit the sewers when next in Brighton, and to look out for balancing ponds when stuck in traffic jams on the M25.

David Butler, on behalf of Imperial College and BHS Southern Section, thanked the speakers for such an interesting and thought-provoking evening.

Richard Boak
Southern Science Ltd

BOOKS

Everything you didn't know about Scotland's fresh waters

The Fresh Waters of Scotland: A National Resource of International Significance, P S Maitland, P J Boon and D S McLusky (eds). John Wiley, 1994, 650 pp, ISBN 0 471 94462 9. Hardback only, £75.

The Fresh Waters of Scotland is a special volume of 31 papers marking the 25th anniversary of the Scottish Freshwater Group: most of them were presented at a special meeting of the group in 1993. It is divided into four sections, covering *Defining, classifying and evaluating the resource, Using the resource, Pressures on the resource* and *Integrating conservation and development.*

It is beautifully presented, including a comprehensive index and numerous photographs which add to the value of many of the contributions. Several of the reference lists are also very lengthy, constituting a valuable resource in their own right. A glossary would have been a useful addition, however, since the range of topics covered is very broad.

The book offers a unique compilation of authoritative papers describing almost every aspect of Scotland's freshwater resources — except hydrology! The coverage of water chemistry (Harriman and Pugh) is solid and relates well to other chapters; that of fluvial geomorphology (Werritty *et al.*) is imaginative and illuminating; resource use comprehensive (see below); forestry impact very general, and the chapters on running and standing waters have little relevance to hydrology as we know it. The lack of a chapter on physical hydrology proper is a glaring omission.

Its value therefore lies in providing information either tangential to hydrological studies or concerning resource management in its wider context. As such, it offers an opportunity to explore the many and diverse links between our own specialisms and others with which we might only rarely make contact. The focus on ecology, dominating Section One in particular, reflects recent interests of the Scottish Freshwater Group.

Many of the contributions are by well-respected, authoritative authors who draw on many years of experience

within their respective fields. The chapters on Water Supply (Macdonald), Hydro-electric Generation (Johnson) and Domestic and Industrial Pollution (Hammerton) are particularly valuable in this respect.

By roaming through the great range of topics covered, the reader may gain surprising new insights into the species supported by Scotland's fresh waters, man's impact on them and the history of managing the resource. For example, the position of north-west Scotland as the UK's main stronghold of the Black-throated Diver rests precariously on a mere 150 territorial pairs. By contrast, a map showing the distribution of Otters reveals a presence in almost every 10 km square, including the urban rivers of Greater Glasgow. A Royal Commission reported in 1872 that the waters of the lower Clyde were causing corrosion of ships moored in the river! It is unfortunate that some of the papers are somewhat inaccessible to the non-ecologist.

The theme running through the volume (and distilled in the final chapter) is the challenge of bringing together development and conservation. The recurring conclusion of many contributors that current conservation measures are inadequate to protect many elements of Scotland's natural heritage can seem rather tedious, but the book does serve as a convincing testimony to the very rich diversity within natural systems found in Scotland. The *national* significance of water resources, however, in terms of their historical significance and current uses, is under-emphasised in comparison with *international* significance for biodiversity.

The role of the forthcoming Scottish Environment Protection Agency is discussed by several authors. Government commitment to environmental protection is unanimously (and repetitively) regarded with some disdain, but the value of European legislation, and local multi-agency initiatives, such as the Tweed Foundation, is recognised. Some illuminating insights are presented.

For its breadth in describing the resource, and depth of analysis on the challenges of environmental management, this book is a valuable source of reference material and deserves a place in the library of anyone concerned with the freshwater environment. The resources of Scotland are indeed significant in an international context. However, the poor hydrological coverage of Scotland's rivers and lochs, significant for example in relation to the abundance of resource, great floods, snow hydrology and land-use impacts — as well as providing an important input to the development of freshwater ecosystems — represents an important opportunity missed.

Andrew Black
Stirling

Lake and reservoir siltation

Geomorphology and Sedimentology of Lakes and Reservoirs. Edited by J. McManus and R. W. Duck. John Wiley & Sons, Chichester, 1993. 278pp hardback/ ISBN 0-471-93773-9.

This is a book produced in the British Geomorphological Research Group series and is based on the need to know how quickly lakes and reservoirs are being infilled: this was the theme of a BGRG meeting held in Spring, 1991.

The book is laid out as 16 chapters, which is somewhat misleading as a casual glance may indicate that this is a 'text book'. This is not the case. The chapters are individual research papers, mostly specific studies on individual lakes and as such, there is necessarily a great deal of overlap of methods and techniques and some of the work reported relates to short and superficial studies.

The basic techniques are concerned with accurate surveys, including the use of shallow seismic methods and side-scan sonar. Core analyses, usually on a small number of samples, study the history of the sedimentology using mineral (organic and inorganic) analysis, pollen and radioactive isotopes including caesium, and make use of the Chernobyl spike.

The problem most often evident in the studies is a lack of accuracy, particularly in obtaining satisfactory mass balances of input and output — errors of 50% are quoted. This is exacerbated by the short-term nature of many of the studies which leads to 'guessing' longer-term effects such as climate change and the effect of occasional but very important large floods. The value of long-term data is well illustrated in a paper on sedimentation in an Iranian reservoir where the siltation rate over 17 years averaged about 2% of the volume. A further set of data over seven years showed the effect of desiltation strategies which resulted in reclamation of 7% of the reservoir capacity. This study is well reported in a good paper. Another investigation used electron microprobe analysis in a study of diatoms which account for most the suspended load in the outflow of a Scottish lake. The diatoms have been found to concentrate barium, resulting in barium-rich sediments.

The overall impression given by this collection of research papers is of an area with plenty of opportunity for more accurate work, which may be achieved by longer (or repeat) studies of selected sites. As background literature for such improvements, this book has a useful role to play and provides a wide range of references into the extensive literature of lake and reservoir siltation.

D Brian Smith
Wantage

The NRA and the customer

'NRA Customer Charter', National Rivers Authority, January 1994, 24 pp.

Not wanting to be left out of Citizen Major's drive for accountability in public service, the NRA published its 'Customer Charter' booklet in January '94. I was pleased to note that its 24 (A5) pages were printed on recycled paper and deeply impressed with the additional news that it was totally chlorine free and that the cover was coated with a water-based varnish. As this intelligence was coupled with the reminder that the organisation is committed to protecting and enhancing the water environment, I presume the expectation to be that the booklet is destined for early flushing!

So much bumph is generated by so many organisations that most has to be disposed off quite rapidly if one is to remain sane. Is the charter designed to be read and chucked or to be filed away for future reference? I was expecting the former but, after reading it, I have decided to keep it. It is easy to be cynical about this kind of thing and I was quite tempted to take the mickey. For example, how can I sensibly benefit from the knowledge that, 9 times out of 10, if I report a load of dead fish before 3.00 p.m., NRA sleuths will be on the scene within 2 hours? Chances are that mine would be the tenth report, or so it might be explained if I should ring at 5.00 p.m. to see what was keeping them! Yes, easy to mock, but on the whole I was quite impressed with the effort that had gone into producing a concise account of what the NRA is about and how we, the citizenry, relate to it. Apart from one or two bits of jargon (who, outside the industry, understands what *main* river is?), it is written in plain English and is well laid out.

For me, the most useful pages are those listing addresses and 'phone numbers for the NRA regional and area offices as well as many other relevant organisations. There is also a list of publications although, confusingly, it does not relate very well to those recommended in the text for further reading. Most of the text, however, is concerned with describing what the organisation is trying to do and emphasising how open, friendly and caring it will be to us in the process (whilst at the same time being efficient and giving good value for money). It is impossible to read it without being torn between genuine admiration for the objectives and a certain irritation with some of the more bland and empty phrases, but on the whole the former triumphed.

