An overview of hydrological forecasting in a multi-functional Water Authority

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Abstract. The 10 multi-functional Water Authorities of England and Wales, are each responsible for all water related services, including water supply, sewage treatment and river management. Real time hydrological forecasting forms part of two important functions of river management, viz. flood forecasting and low flow management. This paper sets out to describe the role of forecasting in both of these functions within Severn-Trent Water Authority, the second largest Water Authority in England and Wales.

THE NEED FOR FLOW FORECASTING

Over the last 50 years the forecasting of river flows in England and Wales has developed in response to two types of demand. Firstly, Water Authorities (Fig. 1) have been called upon to provide warnings of unusual conditions on major rivers, partly in connection with recreational uses such as fishing and boating, but more especially as a means of minimizing flood damage.

The second demand has arisen internally within the Water Authorities on account of their responsibilities for the management of resources and the provision of public supplies. Consumers expect each Authority to manage the water resources which are available in any given year so that restrictions on consumption are not applied unless they are really necessary. Equally, in the event of a severe drought it is likely that consumers would prefer relatively mild restrictions such as hose-pipe bans or pressure reductions to be imposed sufficiently early. Factory closures and other social disruptions caused by the compulsory use of standpipes might follow unless stocks are conserved at a sufficiently early stage.

A third demand is now arising as more sources are operated on a conjunctive basis in England and Wales. Where, for example, additional direct and continuous abstractions are required from a river, regulating reservoirs or groundwater storage may offer the most economic method of augmenting low flows. Such an arrangement takes advantage of the natural runoff from the basin, reserving storage for those occasions when it is really needed.

The principal distinction between the forecasts which are required by these various demands is the relative time scales. In the Severn and Trent basins the times of concentration of many rivers for which flood forecasts are required vary from a few hours to about five days. In contrast, the critical periods of many of the larger reservoirs vary from about 90 to 200 days.

Flood forecasting requires a reliable but rapid system both for collecting field
data and for preparing and disseminating forecasts. There is little opportunity to correct misinterpretations, to arrange for a communication link to be repaired within hours of its failure, or to ascertain why the hydrological model might not be simulating runoff as expected. The fast moving pace of flood events calls for a highly disciplined yet flexible approach.

Speed of action is not so critical for the management of direct supply reservoirs. Instead the possible duration of the drought brings other problems. For example, forecasts of runoff are usually highly qualified by the uncertainty of effective rainfall during the forecast period. Resort has to be made to techniques whereby assessments of historical inflows can suggest how present storage might react with possible options for abstraction. Much of this analysis can be undertaken well in advance of a drought. Often simple control rules presented in graphical form can indicate the need for various reductions in future abstractions.

The relatively recent development of operating sources conjunctively or in combination introduces a mixture of these requirements, often with more exacting standards of accuracy. For example, when a flood routing model uses flow as the primary variable, flow is ultimately converted into level for the definition of inundated areas. As levels are often relatively insensitive to out of bank flows, an error margin of 10 to 25 per cent in flow might be quite acceptable. Yet on the same river, an error margin of less than 10 per cent might be required during the routing of unsteady low flows in connection with river regulation.

GENERAL REQUIREMENTS OF A FLOW FORECASTING AND WARNING SYSTEM

In order to be effective a forecasting system has to encompass the following requirements:

(1) To be alert. Constant vigilance is generally required, although advantage can now be taken of automatic monitoring and alarms. These facilities can improve the overall standard and allow staff to change from shift duties to standby arrangements.
(2) To appraise the situation with reasonable accuracy and reliability. Again recent improvements in sensing devices and telemetry permit more rapid and accurate assessments of basin conditions. In the Severn–Trent Water Authority the constraint is now mainly financial and economic.

(3) To forecast the future outcome in sufficient time for appropriate action to be taken. For some events, such as flood peaks with response times of several days, the time available to prepare forecasts may be quite adequate. But there may be insufficient time (a) for remedial action to be taken for events of short response, say less than 4 h; (b) where corrections to previous forecasts do not leave enough time to implement changes to earlier decisions; or (c) where corrections would lead to such a loss of public confidence that the interests of the community would best be served by not implementing the corrections.

