THE ACQUISITION AND ARCHIVING OF RIVER FLOW DATA – PAST AND PRESENT

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Background

The rational exploitation and management of water resources depends to a considerable degree on the ready availability of hydrological data. For scientifically based management strategies and optimal engineering design procedures to be developed, large volumes of river flow data need to be collated, organised and analysed. Whether designing a dam or assessing the volume of contaminants which – without detriment to the aquatic environment – may be discharged into a particular river or stream, a detailed knowledge of the expected range of flows is required. The uncertainty associated with the data is also an important factor in determining the limits to which a river system may be managed or the margin of safety which needs to be incorporated into the design of river works. Precision can only be obtained at a cost, of course, and designers of hydrological archives must demonstrate that the resources devoted to data acquisition are justified by the benefits accruing in terms of improved management performance or the prospect thereof based upon the research potential of large hydrological databases.

The processing of river flow data embraces many tasks between the sensing – normally of river levels – on the one hand and the dissemination of information on the other (Figure 11)[1]. The information requirements of managers, planners, researchers and others together with the available instrumentation technology and data handling expertise all have important implications for the optimal system design. The success of any system may normally be judged by its ability to allow for the differing demands of a wide spectrum of data users and, in particular, to ensure that suitably filtered information is available at the right time and at an accuracy level appropriate to the application in hand.

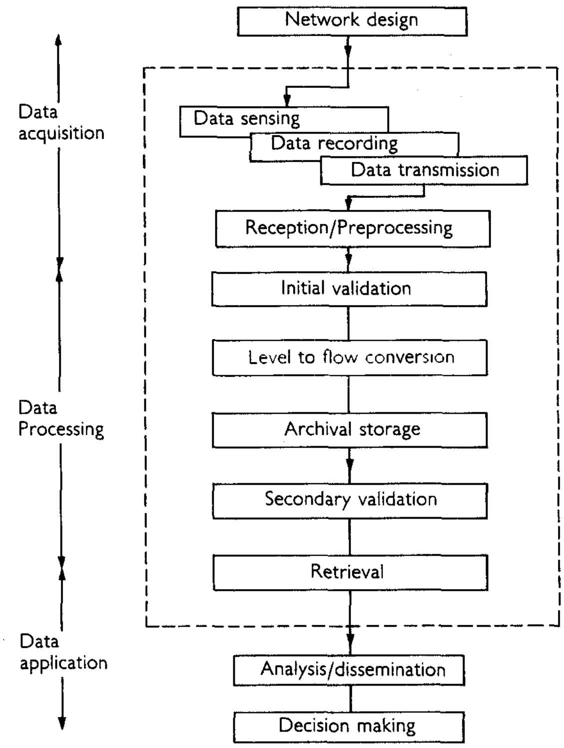

Figure 11. River flow information system flow chart.

The Character of Rivers in the United Kingdom

The data acquisition practices and procedures followed throughout the United Kingdom reflect the characteristics of both the rivers themselves and the catchments they drain. By international standards the UK maintains a relatively dense network of flow measurement stations[2] – approximately one per 150 km^2. This is a necessary response to the diversity of the United Kingdom in terms of its climate, geology, land use and pattern of water utilisation.

UK rivers – mere streams in a global context – are typically short, shallow and subject to substantial artificial disturbance. The total annual discharge of all the rivers in England and Wales barely equates to the average weekly runoff for the Amazon and – nearer to home – the River Rhine contributes a greater input of freshwater into the North Sea than the combined total for all the rivers along our eastern seaboard. With many small basins draining to a convoluted coastline, water resource assessment and

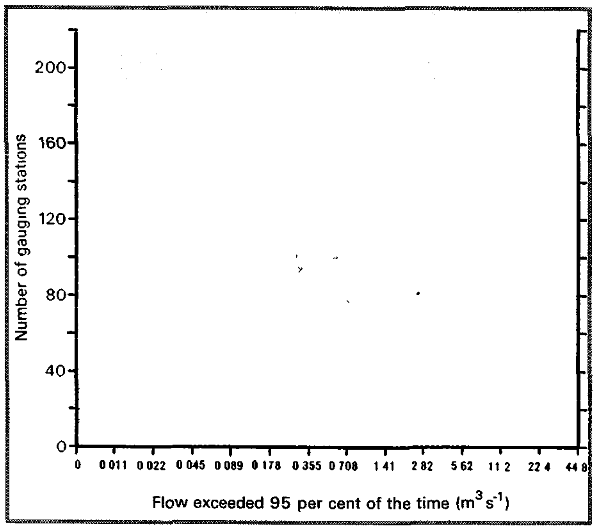

Figure 12. The distribution of 95 per cent exceedence flows for gauging stations in the United Kingdom.

management in the UK inevitably involves considerable monitoring effort – the ten largest rivers in the UK account for only 30 per cent of the overall runoff.

The depth of major international rivers may be measured in a few tens of metres; decimetres are more typical of most UK rivers. This limited water depth places a high premium on reliable instrumentation and rigorous gauging station maintenance procedures to ensure that accurate and representative records of water level – from which river flows are derived – are available. The 95 per cent exceedence flow for more than three-quarters of UK gauging stations is less than one cubic metre per second (see Figure 12). The equivalent water depth for a significant proportion of these stations is below 80 mm – often substantially so – thus any errors resulting from, say, the imprecise setting of the zero of a water level recorder or limitations in the inherent accuracy of the sensing and recording devices may have serious implications (see below).