Feeling like a 'That's Life' researcher, I decided to test a couple of the claims made in the booklet by ringing my local NRA office to find out about the next Flood Defence Committee meeting. Claim No.1: *'Telephone calls will*

be answered within 15 seconds' — Oh dear, the main switchboard took 46 seconds. Claim No.2: *'Committee Services Department will give details of forthcoming meetings'* — They answered their 'phone in 14 seconds and knew the answers straight away. What do you think? — 7 out of 10? The business of the 'phone suggests that the *publication* of standards of service only encourages criticism when they are not met. Personally, I would be satisfied to know that standards exist and that performance is monitored. I do not particularly need to know the details. Nor do I need to be told, several times, that staff wear name badges: this would become obvious soon enough. However, as one of the organisation's commitments is *'openness and consultation in everything we do'*, I guess they have no option but to tell us!

Mike Lowing
Brightwell Baldwin

Travel grants

Grants in the range £75-£100 are available to help members with the cost of attending meetings (see *Circulation 38*). The scheme is open to anyone, but is intended mainly to help students or younger members whose travelling expenses are not met by an employer.

Please apply to the Hon. Secretary (**Paul Younger**, Department of Civil Engineering, Cassie Building, University of Newcastle, Newcastle upon Tyne NE1 7RU, Tel. 0191 222 6000 ext. 7942, Fax 0191 222 6669), including details of the meeting, whether a paper or discussion is to be presented, the total costs and benefits of attendance, brief details of your financial situation, your background and your aspirations in hydrology. A brief supporting letter from a supervisor is also required.

Successful applicants are expected to produce a short report of their experiences in attending the meeting.

Internet hydrology

For those seeking a discussion list for research in hydrology, don't neglect the team at *Monash University* in the eastern suburbs of Melbourne, Australia:

Mail-list: hydro-1
E-mail: listserv@vifp.monash.edu.au
How to?
subscribe hydrology *firstname lastname*

Frank Law
Institute of Hydrology

Radar versus rain gauge revisited

(or should we even try to use radar to measure rainfall?)

It is clear from having attended a number of hydrological radar meetings in the past two years that the question of radar performance versus rain gauge and how best to combine the two (if at all) is still largely unresolved in the minds of many people. In particular at the recent BHS weather radar meeting at the ICE in January there was some discussion on exactly this topic. I do not presume to answer this question in what follows, but offer suggestions and perhaps a few comments to stimulate some debate.

First, and perhaps most important, is that a radar measures returned power from a volume of scatterers. That power is converted to measurements such as reflectivity (hereafter denoted as Z) by a process of calibration. Calibration is an electronic process — gauges do not and cannot calibrate a radar. Having obtained Z one can then estimate rainfall rate (R) using a suitable Z-R relationship. If an incorrect Z-R relation is used, then one can be in error by up to around 40% in the estimate of R.

As an example, it is very common in convective precipitation events to have hail in the precipitation. If the Z values from hail are converted to R using a standard Marshall-Palmer Z-R relationship, which is used in many studies, the error can be of the order of several tens of mm h^{-1}. One might ask the question how many users of UK radar data consider, and if appropriate, account for the fact that snow or hail may be contaminating the R values? Furthermore, should the Met. Office be responsible, as a data provider, for correcting for these effects? Work is already under way by the Met. Office to address these problems.

Correctly estimating the distribution of particles is all important in choosing the Z-R relationship, and this is by no means a trivial process. Battan (1973) gives several pages of Z-R relationships for different rainfall types, different precipitation types and (often, wrongly, neglected) different radar frequencies. No one of these relationships is suitable to describe the life cycle (both spatially and temporally) of a precipitation event. Some very interesting work is being carried out to overcome some of these problems of Z-R relations that vary in real-time. One such study, that provides other references, is Rosenfeld *et al.* (1993).

Second, radars do not measure at the surface and cannot do so because of problems of topography or large areas of water corrupting the data (ground clutter). A radar's beam will generally increase in height as it travels out in range from the radar and so the distance between the beam and the surface increases with range. Over longer distances the earth's curvature also plays a part in this separation. Therefore having first estimated R at a height h, R(h), from Z(h), then one has to determine R(0) from R(h) by assuming a profile that can account for being in snow or ice at the higher levels, through the melting layer (the Bright Band problem) to the lower levels, where there is possible evaporation and orographic enhancement. In assuming this profile one is automatically provided with a means by which to correct for these problems described.

Within this procedure it might be argued that more effort should be concentrated on combining vertical measurements, from a number of instruments including vertically pointing radars, with dynamic microphysically-based models of the profile — a number of such models do exist, and while they do have various deficiencies one could argue that little effort would be required to upgrade them.

Third is the problem of attenuation at C-band — the frequency of many of the world's operational radar systems (with one notable exception, the USA, whose motivation for having a radar network is somewhat different to the UK's). If not corrected, attenuation can be a real problem, but worse still, many correction algorithms are cumulative and hence extremely unstable. It is vital to correct on a radar bin-by-bin basis and this is best done on the Z values.

Of course attenuation is only one part of the propagation effects that a radar beam will undergo. In systems that make phase measurements they too can be affected. The use of differential phase measurements (Φ_{DP} and K_{DP}), using polarisation diversity, that at S-band offer improved estimates of R (for the heavier R values), can be badly affected at C-band by a backscatter phase component. Another polarisation parameter, this time an amplitude measure, traditionally proposed to improve R estimates is differential reflectivity (ZDR) which is also badly affected by differential attenuation effects at C-band frequencies and above.

A number of other problems have to be overcome with radar measurements, but they are of lesser importance when calculating estimates of R. Typically these include anomalous propagation,

along with beam refraction and ducting, the presence of strong updraught/downdraught columns and bistatic scatter. Having mentioned all these problems, why consider using a radar at all to estimate R? Well, what is the alternative? Rain gauges are a single point measurement and only represent the actual rainfall at the gauge site itself: leaving the instrument problems aside, one only has to be a few kilometres either side of the site and the rainfall can be very different. The amount of difference will depend on the meteorological event, but it will be at its worst in localised heavy convection — just the type of event one would like to measure well from the point of view of flood forecasting.

Further, for many applications it is necessary to know about the spatial distribution of the precipitation. and even dense gauge networks cannot resolve this as well as radar measurements. Many radars have range bins that are only a few hundred metres in length, with an angular resolution generally of 1°. It is only when converting from polar data to a Cartesian grid that one can lose accuracy (either as a consequence of the methodology used, or as a deliberate action to reduce the quantity of data). Remember too that radars can be used to provide estimates of many other measurements besides rainfall, and not all applications of radar require measurements at the surface.

If rain gauges give such inaccurate measures of R as one moves further from a point, why use them? Why not simply use radar measurements? Well the answer is that if one is using a radar to attempt to measure values of R at the surface, then it should be compared with independent measurements made at the surface — but how? Immediately one tries to make this adjustment (*not* a calibration) one faces a problem. The decorrelation time of the precipitation is generally much shorter than the time taken from it being sampled by the radar to being recorded in the rain gauge. Hence even a perfectly calibrated radar will not give the same answer as a gauge directly under the sample volume, because they are not measuring the same thing. Rapid response rain gauges are one answer, but are there other methods that can be used?

Gauge adjustments should be done using rainfall accumulations over integration periods of 30 to 60 minutes, employing standard methods to combine rain gauge data. By using accumulations over the longer integration times one can provide more appropriate comparisons between gauge and radar. In convective rainfall the typical lifetime of individual cells is around 60 minutes and hence considering accumulations of this length provide a much more appropriate comparison of storm totals. One can also build in to this methods for assessing in real-time whether a gauge is performing well enough to be useful in adjustment processes, but these methods are best done on the polar data — simply because the statistics of the data relate to the polar nature of radar measurements and not to the Cartesian form the data are often presented in (Archibald, 1994).

By way of a summary one might say that neither radar nor rain gauge gives a "true" value of surface rainfall everywhere. In moving towards a measure of this "true" value one must have suitably calibrated equipment and methodologies for adjusting the spatially superior radar data by gauge measurements that take account of the meteorological systems present. Of course by improving measurement accuracy one will also improve forecast quality.