(4) To have a reliable system of communication between forecasters and the public. Several years' effort in Severn–Trent Water Authority has failed to eliminate some basic difficulties. Despite the organization of simulated events and the training of people who are directly involved, there remain a significant number of recurrent cases of communication failure. For example a precise forecast given to the police for transmission to inhabitants may not be interpreted correctly. The public often wish to obtain further assurance; bypassing the local communication centre, their attempts to telephone the duty hydrologist directly can distract his attention from his primary function. Many other examples could be cited.

(5) To maintain public confidence in the forecasts. There was an excellent public response in Britain to requests to save water during the 1976 drought. This was largely because the weather was hot and sunny for several weeks and the public could see the effects for themselves. There was also adequate opportunity for publicity. By comparison, most floods are sudden, and the media are often forced to report the consequences rather than make predictions. Surveys both of agricultural and industrial communities (White, 1974) suggest that there is an alarming ambivalence to warnings of natural hazards such as floods, especially if the hazard occurs infrequently, at intervals longer than 5–10 years. Careful consideration has to be given to the methods used to disseminate warnings to the public if a suitable response is to be expected.

(6) To prepare and be able to implement contingency plans of action. Some local authorities in England and Wales have established well defined emergency procedures which are implemented upon receipt of an appropriate flood warning. Houses can be evacuated, perishable goods removed to safety and appropriate measures taken to maintain basic transport and communications. However, there are many other areas where procedures are poorly defined despite a significant risk to the community. Such areas are often protected from frequent flooding and the inhabitants may believe that there is no risk.

The preparation of contingency drought plans has recently found little enthusiasm in parts of Britain possibly because of the mistaken belief that the 1975–1976 drought had a severity exceeding 1 in 1000 years. The public regarded the 1976 drought as unique to their experience, but in terms of resource management such conditions are fairly frequent. For example, the depletion of storage in the Derwent Valley reservoirs, one of the principal sources of concern during the 1976 drought, would be expected to recur on average once every 8–10 years.

EXPERIENCE OF FLOW FORECASTING WITH A REGULATING RESERVOIR

This section refers to the experience derived from the operation of Llyn Clywedog during the 1975 and 1976 droughts.
FIGURE 2. The River Severn Resource System showing the location of Llyn Clywedog, the Bewdley control point and other features.

The location of Llyn Clywedog is shown in relation to the River Severn in Fig. 2. Following its construction in 1965–1967, the 50 000 ML reservoir capacity provided a notional increase in yield for abstractions from the river of 200 ML/day over a 90 day critical period. Until 1979 the statutory requirement stipulated that sufficient quantities should be released from the reservoir to maintain a minimum flow of 727 ML/day at Bewdley, a velocity area gauging station some four days’ travel time from the reservoir.

Flows below 727 ML/day would have occurred at Bewdley during the summers of 1975 and 1976. In 1975 some 25 000 ML were released, but in retrospect it was seen that about 66 per cent of this was surplus to the volume which was strictly necessary to satisfy the statutory requirement. In 1976 the corresponding figures were 39 000 ML and 15.5 per cent. The primary reasons for the excess releases were imperfect flow forecasts, flow measurements and abstraction predictions. These stem from:

(1) the time taken for releases to reach the control point;
(2) inadequate information on unsteady abstractions and associated discharges above the control point;
(3) variability in the level–flow calibrations at velocity area gauging stations; and
(4) uncertainty in the response of runoff to rainfall between the reservoir and the control point.

It is estimated that flow forecasting difficulties accounted for 25 per cent of the 1975 release and 5.5 per cent of the 1976 release (Goodhew, 1977). These problems are greatest at the beginning and end of the regulation season or when showery weather predominates. Under such conditions, recessions are much more difficult to forecast, and the variability in flow frustrates the confirmation of gauging calibrations near the low end of the flow range.
Various improvements are currently being made:

1. An increasing number of significant tributaries can now be gauged in real time. Considerable improvements have been made to the gauging stations between the reservoir and the control point.