In order to reduce the uncertainty associated with computed flow values, especially in the low flow range, gauging stations are commonly sited where any significant change in discharge is accompanied by a substantial change in water level; thus, by natural or artificial means, attempts are made to maximise what is termed the 'sensitivity' of the measuring station. Despite some careful documentation of the importance of sensitivity[3] and an enterprising approach to gauging station design, the margin of uncertainty associated with discharge values can remain substantial. Figure 13 illustrates how a modest error in the determination of water depth can result in a substantial error in the computed discharge rate. Notwithstanding the skill with which gauging reaches are selected or measuring weirs designed, the penalties associated with imprecise stage monitoring can remain obdurately severe.

Table 5 lists the percentage errors in discharge arising out of a ten millimetre systematic error in the measurement of water level at a stage corresponding to the 95 per cent exceedence flow (see page 41). Taken together, the featured stations are typical of UK flow measuring conditions but individual gauging stations may not be representative of any particular river or region. Not surprisingly the larger errors tend to correspond with the smaller catchments which, generally, are among the most hydrologically valuable; the flow regimes tending to be little disturbed by artificial influences. It is evident also from Table 5 that hydrometric standards need to be maintained at a high level if confidence is to be placed in flow values particularly those likely to be experienced during periods of drought.

River Flow Measurement

In antiquity, despite the crucial importance of water to all civilisations, river flows were invariably determined on the basis of depth alone; water velocity was ignored even by the Romans whose artefacts testify to a considerable water engineering expertise. Hero of Alexandria is credited with the initial suggestion (circa 100 A.D.) that discharge was, indeed, the product of cross-sectional area and speed of flow; he used a volumetric method to determine the outflow from a spring and to demonstrate the importance of velocity[4]. This fundamental principle was forgotten and practical application awaited its independent discovery by Castelli in 1628[5]. Perhaps inevitably, it fell to Leonardo Da Vinci to demonstrate a measurement technique – employing simple floats – to investigate changes in river velocity[6,7]. With a pioneering understanding of velocity distribution Leonardo was able to appreciate that surface floats suffer from a number of disadvantages – principal among these being the inability to assess the mean velocity in the vertical profile. A more sophisticated approach was heralded by Sartorio's initial design for a flow measuring device[8] and,

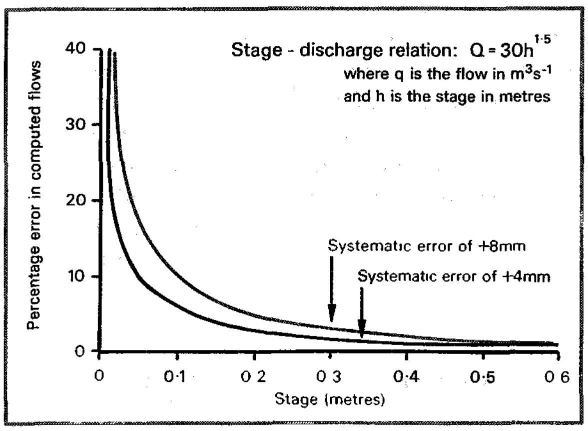

Figure 13. The effect of systematic errors in stage measurement on computed flows.

TABLE 5 THE SENSITIVITY OF UK GAUGING STATIONS

Note: The 'sensitivity error' referred to in this table relates to the percentage change in flow associated with a 10 mm change of water level at a stage corresponding to the 95 per cent exceedence flow. For an explanation of the Station Type codes see page 96.