A great help to research in the field of radar hydrometeorology would be a radar archive that was as comprehensive as that for rain gauges. This will never be so, and the UK has fallen behind in this respect. The Met. Office and the NRA are now taking steps to address this issue.

I have raised many points in this note and attempted to answer some of the questions: I hope this has been achieved to some degree. The answer to the question in the sub-title is of course a resounding "yes". The main point not explicitly stated already, however, is the multi-disciplinary nature of radar work: there is a need for hydrologists, meteorologists, electrical and civil engineers, physicists, geographers and mathematicians (in no particular order!) to combine their knowledge in order to continue to move this science forward at the speed of progress as it has had since the late 1940s.

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Dr Paul Hardaker
Metstar, UK Meteorological Office

Low flow management

BHS Pennines Section Meeting
University of Huddersfield
2nd November 1994

Notoriously abundant rainfall in much of the Pennine region means that the problem of low flows has received less media attention here than in some other areas of the UK. However, it is still a cause for concern and around 50 members attended this meeting in the Department of Geographical and Environmental Sciences, focusing on the hydrological and ecological importance of low flows and on various aspects of their management.

Hilary Smithers (NRA North West Region) opened the meeting by reminding the audience that sustainability is a key concept at the heart of UK water policy, necessitating attempts to balance conflicting needs, to prevent further environmental damage and to provide long-term holistic solutions. Methods to achieve such solutions may include reduction or revoking of abstraction licences, approaches such as bed lining and augmentation, the recycling of surface water or the relocation of abstraction points. She explained that the achievement of such a solution is rarely simple. There is a need to establish the nature and scale of the problem, to assess cost/benefit ratios and to negotiate agreements with interested parties. The need for realistic time scales was also stressed.

The Lowther scheme is the only one of the 20 Priority Sites for Low Flow Alleviation (ALF) identified by the NRA nationally that occurs in the North West Region, and was described by **Matthew Scott** (NRA North West region). Concern arose because tributaries of the

Lowther have been intercepted to augment Haweswater inflows, causing extensive lengths of dry river bed with consequent environmental impacts. Surveys of water resources and fisheries/invertebrates in 1990 and 1991 revealed that only 8.9% of average annual runoff is allowed to pass as compensation or prescribed flow, whereas 15-30% is required to safeguard fisheries. The water resources scheme has resulted in a loss of spawning and rearing habitat and of migratory juvenile fish.

Recommendations therefore included the setting or increasing of prescribed flows in particular target areas, the increase of compensation flow from Wet Sleddale reservoir during November and December, and the screening of all intakes to prevent fish loss.

As this is an ungauged catchment, there was a need to estimate flow passing each intake. HYSIM was used to make predictions which were verified on a neighbouring gauged catchment ($R^2 = 90.9\%$ for monthly values, 84.7% daily) and then applied to produce flow duration curves for individual catchments in the Upper Lowther.

In the final section of this paper, **Natasha Fellowes** (NRA, North West Region) discussed the economic justification of ALF schemes. She suggested that cost/benefit analysis is seen as a tool to best allocate scarce financial resources, but that the principle of discounting places less emphasis on future problems and therefore takes little account of the need for sustainable development. It is also difficult to assign an economic value to all the benefits accruing from environmental schemes. She outlined the various approaches of economic appraisal used within the NRA, and presented case studies for the Darent and Misbourne schemes.

The main method adopted in each case was contingent valuation (CVM), involving surveys of the public in terms of willingness to pay for various scenarios. Particular difficulties with this type of analysis in the North West region result from the lower public profile of the problem, the remote nature of the sites and the high relative cost of analysis for small projects. The approach to benefit assessment in the North West has therefore been based on a desk study of potential benefits, including hedonic pricing of improved game fisheries (salmon and sea trout) and consideration of aversive expenditure by removing the need for annual restocking. Natasha concluded that cost-benefit analysis will continue to be used, but that there is no means available for assessing the intrinsic value of a habitat. There is potential in CVM techniques, but in the meantime a practical approach must be adopted.

Questions included the requirement for optimisation of HYSIM, but the authors responded that little was needed due to the care taken over initial data acquisition. **Liz Kaar** (NRA North West region) asked about improvements in quantifying intangibles, and was informed that the NRA report recommends the use of the Delphi technique of consulting a panel of experts in order to reduce costs. **Keith Beven** (University of Lancaster) asked whether low flow alleviation is a significant problem in the North West. The authors replied that it is, in that the profile has been raised to the point where one scheme is on a national priority list and the legal aspects must be satisfied.

The second paper was presented by **Ian Johnson** (Institute of Hydrology) and concerned simulating the ecological impact of low flows. He reported that discharge-based statistics such as percentile flows are useful for indicating the relative severity but provide no measure of the negative impacts of low flow periods upon fish, macroinvertebrates or aquatic macrophyte populations. One technique being increasingly used in the UK is the Instream Flow Incremental Methodology (IFIM) which provides a quantitative measure of the "well-being" of the river ecology. It defines the available physical habitat for individual target species at various life stages, and assumes that preferences for a range of flow velocity, depth, cover and substrate will cause habitats to be selected in order of suitability. IFIM is implemented by means of the computer model PHABSIM, which is used to generate relationships between habitat and discharge. Ian described the need for calibration with field data and stressed the importance of obtaining habitat duration curves, since a relatively small change in flow can have an important impact on ecology. He acknowledged that IFIM requires a large amount of data collection, but indicated the advantages of being able to simulate the effect on habitat of a changing river regime.

A basic requirement for applying the IFIM technique is an estimate of the low flow regime at the site of interest. In the absence of gauged data this may be estimated by the Micro LOW FLOWS software package, which was described and demonstrated by **Karen Irving** (Institute of Hydrology). The model is based on catchment characteristics, including data from soil association and standard rainfall maps, and can provide estimates of flow duration curves at over 25,000 river sites within the UK.

Next on the programme were two student papers, allowing postgraduates to report on their research in progress. **Cath Padmore** (University of Newcastle upon Tyne) discussed the need for a geomorphological classification for the assessment of environmentally acceptable flows, aiming to extrapolate PHABSIM from reach to sector or catchment scale and to produce a working channel typology with national application. Data collection sites include a variety of morphological units such as boulder channel, bedrock channel, cascades, pools and actively wandering braids. A regulated reach and the seasonal effects of vegetation are also to be considered.

Rob Lamb (University of Lancaster) described his work on estimating master recession curves, developed using MATLAB. He suggested that automation has the advantage of handling large amounts of data which are increasingly stored in digital form, but that such an empirical approach still requires judgement in selecting representative recessions, especially as data may be sparse for a particular range of discharge. The interactive system therefore allows a flexible approach to the prediction of base flows.

The final paper of the afternoon moved away from the hydrology and ecology of low flows to a consideration of operational and economic aspects of management. **Keith Ainsworth** and **Mike Tunnicliffe** (Yorkshire Water Services Ltd) reported upon the national metering trials which were set up in 1989 to provide information on the costs and benefits of widespread domestic metering in the belief that this may provide a solution to "the apparently continuous rise in water consumption".

The effect of the trial on demand in Yorkshire was a decrease of 13%, and this was maintained after the end of the trial. Nationally the average decrease was 11%, and demand was found to be related to occupancy rate. In Yorkshire, some 80% of properties saw a reduction in water bills, to an average of 29%. However, metering does carry significant installation and operating costs. The former have been calculated at £165 for an internal meter and £205 for an external meter, and the latter at £19.08 annually per property in excess of the rateable value system (1992 prices).

At the end of the trials, participants in Yorkshire were allowed free choice to remain metered or to return to water charges by rateable value. Only 37% chose to retain the meters. Keith concluded that metering is a viable option and that some reduction in demand may be associated, but that several customer issues are still to be resolved. He acknowledged that an adverse effect on a number of customers (for example large families or people with medical problems) may generate considerable publicity, and suggested that the trials have provided valuable information which will assist in the decision making process.