2. Use of bankside reservoirs at two abstraction points above Bewdley will help to reduce operating losses at the control point.

3. The statutory requirement has been changed to maintain a minimum flow at Bewdley of 850 Ml/day averaged over five days. The required release from Llyn Clywedog is now limited to a maximum of 500 Ml/day.

4. It is hoped to establish correlations between antecedent winter conditions and summer recession rates (Dobson, 1978).

5. Hydrometric data will be collected at the forecasting centre using improved equipment. It will then be used with better rainfall—runoff and routing models.

All these measures are aimed to improve the accuracy of both flow forecasts and release requirements.

FLOW FORECASTING FOR FLOODS

Following the Land Drainage Act 1930 central government has encouraged land drainage authorities in England and Wales to reduce the frequency of flood damage by providing financial grants towards capital costs. To obtain this aid, the drainage authorities have had to demonstrate that community benefits would compare satisfactorily with costs. When this economic test was first introduced there was comparatively little difficulty in identifying projects with benefit—cost ratios well in excess of unity. As this test also helped to order priorities for investment, it is not surprising that some of the alleviation projects which have not yet been started may not be economically worthwhile. As a consequence, more attention is being given to flood warnings with a view to providing a more economic method of reducing some of the damage in unprotected areas.

Reports from the USA (Yevjevich, 1972) and from Britain (Harding and Parker, 1974) confirm that following the construction of alleviation projects a false sense of security can develop in flood plain areas. More recent work (Chatterton et al., 1979) indicates that in the Midlands of England large benefits could be obtained from flood warnings given for severe events, i.e. worse than once in 50 years.

Overall it is likely that higher standards of performance of forecasting systems will be required during the next few decades in England and Wales. Fortunately, advances in instrumentation and modelling have removed many of the uncertainties in forecasting ability, and the principal constraints are now financial, social and political considerations. A single major devastation alone could swing political attention, and in its wake financial resources, on to the need for improved flood warning.

The forecasting models inherited by the Severn—Trent Water Authority from its predecessors in 1974 were generally level to level and rainfall to level correlations. Although these often provided good forecasts for the middle and lower reaches of major rivers, unusual patterns of rainfall occasionally produced atypical tributary contributions and uncertain forecasts below confluences. A loss of public confidence could result from only a small proportion of inaccurate forecasts.

Some work was undertaken prior to 1974 to improve forecasting reliability, with the Trent River Authority developing a conceptual model (Manley, 1975). However, until 1978 the model, known as HYSIM, was largely used to improve flow records and it is only now that it is being applied to the real time problem of forecasting.

By the mid 1970s other studies had led to renewed interest in more simple rainfall—runoff models, often incorporating self-correcting mechanisms to improve forecasts.
Before they would commit themselves to any one model, hydrologists at the Severn—Trent Water Authority decided to investigate the relative performance of several rainfall—runoff models. Within the Authority, comparisons were made between three conceptual models. These were HYSIM and two versions of an isolated events model developed by the Institute of Hydrology, Wallingford, UK (Natural Environment Research Council, 1975). These models are described in the paper by Manley et al. (1980) at this Symposium.

The Authority simultaneously supported research at Birmingham University into two linear rainfall—runoff models, namely the unit hydrograph technique and a simple black box model. This work is outlined by Simpson et al. (1980) at this Symposium. Initial comparisons between all the models indicated that in the absence of self-correcting mechanisms there was little to choose between the three conceptual models and the unit hydrograph technique. However, more exhaustive tests are under way, and if the results are available the final comparison will be presented during the Symposium. At the time of writing the only model which did not meet the Authority’s requirements was the simple black box model.