Station Number	River	Station Type	Catchment Area km^2	Mean Flow m^3s^{-1}	95%ile Flow m^3s^{-1}	Sensitivity Error %
004001	Conon	VA	961.8	45.62	8.59	5.5
007001	Findhorn	VA	415.6	13.22	2.05	13.9
008006	Spey	VA	2861.2	64.61	19.18	4.9
008008	Tromie	VA	130.3	2.40	1.18	7.3
012001	Dee	VA	1370.0	36.40	8.40	5.2
015006	Tay	VA	4587.1	158.10	42.84	1.9
021009	Tweed	VA	4390.0	76.71	14.02	4.5
023001	Tyne	VA	2175.6	43.87	5.44	6.5
024005	Browney	CB	178.5	1.73	0.34	13.7
024009	Wear	FV	1008.3	14.78	3.29	7.8
025019	Leven	FV	14.8	0.20	0.06	25.0
027029	Calder	C VA	341.7	8.74	2.30	5.0
027035	Aire	VA	282.3	6.04	0.52	15.9
027041	Derwent	C	1586.0	17.53	4.92	5.5
027051	Crimple	FV	8.1	0.11	0.01	54.0
027055	Rye	C	131.7	2.36	0.55	22.1
028003	Tame	VA	408.0	5.84	2.70	3.3
028012	Trent	VA	1129.0	12.52	5.04	3.6
028025	Sence	C	169.4	1.51	0.25	22.4
028026	Anker	C VA	368.0	2.82	0.61	13.6
028044	Poulter	C	65.0	0.33	0.17	21.2
031006	Gwash	C	150.0	0.86	0.29	23.3
033012	Kym	CB	137.5	0.63	0.02	65.0
036006	Stour	FL	578.0	2.83	0.50	7.9
037008	Chelmer	EW	190.3	1.02	0.27	15.6
038007	Canons Brk	FL	21.4	0.20	0.05	32.0
039016	Kennet	C	1033.4	9.65	3.98	6.4
039019	Lambourn	C	234.1	1.72	0.79	13.3
039020	Coln	C	106.7	1.34	0.38	21.3
043005	Avon	C	323.7	3.43	1.15	8.9
043006	Nadder	C	220.6	2.88	0.94	18.8
048005	Kenwyn	CC	19.1	0.38	0.05	15.6
049004	Gannel	C	41.0	0.69	0.10	38.2
052004	Isle	C VA	90.1	1.31	0.26	22.7
052010	Brue	C VA	135.2	1.89	0.26	21.5
053017	Boyd	FV	48.0	0.57	0.05	27.5
054004	Sowe	C	262.0	2.94	1.03	8.6
054012	Tern	FV	852.0	7.09	2.41	4.2
054019	Avon	C	347.0	2.50	0.48	15.0
056001	Usk	VA	911.7	27.67	4.34	5.1
065005	Erch	C	18.1	0.60	0.09	45.0
075001	St John's Beck	MIS	40.9	0.88	0.16	12.5
090003	Nevis	VA	76.8	6.28	0.57	8.8

subsequently, the important development work undertaken by Estevao Cabral; the two-hundredth anniversary of his first rotating-vane current meter (see Figure 14) was celebrated in 1986[9]. Considerable further research and refinement has resulted in the modern family of current meters which provide a robust and reliable means of measuring flow except at the very extremes of the velocity range.

Current meters generally provide a measure of flow rate at an instant of time only. For continuous discharge monitoring a relation is required between water level and discharge to permit a continuous, or intermittent, record of river stage to be converted into discharge. A primary objective in selecting gauging stations is thus to locate a reach characterised by its ability to maintain a sensibly unique relation between water level and discharge – where water levels are then determined by a permanent 'control' (see below). World-wide, some 90 per cent of all gauging stations are of the open river section, or velocity-area, type. Consistent with the somewhat singular hydrometric conditions experienced in the UK, simple velocity-area stations make up well below half of the national network. The small size and minimal navigational use of most UK rivers, together with the attraction of grant-aid (until the mid – 1970s), served to stimulate the design and installation of a versatile group of gauging weirs[10].

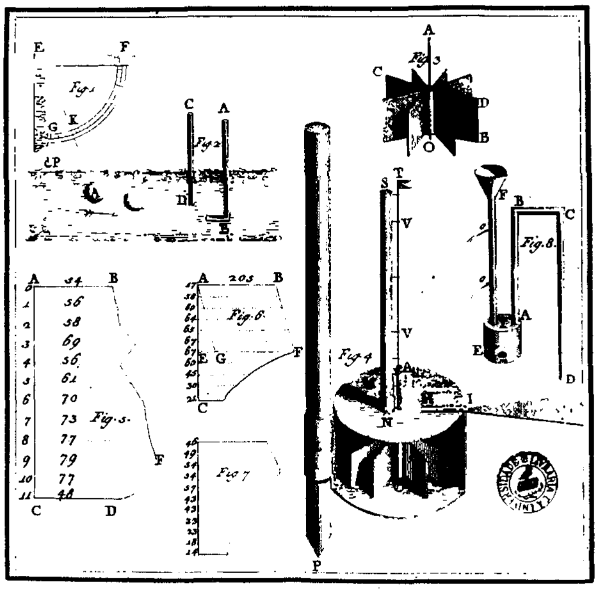

Figure 14. Eighteenth century design sketch for Estavao Cabral's rotating-vane current meter.

Although the requirements of migratory fish and the need to avoid substantial afflux (the increase in upstream water levels resulting from the installation of a weir) were, often, important design constraints, a large proportion of the gauging stations constructed over the last 40 years are weirs with known hydraulic characteristics. Such structures allow a laboratory derived, or theoretical, calibration to be used for the conversion of upstream water level to flow. A wide variety of weirs and flumes, reflecting significant regional preferences, were constructed after the Second World War but a greater measure of uniformity followed the development – in the 1950s – of a triangular profile weir designed by E.S. Crump (see cover)[11]. This robust and easily constructed weir is capable of monitoring flows with considerable precision and is, potentially, able to measure discharges in the non-modular range (when downstream water levels disturb the simple relationship between upstream head and the flow across the structure – see page 35). The desire to increase sensitivity in the low flow range led to two important design innovations[12]. The first involved compounding – providing several crests set at different levels normally separated by divide piers. The second, more aesthetically pleasing, adopted a shallow 'V' profile to achieve a greater depth for a given discharge. Table 6, which provides a breakdown of the different types of flow measurement stations in the United Kingdom, testifies to the success of the Crump profile weir. Whilst measuring structures predominate – this is especially true of England and Wales – it should be noted that the distinction between station categories can, in reality, be rather artificial. Many Flat V weirs, for instance, are effectively river sections (calibrated by current meter) above the lowest flow range; in any case, all types rely on the velocity-area principle. Work on refining the calibration of standard weirs continued in the 1960s and 1970s, mostly government funded and much of it undertaken at the then Hydraulics Research Station; many of the results were subsequently consolidated into a fund of practical guidelines which form the basis of a number of British and International Standards.