Matthew Scott (NRA North West) asked about alternative methods of charging for water and was informed that the Council Tax cannot be used for this purpose. **Mike Law** (NRA Northumbria/Yorkshire region) raised a question regarding statistical control

in the comparison of demand with unmetered customers, and **Dave Stewart** (NRA Northumbria/Yorkshire region) asked under what circumstances a water company would wish to introduce a policy which would increase costs and reduce income, suggesting that this might necessitate a change to higher tariffs in future.

The papers covered a wide variety of concerns on the topic of low flow management and provoked some interesting discussion. Thanks are due to all the speakers for their contributions.

Dr Jill Labadz
University of Huddersfield

News from Members

New year honour

Congratulations to **Professor David Newsome** on his award of the CBE in the New Year's Honours List.

Members' new venture

We've just had details of a new organisation *Water Resource Associates*, a network of consultants in hydrology, water resources and environmental issues, comprising five directors and 12 consultants. The group contains *two* ex-Presidents, and only one of the 17 is *not* a BHS member, so it is likely that any problem on which you might be seeking outside help will fall within their sphere of interests. Please write, telephone, fax or e-mail for a brochure to Water Resource Associates Ltd, P.O. Box 838, Wallingford OX10 6DX, tel: 014191 838190; fax: 01491 838790; e-mail 75337.2741@compuserve.com

President's baby

Sue Walker and her husband, Nick, are delighted to announce the safe arrival of Catriona Nicola on 18th January 1995. Catriona weighed in at 3.98 kg (81b 12½ oz for the traditionalists!). It appears that Catriona is not a natural hydrologist — judging by the way she screams at bath-times!

Groundwater flooding: a time to run?

BHS Southern Section Meeting Imperial College, London 7th December 1994

There were two speakers at this meeting: **Simon Taylor** (Sussex Area Water Resources Manager) on the cause of the Sussex floods, and **Helen Lucas** (Hydrogeologist, NRA Thames Region) on rising groundwater in London.

Simon began by considering the cause of the floods which had inconvenienced Sussex and led to headlines throughout the country. The River Lavant rises in the South Downs as a Chalk stream and passes through Chichester on its way to Chichester Harbour and the sea.

The average rain in winter is 600mm, but in 1993-94 the total was 850mm. The Chalk aquifer became full and the Chilgrove well at the catchment head became artesian, resulting in huge spring flows and some direct surface runoff (see *Circulation 41*). The valley bottom ditches became full and roads became river channels. This was fine until the water reached a village, then flooded it. Crystal clear groundwater — rather than the normal silt-laden flood water — caused the flooding and closed the roads and villages. The problems became even worse when the flat alluvial coastal plain was reached and the river burst its banks, spreading across the coastal plain. In Chichester itself the city centre culverts could take about four cumecs: the river flow was eight. Surcharging took place and pumping was required to cream off the top of the flood. Major disruption was caused to the whole of the city and its surrounding areas. Consultants Posford Duvivier were appointed to analyse the floods. Once the groundwater level at Chilgrove reaches 69.5 m AOD, with further heavy rainfall river levels and flows rise rapidly. This level, which indicates a zone of rapid transmissivity in the Chalk, will now be used as an alarm trigger .

Around the north-east of the city the flow took another route, flooding gravel pits and cutting roads on its path to the sea. The water then ran up against the coastal defences and became tide-locked: this water had to be pumped over the sea wall. Measurements were taken in all sorts of strange locations, but perhaps the oddest was in the fast lane of the A27 Westhampnett bypass.

Mike Price asked whether there was leachate movement in gravel pits and what were the groundwater flows and levels. Simon replied that this was a high transmissivity zone, but he was unsure about leachate movement. Packer tests in the catchment did seem to indicate that the levels were in this high transmissivity zone. Gravel pits were acting as large wells. There was some indication of leachate movement, but not huge problems. More gravel digging could provide another threat.

Howard Wheater asked what was the frequency of the event. This was very difficult to calculate on the river because of the short record. Individual rainfall events were not excessive; groundwater records were very long. A combined probability analysis gives groundwater 1 in 100+, rainfall 1 in 40, while the river only has 17-year records. Local archives show flooding every 25-30 years but this event was more serious. More work was required. The present city flood defences will protect against 1-in-25-year floods and the MAFF indicative standard is 1:100. The upper Lavant valley villages were more difficult and the majority of the defences approach MAFF indicative standards.

Briony May asked what warnings were given — were people aware? Simon replied that warnings had been given, but not always noted. Although initial warnings had been given in Chichester, but events had later gone out of control. There was some difficulty with landslip erosion, mainly on new road embankments and similar landforms.

Mike Mansell-Moullin asked what Direct and Indirect damage levels were, and whether there were also two sets of flood events, which meant a frequency curve drawn from one point. Simon did not disagree with this. He said the NRA were being careful and not stating exact levels. Direct damage was around £6M but the potential was for some £16M.

Simon illustrated the possible routes for an alleviation scheme. Asked was there evidence for something happening in three weeks' time, he said levels were around average, like the last year.



NRA Resources Officer Ross Mackintosh measuring river levels on the new A27 bypass

(Photographs by David Nicholls)



A car stranded on the old A27

Rising groundwater in London: an update

Helen Lucas began by reporting that water levels were rising in the Chalk beneath London by some 2.5 m per year. This is causing increasing concern for tunnels and deep basements/foundations in the capital.

The Chalk aquifer is overlain by younger clays, silts and sands. Recharge comes from the Chilterns and the North Downs. The aquifer had been developed extensively for water supply and resource exploitation had drawn levels down well below sea level. The original piezometric level was some 7m AOD. Since 1966 abstraction in central London has decreased from around 80 to 30-40 Mcumecs/year because there is less industry in the inner city. Groundwater levels have risen from -83m AOD to -47m AOD since the 1970s. All the city's buildings and tunnels were built during the period when groundwater levels were depressed.

In 1989 the construction industry's research association CIRIA concluded that there was a serious problem, and that better monitoring was required, along with a strategy to deal with the problem: the NRA took this on. Thames Water Utilities abstraction aspirations have aided the monitoring. Data were collated and published every year as annual groundwater level maps. The data have been linked to a finite element groundwater model, which has been uprated and extended over the last five years. The model is giving very good results, both in the form of groundwater hydrographs and as maps.

Model extrapolation is highly sensitive to abstraction regime. Using the baseline scenario, groundwater levels will reach 0 AOD by the year 2040. This would lead to artesian conditions in areas such as the Lea Valley. Different abstraction regimes can give a difference of 10-15 m in level for 2040. As that date becomes nearer the prediction becomes more refined.

The controlling strategy requires increased abstraction. Many PWS licences towards the City were underused because of the depressed levels. Greater use would help to alleviate matters and could stabilise the situation: up to 70Ml/day could be abstracted for this purpose.

There are limitations for TW Utilities because a number of small abstractions (typical yields of 2Ml/day) would be required. Quality and salinity problems abound and buying sites for abstraction/treatment works in the City would be prohibitively expensive. The problem therefore comes back to the NRA, and pumping to waste may be required in the future. The costs of this may fall on the owners of the assets.

Mike Price said it was difficult to abstract the water from the City. He estimated 35 Ml/day coming in and asked whether it was possible to catch it on the outside of the basin to help solve the problem. Helen agreed: we needed to go out from the centre and abstract from the confined aquifer to prevent problems of Chalk streams drying up.

Howard Wheater asked at what levels of rise did people become seriously worried. Helen said London Transport were already seriously worried and some limited pumping might already be occurring. Simon Taylor said that the water would be pumped either into the supply or to the sewer system. The infrastructure was already there and the flow would eventually reach the Thames.

Charles Jones asked if the NRA found that model boundary conditions were very sensitive, and whether the old spring system would be regenerated. Could this be taken into account in the modelling, along with throughflow, leakage and abstraction? Helen said the water had been looked at as a useable resource. The water balance was reasonable because of the large outcrop, but this was a general overview and could not deal with the individual spring systems.