Three alternative routing models were examined by the Authority, namely the routing elements of HYSIM, a Muskingum technique developed by R. Douglas and the variable parameter Muskingum—Cunge technique known as FLOUT (Price, 1977). A comparative study of these three models is being undertaken on the River Avon. It is anticipated that the relative differences between these techniques will be small. More significant forecasting errors are likely to arise from uncertain relationships between flow and level, from errors in rainfall—runoff models and, to a certain extent from atypical lateral inflows.

More acute and practical problems also arose from these investigations. Firstly, the importance of interrogable raingauge networks was emphasized and studies (Bramley, 1979) were put in hand to ascertain optimum densities. Secondly, the need for high quality flow hydrometry was confirmed despite the practical problem of measuring out-of-bank flows. Thirdly, in order that best use could be made of hydrological staff, some automatic method of collecting field data was necessary.

FURTHER DEVELOPMENTS IN THE FLOW FORECASTING SYSTEM AT THE SEVERN—TRENT WATER AUTHORITY

In the Severn—Trent Water Authority the general philosophy is to realize the potential benefits of flow forecasting by developing the technological aspects of the system. Contingency plans may then be prepared in detail.

One promising method of enhancing the collection of rainfall data in real time lies with weather radar. In 1979, the Authority started to receive radar-based data from an aerial at Clee Hill in Shropshire. This installation is operated on an experimental basis by the UK Meteorological Office. Within the effective radius of measurement the aerial has good visibility over much of the Severn basin and over a small part of the Trent basin. It is intended to ascertain during a three year period how this information can best enhance the present data which are obtained from interrogable raingauges. In the longer term it is likely that the Authority will compare the marginal benefits of using data from a radar system with the associated marginal costs.

Having already taken steps to evaluate suitable rainfall—runoff and routing models, the Authority is proposing to obtain two identical sets of communication and processing equipment. These will be installed at the forecasting centres for the Trent and Severn basins, at Nottingham and Malvern respectively. Each set will comprise an automatic data scanner and a dedicated minicomputer, estimated to cost just over £125 000 (about $275 000). Compared with the cost of other systems installed else-
where during the last decade, this promises to be very good value. Advantage has been taken of the existing public telephone system, and the costs of computing hardware have reduced significantly in real terms.

Each scanner will be capable of interrogating up to 200 rainfall, river and reservoir gauges in selected sets and sub-sets. The frequency of interrogation will depend on the number of gauges within a polling routine. All gauges can be sensed at frequencies varying from 2 to 24 h, whilst for example up to 50 gauges may be called every 20 min. The intention is to scan each basin relatively infrequently and in the event of any anomaly being noted, to scan the set of gauges for that area more often. Memory and alarm facilities are incorporated into the scanner so that if a reading lies outside a predetermined threshold an alarm will be raised. Whether upon receipt of an alarm or on his own initiative, the duty hydrologist can call up previous and current data from the memory. He will be provided with a printer/terminal for use at home.

A similar method of operation will apply to the minicomputers. For much of the time it is anticipated that each machine will be used for routine work such as the processing of historical data. But priority will be given to flow forecasting as the need arises.

Each computer will have a core store exceeding 150k bytes with fixed disk and diskette storage, hard copy and graphical output facilities. The hydrologist will also have remote access by a portable terminal and telephone line. Appropriate software will be developed so that field data obtained by the scanner can be applied to one or more hydrological models with the opportunity for manual interaction.

The physical size of a scanner or a minicomputer is little more than that of a four drawer office filing cabinet. Each machine can operate in a normal office environment with a reliable power supply and telephone service. The purchase of identical equipment for the two centres will allow one set of machines to cover for the other during maintenance or breakdown periods.

One advantage of this hardware is its flexibility. The software is being designed to produce a set of forecasts which will best serve the present needs of the community. However, it will be relatively inexpensive to make modifications in line with future needs.

By about 1983 it should be possible to define the complete scope of the system's capability. At that stage it will be appropriate to prepare detailed contingency plans so that the community can be expected to respond positively and reap the benefit of flow forecasting.

Acknowledgement. This paper is published with the permission of the Director of Operations of the Severn–Trent Water Authority. The views expressed are those of the author and are not necessarily those of the Water Authority.

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