By the late 1960s runoff from approximately two-thirds of Britain was gauged, directly, at least once. However, the arrangements for flow measurement remained unsatisfactory in a number of areas; a stable stage-discharge relation cannot be expected where, for example, confluences with other streams, tidal influences, sluice gates and other features such as weedgrowth, limit the range of effectiveness of the station control. The effect of these disturbances tends to be especially severe on rivers with a very shallow bed gradient. A number of novel attempts were made to utilise water surface slope to help determine discharge (see Plate 2) but most encountered formidable practical difficulties – most critically the inability to detect (at that time) very small differences in water level over the measuring reach[13]. Such problems served to stimulate research interest in new flow measurement techniques. Ultrasound appeared to offer considerable promise; by timing acoustic pulses traversing a river section along an oblique path, in both directions, a measure of the mean velocity can be obtained from the differences in the timings of the pulses – flow may then be computed from a knowledge of the cross-sectional area corresponding to a given depth[14]. Much important development work was completed in Britain and a prototype ultrasonic station was installed on the Thames, at Sutton Courtenay, in 1973[15]. Further

TABLE 6 TYPES OF GAUGING STATION IN THE UK

Station Type	Number
Velocity-area	416
Flume	77
Flume/Velocity area	4
Broad-crested weir	24
Compound Broad-crested weir	36
Broad-crested weir/Velocity-area	16
Crump Weir	149
Compound Crump Weir	97
Flat Vee weir	112
Flat Vee weir/Velocity-area	45
Essex Weir	23
Thin-plate weir	56
Thin-plate weir/Velocity-area	5
Ultrasonic	16*
Electromagnetic	5*
Miscellaneous	110
Total	1191

* A significantly larger number of ultrasonic and electromagnetic gauging stations have been, or are being, installed and await final calibration and commissioning.

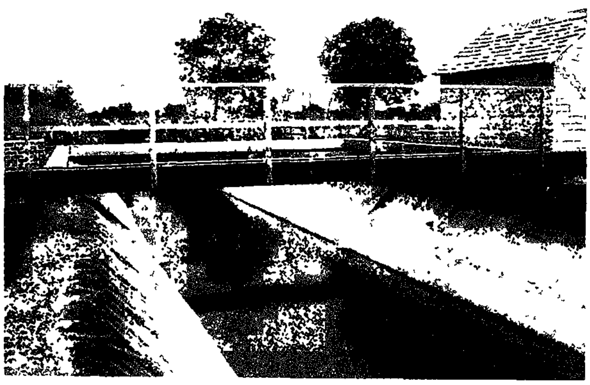

Plate 4. Electromagnetic gauging station on the Swill Brook (Thames Water) showing the overhead coil and bed insulation.

minute voltages are generated). The cost and power consumption have tended, also, to limit the method's application to rivers where other techniques are inappropriate. Nonetheless, the aesthetic advantages of a system which, like the ultrasonic method, can be designed to have very little visual impact (see Plate 5) may well stimulate its wider use especially where the need for bed insulation becomes unnecessary as ever more discriminating means of signal detection are developed.

Stage Sensing

Stage is the elevation of the water surface with respect to the established datum – typically the level of zero flow or the crest of a measuring structure. It is the most fundamental measurement in hydrometry and, in the UK, the uncertainty in the stage measurement largely determines the accuracy of the derived discharge data.

Until the nineteenth century, water level measurement normally involved the direct reading of levels marked on a graduated scale in, or beside, the river. Such measuring devices are considered the oldest hydrometric instruments – records of flood levels on the Nile date back about 5000 years[20]. The sensing mechanism is, of course, the human eye and the use of graduated scales in the form of gauge-boards continues to play a dominant role in hydrometry in many parts of the world. At all but secondary gauging stations in the UK, however, the sensing of stage had, by the 1950s, become entrusted to float-based systems. Normally the float is housed in a stilling well (or tube), to allow the water level to be sensed and recorded by one of a variety of methods undisturbed by surface oscillations or wind effects. Float-activated water level sensing is a simple and reliable technique which has found wide application where stilling well construction is practicable and its cost justifiable; it remains by far the most widely used sensing method in the UK. At a very small number of primary gauging stations – more commonly where only short-term surveillance is involved – water level sensing exploits the relation between water depth and hydrostatic pressure. Pneumatic sensing devices (or 'bubble' gauges) in which a continuous stream of bubbles are emitted through an orifice are normally installed in the river itself; the gas pressure in the tube leading to the orifice is dependent on the water depth. Rather more popular are pressure transducers which allow water levels to be monitored by a semiconductor sensing element which measures the hydrostatic pressure of the water column over a diaphragm transducer and transforms it into an electrical signal. Before the introduction of the ultrasonic gauging method, acoustic level gauges were rarely used for routine hydrometric monitoring. However, at a number of modern installations ultrasound transducers are deployed both to measure water velocity and to determine water depth – the pulse of ultrasound normally being reflected from the water surface allowing the water depth to be determined from the travel time to and from the transducer[21].