Peter Midgley
NRA, Worthing

Prize for New Zealand tales

The prize for the best article in *Circulation* has been awarded to **John Adams** for his travellers tales from New Zealand – Aotearoa (*Circulation 42*). This was full of detail about the practical organisation of hydrometry in that part of the world, but managed to be a most entertaining read as well.

Planning water supply systems

BHS National meeting
University of Newcastle
16th December 1994

Speakers were invited to present papers describing techniques currently in use for planning the development and operation of water supply systems. Discussion of the validity of the methods, their advantages and limitations, was encouraged. This report aims to give a very brief outline of the papers, together with a summary of points raised in discussion. Full copies of the contributed papers are published by BHS as *Occasional Paper 4*, obtainable from *Angela Gurnell* (address below).

The first three papers described aspects of work carried out in support of the NRA's recent *Strategy for Water Resource Development*. **Nigel Fawthrop** and **Glen Watts** described methods used by Anglian Region to calculate the yields associated with possible additional reservoirs or transfers from the Trent. Four existing computer models, for the Trent – Witham – Ancholme , Rutland, Grafham, and Ely Ouse – Essex, were adapted and linked. This was done by ensuring that output from each model could be used as input to the next. Data were available for all rivers from 1972, with records for the Trent and Witham extended to 1932. About 300 simulations were carried out altogether, establishing (by trial and error) control rules for use in the Ely Ouse – Essex system when additional reservoirs were incorporated. This large volume of work was carried out using existing in-house models by experienced users. It was consistent with earlier work in the region, and allowed continued co-operation with the water companies. There were inconsistencies between models but these were not thought to be significant for the Strategy.

Discussion raised the issue of reliability, and here the different models used different assumptions. The Ely-Ouse – Essex model calculates the maximum constant yield available over 60 years of record, whereas the yield of Rutland includes the effect of water conservation measures. Since the work was calculating marginal rather than absolute yields, these discrepancies were not felt to be critical within the applications described.

Enda O'Connell pointed out that the large variations in the Strategy demand forecasts meant that it was necessary to consider a wide range of scenarios, even if some were thought very unlikely. This was also true of north-west England, where the impact of possible redeployment of Lake Vyrnwy was discussed by **Hilary Smithers** and **Tim Wyatt**.

Their paper described some of the work carried out in conjunction with North West Water Ltd using Power and Water Systems Consultant's generalised Modular Optimisation/Simulation Program (MOSPA). This has been widely used in the region for a number of years, so work again drew on previous experience. The Vyrnwy component of the existing Southern Command Zone model was enhanced to allow detailed representation of the operation of the water bank. Daily data were used for the period 1932-1987, which covers the most severe historic inflow sequence in 1933/4. A range of diversion scenarios was examined, giving firm direct supply rates ranging from the current 173 Ml/d, to a minimum of 60 Ml/d, which is required to maintain local supplies from the aqueduct.

Monthly retention levels were optimised for each scenario assuming constant regulation releases. These were then used in simulations to calculate total supply availability to NWW over the record period. It should be noted that casual water forms a significant part of the total. Time series of regulation releases were also provided by NRA Severn-Trent using their simulation model of the Severn. These were in turn determined by different Severn-to-Thames transfer capacities.

At this point inconsistencies were discovered between the models, and assumptions had to be made about future operation of the water bank. Despite these limitations the work illustrated that even with changes from direct supply to regulation use, the proportion of inflow lost as spill and flood release remained at over 35%. By enhancing the capacity of the Vyrnwy aqueduct it might be possible to provide for increased Severn regulation in addition to maintaining the current value of Vyrnwy supplies to NWW. However this would need to be modelled using appropriate system boundaries.

Discussion centred mainly on detailed aspects of MOSPA. Enda O'Connell suggested that the use of different data sets would allow the robustness of the model to be checked. Tim Wyatt replied that the optimisation was driven by two factors: cost minimisation over the whole record — not just a single dry or wet year — and reliability. This ensured robustness. **John Ringham** confirmed that the model could be used with a variety of time horizons.

Chris Page then described how results from models including Vyrnwy and the Anglian ones had been incorporated in the allocation model, RESPLAN. This was used to find the least cost development plan for a number of scenarios, and the marginal cost of alternative plans. The strategic system was represented by a network of sources and demands, linked by transfers. A five-year time step was used to calculate costs and transfer rates over the 30-year planning period.

In response to questions, Chris said he was able to use RESPLAN without any changes; computational requirements had not been a problem, so he was not tempted to interfere!

The procedure did not necessarily give an optimal solution, but an adequate one. He was also asked about artificial recharge, which was considered as a local rather than a strategic option in the Strategy.

Gerry Spraggs asked about the use of canals. These were potentially useful in Anglian and Thames region, but East Anglia proved to be self-sufficient, and in Thames the transfer rates required could not be achieved by canals. Tim Wyatt asked what had become of Kielder: schemes to use this water were uneconomic because of the capital costs of pipelines to Anglian region.

There was discussion about the discount rate used in the calculations, and John Ringham pointed out that water companies were not happy with the Treasury's recommended rate of 6%. Modelling had not taken account of changes in operating costs over the time period.

The morning session ended with a period of general discussion. **Ben Piper** said that the strategy had set the field, and asked where one went next. Needs would arise on different timescales in different regions, and it would be necessary to analyse at a more detailed level. Enda O'Connell asked how we should build environmental sustainability into our plans. Chris outlined the environmental work carried out for the strategy and commented that it was difficult to quantify. He did not think we had defined environmental

sustainability. **Michael Lloyd** thought the strategy should have paid more attention to energy consumption, and pollution too. There was support for the idea that methods were needed for costing the environment, but a shared perception that it would be difficult.

Nigel Fawthrop pointed out that individual schemes were subject to detailed environmental assessment, but RESPLAN was only a high-level tool. Several of the NRA modellers agreed that the work had been a useful learning experience, and had demonstrated the need for a single inter-regional model for further work.

Paul Crockett underlined the importance of liaison with the regional water companies. **John Hall** commented on the age of the models described, but it was generally agreed that there was no point reinventing the wheel, and the work had demonstrated their robustness.

The afternoon session began with a paper written by a large team from IH and NRA Northumbrian and Yorkshire region, describing the application of the River Flow Forecasting System (RFFS) and HYRAD software packages to real-time rainfall and river flow forecasting in Yorkshire. RFFS has a generic algorithm structure which allows a wide variety of models to be included in a specific application. These are all provided with updating facilities to enable the use of recent telemetered data to improve forecasts. Any updates can be propagated downstream. Calibration and reconfiguration to a new river network are both straightforward. Sub-networks can be operated separately.

The model algorithms incorporate strategies for dealing with missing data. HYRAD complements RFFS by providing a linked weather radar system operating in real time. It acquires data from a variety of sources. In Yorkshire the RFFS has mainly been set up to provide a four-hour warning of flooding in the middle and lower reaches of main rivers, including the tidal Ouse. In this region there are around 5000 houses in unprotected flood plains, and the potential annual benefit of timely warnings is estimated to exceed £1m. The paper described how the Yorkshire system is set up, and also lists other applications.

In the second paper of the afternoon **Paul Jowitt** described how the computer package Droughtwatch has been used in Northwest England to monitor risks to water supplies and reliability during dry periods. As a drought develops, operating policies may need to be adjusted if conditions become more severe than the design. This is frequently necessary on an individual reservoir basis.

Droughtwatch utilises historic records and current reservoir stocks to calculate the maximum yield sustainable under various inflow scenarios. It can also be used to estimate month of failure if the current draw-off rate is maintained. Later in the season it can be used to assess prospects of refill, again under various inflow scenarios. Droughtwatch is based on critical period techniques developed and applied for many years in the north-west. A limitation of the technique is the lack of long historical data sets for many of the region's reservoirs. These are currently generated by comparison of estimated mean annual flow ratios.

In discussion, Paul agreed that Droughtwatch was not predictive, but its calculations reflected the long series of historic records used to derive the statistics. Bob Moore suggested that the analysis could be conditioned on several factors such as the current storage state. In the Thames Region models were conditioned on current hydrology, e.g. rainfall or groundwater status, but Droughtwatch preferred to leave the choice to the user.