Plate 5. Electromagnetic gauging station on the West Beck (Yorkshire Water) installed with the coil in the bed of the channel; the insulating material is held in place by a concrete-lattice revetment through which vegetation will recolonise the river banks.

Recording

Water level recording technology evolved at a relatively gentle pace until a decade or so ago. Principally this reflects the reliable performance of the instruments which gradually superseded the original manual recording of water levels. The float-driven chart (or analogue) recorder was introduced in the middle of the nineteenth century and, with a number of important refinements, continues to dominate stage recording on a world-wide basis. Over 1200 – of various designs – are still used within the UK. The instrument is essentially simple in principle and in construction; a pen being driven by the angular movement of a pulley which responds to the rise and fall of the float in the stilling well below. Some early recorders were designed with a built-in calibration to allow flows to be registered directly.

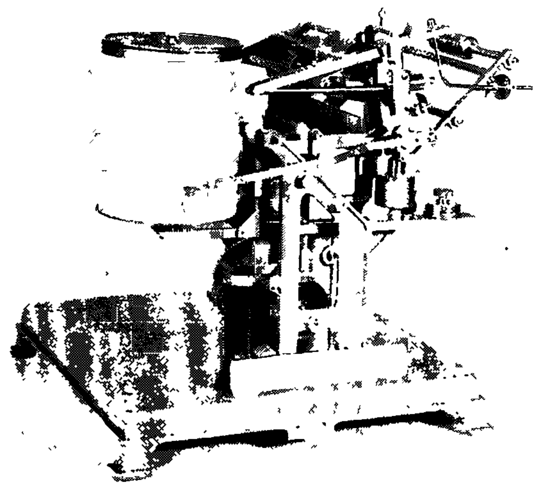

Plate 2. Gradometric Recorder—designed by Thames Conservancy to record flow rate based upon the water surface slope as measured between two stilling wells in the same reach.

research, building on field experience, led to the introduction of more sophisticated, and reliable, multi-path systems backed up by considerable on-site computing capabilities. Following the successful deployment of an early ultrasonic system relying on a single pair of transducers[16], a milestone was passed in 1985 when a multi-path system was commissioned at Kingston on Thames to continue the 100 year flow record derived, until 1975, from the complex barrage of weirs and sluices just downstream at Teddington[17].

The limited range of levels in regulated rivers like the Thames is well suited to the ultrasonic technique but by the late 1970s versatile systems were being deployed on rivers with substantially greater water level variation. Plate 3 illustrates a modern ultrasonic gauging station which incorporates 16 pairs of transducers with an on-site micro-computer to determine mean velocity; a complicating factor at this site is the skewed flow pattern which necessitated the installation of two sets of transducers on each bank in order to make allowance for the non-uniform flow.

A feature of many modern installations is the attention paid, at the design stage, to ensuring – as far as is practicable – a sensibly continuous flow record; access and site facilities are normally excellent with the tranducers and instrumentation amply protected against accidental or deliberate damage; some duplication is also common to provide a measure of security against instrument malfunction. Several modern stations, provide for pairs of transducers to measure velocities beyond bankfull; the magnitude of floodplain discharge rates is often the least convincingly assessed component in the overall flow.

More than 30 ultrasonic stations are currently in operation; the technique has proved particularly successful in rivers subject to intermittent reverse flow (for instance in tidal reaches). However it is not a suitable method for channels affected by heavy weedgrowth or significant bed instability; steep temperature gradients or high concentrations of suspended solids can also degrade performance by refracting, or attenuating, the ultrasound beam albeit for a limited period. Under such circumstances – and where the need for flow data can justify the expense – an electromagnetic gauging station is often a viable alternative. The electromagnetic technique is only an innovation in relation to river applications. The method was first suggested by Michael Faraday[18] and early estimates of the flow through the Straits of Dover relied on the same basic principle – that an emf will be induced in flowing water as it cuts a magnetic field. For hydrometric applications a vertical magnetic field is created by a coil buried in the bed of the river or installed above the measuring section (Plate 4). Considerable refinement – mostly relating to the need to distinguish the very small induced voltage from a background emf – was necessary before a practical river flow measurement technique evolved. A small experimental installation[19] at Princes Marsh on the Rother provided much valuable design information and, over the last decade, a number of primary electromagnetic stations have been installed. Early field experience was a little mixed with a few sites operating unsatisfactorily under very low discharge conditions (when only

Plate 3. Ultrasonic gauging station on the River Trent at Darleston (Severn-Trent Water). The transducers mounted on the steps are used to access velocity in the channel; those mounted on the gantry help provide a measure of overbank velocity (the ultrasound flightpath extends to a corresponding set of transduces on the bridge abutment).
Note: Following a major flood in 1987 this station is being recommissioned with a different configuration of transduces. Out-of-bank velocities will be measured using a single-path ultrasonic system—the flightpath extending across the full width between the bridge abutments.