In a stimulating presentation John Ringham gave the water supply operator's view. He wanted hydrologists to take a broader approach. Supply systems were dynamic because of the variation in hydraulic and service level, as well as hydrological, constraints. Existing models at different levels were being linked into a hierarchy. This process is described in detail in the paper. Model integration was seen as the means of improving control of reliability, better budget forecasting and monitoring, and improved response to pollution incidents.

On the Dee these occurred roughly 10-15 times a year, and water lost was equivalent to the total Liverpool demand for 24-72 hours — a significant management problem. Data issues were highly significant to the operations manager. Information tends to become aggregated for presentation to senior management. This seriously reduces its value to the modeller. Time steps may also be too long. The corporate database is not a comfortable home for the modeller's data, and he has little control over its security.

In response to a question from **Paul Hodge**, John described how reservoir control rules are optimised to allow maximum use of casual water, varying seasonally, and also the incorporation of a variety of electricity tariffs, including pool pricing.

Derek Jamieson's paper described Eureka EU 487, a wide-ranging international collaborative research programme which aims to develop a comprehensive decision-support system for integrated river-basin planning. It combines GIS, database technology, optimisation and expert systems. The objective is to provide a seamless system, to empower the non-expert decision-maker. Within the foreseeable future, models will be selected and fitted automatically, with safeguards to prevent the user making inappropriate choices. Modelling techniques are likely to be relegated to the status of an analytical kernel in a decision-support system.

The system aimed to be all-encompassing, including rivers, aquifers and estuaries, lakes, reservoirs and coastal waters, in terms of both water quantity and quality. Each application would be customised to address the significant issues. The Thames catchment has been used for a prototype application, and a pilot application is nearing completion in Mexico. Implementation costs were difficult to estimate, but extremely large compared to conventional modelling! Data preparation is a highly significant component. The overall aim was to provide an effective framework and decision-making tool for planning major water resource developments, for example to select suitable sites for new reservoirs.

This paper generated lots of questions. It emerged that models chosen for incorporation were mainly rewritten by the project partners to avoid issues of intellectual property rights. **Paul Younger** was concerned that the vital updating of the knowledge base would be neglected. **Matthew Hays** wondered if it would become available on the Internet, but Derek pointed out that the developers were looking for an eventual profit! **Paul Crockett** invited us to consider how far WAMS met the aims of this project. Derek replied that Eureka EU 487 was a decision-support system whereas WAMS was a management information system, and Eureka EU 487 had not yet been networked: unfortunately it had not been sufficiently advanced to bid for WAMS. **Rod Hawnt** suggested that the two systems were complementary.

K. Vijayaratnam gave a short presentation emphasising the importance of considering all the (possibly conflicting) issues in a major water resources project such as dam construction. His multi-criteria method was used to measure the extent to which objectives were met by particular solutions.

This was followed by a wide-ranging general discussion. **Sue Walker** set the ball rolling by reminding us that earlier speakers had emphasised that experts are needed to run models, whereas Derek Jamieson wants the non-expert to run models and use them as a basis for decision-making. Which was preferable? Derek drew the analogy of a car driver not needing to know how the engine works in order to get from A to B. However several members of the audience thought this was highly risky: when the car broke down he would have to call in the real experts.

Paul Jowitt pointed out that there could be four passengers in the car, all with different ideas about where they wanted to go. Even expert planners will have different multi-objectives, and therefore resolution of conflict is the key

to success. This point was echoed by Paul Younger, who emphasised that the operator of such a wide-ranging system also needed a broad remit, rather than fragmented local responsibilities. Derek did not disagree, but he pointed out the value of a tool which allowed options to be evaluated from different standpoints.

Enda O'Connell asked what QA systems were incorporated into Eureka EU 487. Derek said that the system assumed that data were clean and quality-controlled by the pre-processing, but it was intended to provide audit trails, to enable decision-making paths to be verified and to aid post-project reviews. John Ringham was concerned that the use of large systems such as Eureka would stifle innovation, and discourage lateral thinking, which often produced cheaper solutions.

Tim Wyatt asked about the role of optimisation, and also suggested that the use of public domain models was in danger of limiting the project to yesterday's technology. Derek replied that decision support capability was still under development using the latest technologies. The only public domain software included was FAO's CROPWAT, for demonstration purposes.

The meeting concluded with thanks to all the speakers, to the many contributors to discussions, and to the audience — many of whom had come considerable distances.

Hilary Smithers
NRA North West Region

Coastal flooding in the Clyde estuary

Scottish Hydrology Group and Hydraulics Study Group
University of Glasgow
8th December 1994

At a joint meeting of the Scottish Hydrology Group and the Scottish Hydraulics Study Group, **Dick Collar** and **John Townson** (Strathclyde University) and **Yusuf Kaya** (Babtie Shaw and Morton) presented the findings of a study of coastal flooding in the Firth of Clyde, which had been commissioned by the Clyde River Purification Board.

In January 1991 a very severe storm surge had occurred in the Firth causing flooding in several coastal towns. Rothesay in particular suffered damage estimated at £4.5 million. This extreme event seemed to be rather localised, with a return period possibly of several hundreds of years in the Inner Firth but only around 15 years some 30 km further up the estuary in Glasgow. Indeed, there seems generally to be little relation between the magnitude of tidal surges at each end of the estuary.

An analysis of 80 years of tide data, and also of the susceptibility of property to flooding, suggests that, typically, around £300,000 damage occurs each year along the Clyde coast, and that a reasonable four-hour warning might save around one-third of this total.

A coastal flood warning scheme will require sophisticated hydrodynamic modelling of the Firth and its estuary, with a variable grid size between 1.5 km and 200 m, and interfacing along an Irish Sea boundary with the Met Office 12-km-grid storm surge predictive model. It appears that more than a third of the any surge is generated locally within the area rather than propagating from the Irish Sea. Forecast wind speed and direction are also necessary inputs, both for surge effect and for surface wave prediction.

A modelling study suggests that for several surge events, monitored at eight sites, an accuracy of around 0.1 m in water level is achievable. It looks as though a warning scheme may be practicable, both technically and in cost-benefit terms.

James C Curran
Glasgow

PhD thesis

Self-mulching properties of soils

Anthony William Warren's PhD thesis (from Birkbeck College, University of London) is entitled *The self-mulching properties of soils*. He describes an examination of the inherent properties of soil that control evaporation of water. After differentiating between the effects of vapour diffusion and capillary condition within soil pores, capillary conduction is shown to be of prime importance rather than vapour diffusion traditionally thought of as the major control of evaporative flux.

Rates of vapour diffusion and capillary conduction are quantified in a series of experiments that examine their influence upon evaporation from columns of non-porous particles, porous aggregates and natural soils. the effects of varying soil surface structure and of various superimposed mulches are also investigated.

Prof. Ian Reid
Loughborough

Environmental impact assessment of river engineering

Scottish Hydrological Group Meeting
Edinburgh
19th January 1995

Almost fifty people gathered on a very wet January night for a talk by **Amanda Chisholm** of the Babtie Group. Amanda gave an excellent overview of the environmental impact assessment of river engineering works, covering the legislative aspects, practical aspects of its application to river engineering, and highlighting some of the major issues.

Assessment was both a procedure and a process by which issues and problems could be identified and effective designs produced. The history and development of environmental assessment was charted from its roots in the USA in 1970, to the more recent

requirements of European, UK and Scottish legislation. Anomalies and deficiencies in present legislation were outlined, particularly with regard to the timing of the environmental assessment in relation to the project design.

Amanda outlined the information generally required to carry out an assessment, highlighting the logical progression of the assessment process from initial scoping through assessment of significance, evaluation of impacts, consultation and consideration of strategies for mitigation. The importance of having a wide view of impacts and possible interactions was stressed. Potential impacts from river engineering works were discussed: the short-term construction impacts, and longe-term ecological impacts. The formulation of an Environmental Statement was discussed: this is a legal document, and it must also be easily understandable by the public.

A number of important issues were identified. A common problem was the uncertainty in making difficult comparisons between different types of issues associated with different alternatives. Identifying the appropriate level of detail for any particular assessment, and the different types of specialist skill required, demanded of the person leading the investigation a particular level of experience. In Amanda's view, he/she ought to be a generalist, whose overview would not be biased by a special interest. This was important if a well-balanced study was to be carried out. In summing up, Amanda stressed the need for an integrated design approach which encompassed environment, engineering and economics.

In discussion, **Dr Vanessa Brazier** (Scottish Natural Heritage) said that she had experienced a wide range in the quality of environmental assessments, and asked if anything was being done to improve standards generally. Amanda outlined the intended role of the Institute for Environmental Assessment and the Association of Environmental Consultants. These were intended to be self-regulating bodies. Quality was often also related to the funds made available for the assessment.

Richard Hackett (Edinburgh Hydro Systems Ltd) asked whether consultants were legally responsible for the content of the Environmental Statements they produced. Amanda outlined the potential problems that could arise if litigation became as common as in the United States, and she thought it was very important that environmental consultants maintained and demonstrated due diligence in their work.

Dr Robin Wardlaw (University of Edinburgh) raised the difficulties of comparing different impacts from different alternatives, and asked if a role was seen for ranking systems or multi-objective planning systems. Amanda saw pitfalls in ranking systems, and thought that multi-disciplinary consultation was best. **Prof. Paul Jowitt** (Chairman) also had reservations about the practicality of scoring and ranking systems.

Dr John Riddell (University of Strathclyde) asked if it was possible to give an unbiased report to a client who was paying for the assessment. Amanda thought it was essential that one did, since the best needs of the client might not be served if objections were then raised later on issues which were identifiable at the time. John asked also whether the consultees in an assessment should be asked to contribute to the cost. Neither Vanessa Brazier nor Amanda thought this was practical, and felt that the developer should be responsible for the costs of an assessment. On a question of fee bids, and the current practice of lump-sum bids for consultancy, Amanda thought that lump-sum bids, although common, were generally not desirable.

Prof. Alan Werritty (University of Dundee) observed that recurrent themes in the talk had been significance, value, ownership and iteration, and asked Amanda to say something about their relationships. Amanda outlined the importance of good practice and of public participation, but thought that the existing legal framework and the broad definition of significance presented a challenge.

Jonathan Cooper (W S Atkins) asked for a view on whether it was better to take a single option or a range of options to the public. Amanda thought it was best to put several options forward, but stressed that this process did not ensure that the preferred option would be accepted.

Robin Wardlaw
University of Edinburgh

New Members

We welcome the following members to the Society:

Bance, P.J. ..... Gravesend, Kent
Browne, T.J. ..... Computing Service, University of Sussex, Brighton
Dils, R.M. ..... Sheffield
Dunn, J.R.J. ..... Rofe Kennard & Lapworth, York
Fallows, C.S. ..... Bolton, Lancashire
Farrell, R.P. ..... Harlow, Essex
Feasby, J.C. ..... York
Hannah, D.M. ..... School of Geography, University of Birmingham
Hawker, P. ..... Sir William Halcrow & Partners, Swindon
He, Quingping ..... Dept of Geography, University of Exeter
Hess, T. ..... Silsoe College, Bedfordshire
Hill, T.J. ..... Institute of Hydrology, Plynlimon
Howarth, S.M. ..... London
Hunt, T.R. ..... Exeter, Devon
Jarvis, W.H. ..... Edinburgh
Jenkin, P.C. ..... Reading, Berkshire
Jung, Myung Ho ..... Hounslow, Middlesex
Kaar, E.T. ..... NRA North West Region, Warrington
Knight, M.D. ..... London
Kotschoubey, B. ..... London
McNaughton, A. ..... Smallfield, Surrey
Mantell, A. ..... Clifton, Bristol
Moss, S.C. ..... Newcastle upon Tyne
Mounsey, S.C. ..... Carlisle, Cumbria
Norouzi Banis, Y. ..... Dept of Civil Engineering, University of Newcastle
Orr, H.G. ..... Manchester
Reynolds, S.E. ..... School of Geography, University of Leeds
Sadler, P.R. ..... NRA South Western Region, Exeter
Samuel, C.R. ..... London
Shrivastava, G.S. ..... Faculty of Engineering, University of the West Indies
Siggers, G.B. ..... London
Small, J.L. ..... London
Stephenson, J.L. ..... Unidata Europe Ltd, Manchester
Toop, C.J. ..... Blackburn, Lancashire
Triggol, A.L. ..... Upton-upon-Severn, Worcester
Walker, G. ..... Dept of Geog. & Geol., Cheltenham & Gloucester College
Warren, R.P. ..... Tynemarch Systems Eng. Ltd, Dorking, Surrey
Wilson, D.A. ..... Huddersfield, West Yorkshire
Wong, K.M. ..... London

21st General Assembly of IUGG, 1995

The Royal Society will provide financial assistance for participants in the 21st General Assembly of the International Union of Geodesy and Geophysics (IUGG) in Boulder, Colorado, 2-14 July 1995. Only non-government scientists of PhD status who are normally resident in the UK are eligible.

Note: The closing data for submissions is *13th March 1995*: application forms can be obtained from Miss J E C Lewis, The Royal Society, 6 Carlton House Terrace, London SW1Y 5AG, Tel: 0171 839 5561 ext 220, Fax: 0171 930 2170.

Outline details of the scientific programme during the 1995 IUGG General Assembly are given in the Second Circular, together with an indication of accommodation costs. Registration fees are listed in the Third Circular. Copies of these circulars can be obtained from the IUGG XXI General Assembly, c/o American Geophysical Union, 2000 Florida Avenue, NW, Washington, DC 20009, USA, Fax (+)1 202 328 0566, e-mail iugg.xxiga@kosmos.agu.org

Financial assistance may also be available, particularly for young scientists, from the Exeter Travel Fund (see *Circulation 44*, p. 18): apply to **Rod Hawnt** *(Tel. 01568 616847)*.

FORTHCOMING EVENTS

Meetings

XXVIth IAHR Congress
HYDRA 2000
ICE, London
11-15 September 1995

HYDraulics Research and its Application next century — *HYDRA 2000* — is the main theme of the next Congress of the International Association for Hydraulic Research. The biennial congresses are the highlights of the Association's activities, as is reflected in this year's range of technical sessions and seminars on the relevance of research to engineering design in the water environment.

There will be four themes: *Integration of research approaches and applications; Industrial hydraulics and multi-phase flows; Future paths for maritime hydraulics*, and *The hydraulics of water resources and their development*.

There are also four seminars planned with a less formal atmosphere to promote discussion of topical issues and act as a forum for the exchange of ideas and opinions: these are *EC MArine Science and Technology research programme (MAST); Hydraulic modelling of ecological criteria; Morphology of rivers, estuaries and coasts;* and *Modelling of two-stage channels*. Pre- and post-congress tours are available.

Further details and registration forms from: Miss Sheila Walton, Conference Office, Institution of Civil Engineers, 1-7 Great George Street, London SW1P 3AA.
Tel 0171 839 9808, Fax: 0171 233 1734.

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Interceltic Colloquium on Hydrology and Water Management
Rennes, Brittany
8-11 July 1996

The similar climatological, geographical and geological characteristics of the peripheral Celtic countries and regions of the european Union (Brittany, Cornwall, Galicia, Ireland, Scotland and Wales) and their ancient cultural and linguistic heritage have prompted the organisation of this meeting by the British, French and Irish IAHS national committees and BHS.

Papers are invited on these themes:
1. Hydrological framework Hydrology and hydrometeorological regimes, hydrogeology, primary biological productivity or rivers and lakes.
2. Impact of Human Activities and Engineering Works Agriculture and water quality, industrial activities, control of flows and discharges, recovering of water quality.
3. Influence of Discharges from Land on the Productivity of Coastal Ecosystems Nutrient inputs, ecosystem typology, algal blooms
4. Function, Uses and Conservation of Wetlands The hydrological and geochemical role of coastal marshes, peat bogs, and humid lowland meadows.
5. Ecological and social Aspects of Water Management Conflicting use of water resources from a quantitative and/or qualitative viewpoint, watershed management, economical and social evaluation of humid zones.