By providing a visual record, in trace form, of water levels over a chosen period, typically a week or a month, important information concerning the flow pattern may readily be identified[22]. However, the analogue trace requires the extraction of individual stage values to facilitate the derivation of flows. This digitising phase provides the opportunity to filter out erroneous or unrepresentative levels but it is a labour intensive exercise and can be the source of significant error when untrained personnel are employed.

The introduction of more sophisticated digitising systems – often incorporating a graphical presentation of the abstracted level values – now provide a versatile means of extracting hydrometric data but the perceived need both for greater inherent accuracy and a greater measure of computer capability led to the introduction of the punched tape recorder (PTR); a major technological innovation at the time. The Surface Water Survey and, later, the Water Resources Board encouraged the deployment of the 16-channel punched tape recorder pioneered by the United States Geological Survey. For a time a five channel instrument also found favour in some parts of the UK. Properly installed such recorders are capable of registering water levels to an accuracy of better than ± 5 mm[23]. By 1975 over 800 punched tape recorders had been installed. Such devices are robust, well understood and trusted. As a consequence most measuring authorities, eventually, adopted PTRs as the primary measuring instrument with a suitable analogue device to provide a back-up in case of punched tape recorder malfunction. Although water levels were recorded in digital form, conventionally at 15 minute intervals, the punched paper tape is only nominally computer compatible; custom made 16-channel readers are required to facilitate computer processing.

After a relatively quiescent period a number of factors combined to place the existing data recording facilities under considerable stress. The requirement for accuracy and reliability levels beyond what was achievable using mechanical devices allied to an increasing need, by water management, for near real-time data served to stimulate the search for alternative recording methods. A further factor was the increasing age of the PTRs and the vulnerability of acquisition systems relying on a technology which had declined to a single manufacturer status.

Ten years ago solid state logging equipment began to be deployed for the recording of river level data in the field[21]. A number of design problems were encountered, particularly in relation to logger capacity and battery performance. In addition, attempts to harness electronic loggers to existing PTRs proved an unhappy marriage of somewhat incompatible technologies[21]. Float-driven potentiometer systems (changing water levels producing a varying electrical resistance) offered a greater compatibility but rather limited precision. A far more effective solution involved the use of optical shaft encoders – the incremental version relies on float movement to rotate a disc on which is engraved a pattern that alternatively transmits and obscures a beam from a light source; by accumulating the pulses a record of water level changes may be made.

In the absence of any national co-ordination, considerable experimentation took place over the period 1978–83 and a number of technical backwaters were explored before suitable recording options were identified. However, innovative enterprise and the pressure of user requirements resulted in logger technology rapidly passing through several generations. From costly, unreliable and relatively clumsy devices with limited storage capabilities evolved 'smart' or 'intelligent' field recording units capable of storing a range of variables, undertaking field processing and data validation and controlling, where appropriate, the transmission of data to processing centres. The associated need for suitable software to receive, archive and utilise the data, however, did not always evolve at the same pace so that, initially, the full potential of the new logging systems remained unrealised.

Transmission

Since hydrometric data were first collected, it has almost invariably been the case that the location, or locations, where the flow information was required was removed – often distantly – from the point at which water levels were sensed. The necessary data transmission involving muscle power or, later, the internal combustion engine, has always been an important feature, and often the weakest link, of any data acquisition system. Notwithstanding its inherent unreliability, the 'manual' form of data transmission served the water industry effectively until the growing operational need for data focused attention on the limitations of traditional data gathering procedures. The collection of water level charts or punched tapes in the 1970s was normally scheduled on a routine basis, typically weekly or monthly. It had the important incidental benefit of allowing for regular site inspections and, where necessary, the carrying out of station maintenance and instrument checks. For particular applications, especially those concerned with flood warning or alleviation, however, data accessibility needed to be (sensibly) immediate. This real-time requirement led directly to the introduction of a variety of telemetry arrangements.

Any telemetry system may be regarded as consisting of essentially four elements: the sensor, an encoding device to convert the sensor output to a format suitable for transmission, a transmission system linking the sensor to a receiving station and a data reception and distribution facility[24]. In the United Kingdom, private or public telephone lines and radio links are used for transmission purposes. The dense, and generally reliable, telephone network encouraged the introduction of interrogable, or dialout, flood warning facilities at many gauging stations in the 1960s and 1970s. Radio-based systems were also deployed to give wide-area coverage. These developments often resulted in the creation of dual monitoring systems, one for operational purposes (where, commonly, no elaborate provision for the systematic storage of the data was considered appropriate), the other to service archiving needs. Whilst potential advantages of combining the two systems could be readily identified, the complete unification of different acquisition systems (with differing objectives and, often, separately staffed) raised a number of practical problems; in particular reconciling the archiving need for continuous good quality data with the less stringent but urgent operational demands proved difficult until recently.

The last five years has, however, seen new technology exploited successfully to allow single data acquisition systems to meet the full range of user needs. In some areas the current data acquisition instrumentation may be regarded as transitional as strategies for the deployment of unified systems are examined and refined.

Typically the modern system consists of a float-driven shaft encoder interfaced to a logging device linked by the PSTN (Public Switched Telephone Network) to a processing centre - see Plate 6. Provision may be made for immediate alarm conditions to be transmitted from the field but, under normal circumstances, 15 minute water levels are stored on site for cheap overnight transmission to microcomputers where the data await initial validation and conversion to flow. The first such systems were introduced in the early 1980s[25,26] and proved themselves both flexible and reliable. Following initial promise, further deployment was rapid. Between 1983 and 1984, for instance, Severn-Trent Water installed a large number of outstations replacing - among other instruments - all the existing PTRs and, now, well over 200 telemetered outstations comprise the principal method for the routine collection of hydrometric data[26]. A major stimulus towards the wider use of telemetry has been the potential for savings resulting from the reduced need to visit sites on a routine basis to collect chart, tapes or removable loggers. Conceptually, sophisticated loggers are able to help determine maintenance schedules by providing warnings relating to, say, battery performance, or unusual patterns of river levels which require investigation.

Not all gauging authorities are responsible for the same range of operational activities and, as a result, the incentive to introduce telemetry schemes may vary as between, for instance, Water Authorities and River Purification Boards. Even where the responsibilities of measuring authorities are identical, very clear contrasts in the rate of deployment of new data acquisition technology have been identified[27]. Nonetheless, over half the flow data submitted to the Surface Water Archive is now been derived from

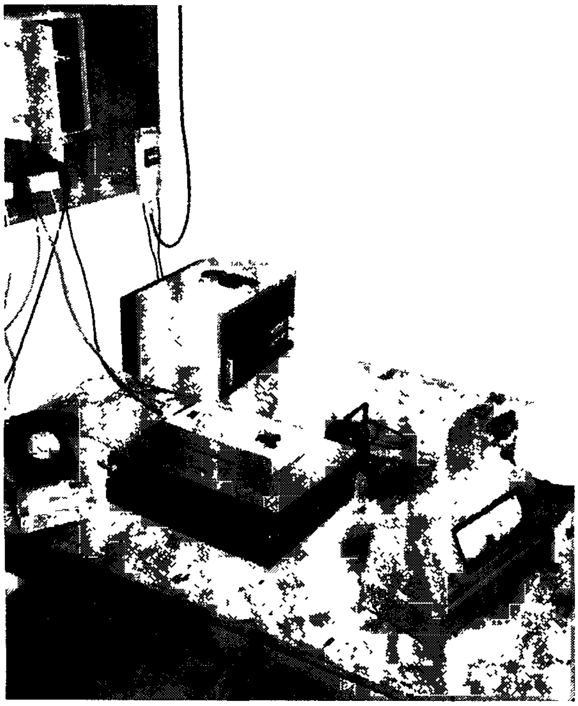

Plate 6. Hydrometric data acquisition facilities at the Spilmersford gauging station on the River Tyne (Forth R.P.B.). The shaft encoder is partially hidden behind an intelligent logger which provides forecasts as part of the Haddington Flood Alleviation Scheme. For the derivation of daily mean flows, 15 minute water levels are transmitted - in batches - to a processing centre in Edinburgh. The analogue recorder (right foreground) provides a back-up to the primary instrumentation.

telemetered water levels (compared with about five per cent, seven years ago) and the PSTN systems in particular are being rapidly extended to embrace most primary monitoring sites. The cost benefits have been clearly demonstrated and evaluated in a number of regions. Generally, PSTN systems have proved more suitable than terrestrial radio links which can be more vulnerable to meteorological conditions and may require unsightly masts to allow line-of-site communication. However, system designers need to keep under review the relative merits of each transmission option. The damage associated with the storms of October 1987 provided a timely reminder of the vulnerability of telephone-based systems. In parts of Kent telecommunication lines were interrupted for up to a week following the near-hurricane force winds on the night of the 15/16th - but river level data were still successfully telemetered from stations provided with a satellite transmission link. Two days later in South Wales, flood warning and flood alleviation procedures were severely hampered when floodwaters from the River Tywi incapacitated the Carmarthen telephone exchange for a critical period.

Data Processing

Most river flow measurement, and the bulk of the data processing, in the United Kingdom is carried out by regional gauging authorities. Currently these comprise the ten Water Authorities in England and Wales, the seven River Purification Boards in Scotland (see page 192) and the Departments of the Environment and Agriculture which undertake a joint operation in Northern Ireland.

The principal data processing task is to reduce a mass of water level data – over three million data items per month – into discharge values, and to provide storage facilities for all the basic data. An important subsidiary activity involves the assembly, or computation, of other gauging station or catchment information which serve to increase the utility of the flow data. For instance, a catchment boundary needs to be delineated and the basin area established before values of runoff can be assessed. The efficiency with which a processing system handles both time series information (e.g. daily flows) and time invariate or feature information (gauging station type, drainage density, proportion of lake in the catchment etc) is a crucial influence on how successfully the archive can be exploited.

When computer-based hydrometric data processing was first introduced in the UK much of the routine conversion of water level to flow was undertaken at a national centre, the Water Resources Board. This made sense at a time when there was limited hydrological and computing expertise available in the measuring authorities (then the River Authorities in England and Wales). The ensuing two decades have witnessed a migration of processing capability to the regions and, in some areas, thence to local offices and eventually into the field itself[21]. This has brocken down, or circumvented, some of the traditional divisions in the acquisition of river flow data (see Figure 11).