Forms to register your interest in attending and/or submitting papers/posters are obtainable from the Colloquium Secretariat:

Alain Jigorel, Institut National des Sciences Appliquées, Département de génie civil, 20 avenue des buttes de Coesmes, 35043 Rennes Cedex, France. Tel (+33) 99 28 65 30 Fax: (+33) 99 63 67 05, Internet: alain.jigorel@insa-rennes.fr

Note that forms should be returned to the Secretariat by *1st April 1995*.

Final Conference of the BBSRC/NERC initiative on POLLUTANT TRANSPORT IN SOILS AND ROCKS
London
16 November 1995

The Final Conference of this Initative is to be held at the Institution of Civil Engineers, London, co-sponsored by the British Hydrological Society (BHS), the Geological Society (GS) and the British Soil Science Society (BSSS).

The transfer of anthopogenic pollutants through soils into surface and grounwaters was identified as a priority research area by both NERC and BBSRC in 1990. £1.2m was made available to fund nine research awards and two studenships in a joint three-year project starting in 1991/2 and finishing in 1994/5.

Results will be presented from projects in

- Design of flow injection instrumentation
- Reduction of nitrate in soils
- Modelling of pollutants in soils and water
- Mechanisms of nitrite formation in soils and river water
- Hydrochemical processes controlling pesticide movement in soils
- Groundwater chemical kinetics of nitrate reduction
- Geochemical processes in chalk at the marine/groundwater interface
- Dissolved organic matter in groundwater as a control on hydrochemical reactions
- Dual porosity hypothesis: is it valid for transport in saturated aquifers?

All members of the co-sponsoring Societies are eligible to attend. The registration fee includes refreshments.

For full details and a registration form please contact Mrs Anne Roberts at the Institute of Hydrology, Crowmarsh Gifford, Wallingford, Oxon OX10 8BB. Telephone 01491 838800. Fax 01491 832256. E-mail amr@uk.ac.nwl.ua

International Conference on WATER RESOURCES & ENVIRONMENT RESEARCH: TOWARDS THE 21ST CENTURY
Kyoto, Japan
29-31 October 1996

The topics to be covered include: Scaling Problems in Hydrology and Water Resources; Modelling of Hydrological Systems; Interactions between Surface and Atmospheric processes; Monitoring Systems/GIS/ Remote sensing; Stochastic/Statistics; Pattern recognition/Fractal/Chaos in Hydrology; Environmental Management; Sustainable Development; Expert Systems/Decision Support Systems; Risk Analysis and Management; Compliance with Environmental Regulations; Human and Social Systems; Climatic change.

Brochures with more details are available from **Bob Moore**, Institute of Hydrology, Wallingford, OX10 8BB Tel: 01491 828800, Fax: 01491 832256

Diary

8th March 1995
BHS Southern Section
"Water in the Middle East"
Venue: Civil Eng. Dept, Imperial College
Time: 5.30 p.m. (tea at 5 p.m.)
Contact: Prof. Howard Wheater, Dept. of Civil Engineering, Imperial College, London SW7 2BU *(Tel: 0171 589 5111 ext 4736/4720. Fax: 0171 823 8525)*

8th March 1995
BHS Midlands Section
"Hydrological research at West Midlands Universities"
Venue: NRA Severn Trent, Solihull
Contact: Paul Webster, School of Civil Engineering, University of Birmingham, Birmingham, B15 2TT. *(Tel: 021 414 5055, Fax: 021 414 3675)*

9th March 1995
Scottish Hydrological Group
"Overseas hydrology: a world of engineering possibilities" — Robert Walker (Babtie, Shaw & Morton); Robin Wardlaw (Edinburgh University)
Venue: Royal Society of Edinburgh
Time: 6.30 p.m. (tea at 6 p.m.)
Contact: Dr Andrew Black, Institute of Hydrology, Alpha Centre, Innovation Park, Stirling, FK9 4NF *(Tel: 01786 447612; Fax: 01786 447614)*

22nd March 1995
BHS South West Section Meeting
Field visit to Bodmin, Cornwall
Wetland Management project: reinstating the natural environment.
Meet at NRA Bodmin Office by 2.00 pm
Contact: Graeme Boyce, NRA South Western Region, Manley House, Kestrel Way, Exeter, Devon, EX2 7LQ *(Tel: 01392 444000; Fax: 01392 444238)*

28th March 1995
BHS National Meeting / Geol. Soc. Hydrogeological Group
"Modelling river/aquifer interactions"
Venue: Burlington House, London
Contact: Dr Paul Younger, Dept of Civil Engineering, University of Newcastle upon Tyne, NE 1 7RU *(Tel: 0191 222 7942)*

3rd-5th April 1995
BHS Postgraduate Symposium
Venue: Salford University
Contact: Dr Kevin Tilford, Dept of Civil Engineering, University of Salford *(Tel: 0161 7455000 ext 3458 Fax: 0161 7455060 E-mail: k.a.tilford@civils.salford.ac.uk)*

3rd-7th April 1995
EGS XX General Assembly
Venue: Hamburg, Germany
Contact: Prof Philip O'Kane, University College, Cork *(Tel: 00 353 21 276871, Fax: 00 353 21 276648, E-mail jpokane@iruccvax.ucc.ie)*

12th April 1995
Welsh Hydrological Group
"History and current strategy for a national raingauge network"
Venue: Chepstow
Contact: Rob Drayton, 208 Fidlas Road, Cardiff CF4 5NA *(Tel: 01222 754879)*

26th April 1995
BHS / Royal Met. Soc.
"Hydrological Radar Experiment"
Venue: Imperial College, London
Contact: Howard Wheater (*see above*)

3rd May 1995
BHS Midlands Section
"Extreme hydrological events in the Midlands"
Venue: to be announced
Contact: Paul Webster, *address above*

10th May 1995
BHS Southern Section AGM
"Wetland management"
Venue: Civil Eng. Dept, Imperial College
Time: 5.30 p.m. (tea at 5 p.m.)
Contact: Howard Wheater (*see above*)

17th May 1995
BHS Pennines Section
AGM followed by technical meeting on "Rainfall modelling"
Venue: University of Lancaster
Contact: Elizabeth Kaar, NRA North West Region, P.O. Box 12, Knutsford Road, Warrington, Cheshire, WA4 1HG *(Tel: 01925 653999)*

7th June 1995
BHS South West Section Meeting
Field visit to Bodmin, Cornwall
"Floods in the South West"
Venue: NRA South Western Bridgwater
Time: 2.00 p.m.
Contact: Graeme Boyce, *address above*

23rd June 1995
BHS National Meeting
"Scale problems in hydrological modelling"
Venue: University of Birmingham
Contact: Dr Tim Jolley, Dept of Civil Engineering, Imperial College, London SW7 2BU *(Tel: 0171 911 5000 ext 3081, Email jolley.t@westminster.ac.uk)*

3rd – 14th July 1995
IUGG Assembly (including IAHS Symposia & Workshops)
Boulder, Colorado, USA
Contact: Penny Kisby, IAHS Press, Institute of Hydrology, Wallingford *(Tel: 01491 838800, Fax 01491 832256)*

4th – 7th September 1995
5th National Hydrology Symposium,
Heriot-Watt University, Edinburgh
(*see separate announcement*)

18th October 1995
BHS Midlands Section
Young Persons' Meeting
Venue: School of Civil Engineering, Birmingham University
Contact: Paul Webster, *address above*

4th December 1995
"Rainfall and flood forecasting in reservoir design"
Venue: ICE, London
Contact: Dr Hilary Smithers, NRA North West Region, P.O. Box 12, Knutsford Road, Warrington, Cheshire WA4 1HG *(Tel.: 01925 653999, Fax: 01925 415961)*

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