From about 1975 considerable effort was devoted to developing flexible user-friendly processing systems but most were linked to mainframe computers and substantial user frustration resulted from the lack of priority afforded to the development and refinement of software required for hydrometric data processing. A positive development, however, was the rapid spread of microcomputer systems designed to undertake the initial processing and quality control of the river level data, allowing archiving and retrieval to remain a mainframe function. Conceptually this approach has a number of advantages; in particular the expertise of local staff with a sound knowledge of river behaviour can be capitalised on to ensure effective validation of the data at source whereas the data handling and analytical capability of the mainframe has until recently made it the preferred choice for data retrieval and analysis. The advent of cheap, powerful microcomputers encouraged many regional and local initiatives. In a negative sense such initiatives were also born out of the lack of any effective co-ordination and standardisation of processing methods and procedures; in any case off-the-shelf systems were unavailable until recently.

A particular complication for the system designer is the number of different data streams with which any comprehensive system has to contend. The revolution in instrumentation and data transmission facilities has not been an overnight phenomenon; the old technology is yielding in a more or less graceful manner, to the new. Consequently, for extended periods, both traditional and innovative acquisition systems are likely to co-exist and provision has to be made to cater for a diverse set of inputs. In 1987, for instance, the Thames Water system was required to handle data from analogue charts, 16-channel punched tape recorders, PSTN and radio telemetered data (every 15 minutes) and from two different solid state logging systems. At many of the gauging stations the downstream water level and/or crest level is monitored as well as the upstream level to facilitate the conversion to discharge. Additionally, input facilities were required for ultrasonic and electromagnetic stations where flows are directly computed on site. Clearly a flexible data processing system was needed and Thames Water adopted a modular approach to system design. Each individual data stream is treated separately and the data transferred into temporary data files which have a common format. From this stage all data are treated in a common fashion. Consequently if a new type of data input (perhaps to capitalise on satellite telemetry) is required, all that is needed is a new input module[28].

Depending on the scope of the archiving system, a range of additional environmental data may be stored alongside the basic flow data. Provision may be made to store both level and flow data together with short time-interval and catchment average rainfall totals. Of particular importance in relation to some strategically important rivers is the need to allow for the impact of man's activities on the natural flow regime. The heavy, and widespread utilisation of water in the UK, combined with the modest flows typical of most rivers, results in artificial influences having a major impact on the flow regime. In 1986, for instance, water abstracted to meet London's water supply needs reduced the flows measured at the Kingston gauging station by over 20 cumecs on average (equivalent to the mean August discharge); this represents a ten-fold increase over the net abstraction at the beginning of the flow record in 1883. Planning and policy development relating to the exploitation of water may be distorted if account is not taken of the quantifiable variations in flow patterns due to artificial disturbance of the flow regime. Equally, unless determined attempts are made to appraise and categorise the hydrometric characteristics of each gauging station – especially their performance in the low flow and flood ranges – inappropriate or misleading deductions may be drawn from the raw flow data.

Data Quality Control

The UK gauging station network represents a public investment approaching 100 million pounds and considerable resources are devoted to the collection and archiving of hydrological and hydrometric data. A proportion of these resources should be used to ensure that the data are of a quality commensurate with the needs of water management and other data users. The presence of large volumes of erroneous data can easily undermine the confidence of both data suppliers and users in any archiving enterprise.

A hydrometric data archive, as with most databases, depends for its success on the ready availability of sensibly continuous data sets of known accuracy. Network design, instrument performance, staff education, training and motivation all play a part in determining the quality of the archived data. A further significant factor is the priority afforded by management to hydrometric activities. The statutory framework within which flow measurement in the UK is organised is of an enabling nature; no direct obligation to gauge rivers exists beyond that necessarily arising out of the operational responsibilities of the water undertakings*. During periods of economic stringency there are inevitably pressures on measuring authorities to reduce monitoring effort and to critically review the functioning of their gauging station networks[29]. Recently such reviews have led to the closure of stations which – in a national perspective – contributed valuable data to the UK hydrological database. A relaxation in standards is evident at other sites. This may, for instance, take the form of a sharp decline in flood gauging at stations perceived, locally, to exist principally to provide flow information relating only to resource management or pollution control.

The non-hydrological aspects of data quality control are of particular importance during a period when hydrometric data acquisition is in a state of flux with major developments in the instrumentation and data communication fields having a substantial impact on the way river flow data are handled and processed. As with much technological progress, dangers can attend the rapid introduction of new systems into a discipline used to a rather pedestrian pace of change. The ability to sense, record, transmit and process flow data untouched by human hand and, more crucially, unseen by human eye may not represent an unmitigated blessing. The contribution to data quality control made by experienced personnel engaged upon laborious manual data examination and processing has not been easy to fully codify and effectively mimic in computer software form.

It will be clear from the above that the quality control of hydrometric data involves a wide range of activities. If hydrometric data acquisition is considered as a production line, it is useful to recognise four reasonably distinct areas where quality control procedures may be applied to good effect[30].

i. Hydrometric field practice and the recording of water level

Virtually every part of a river flow archiving system depends for its input, either directly or indirectly, on the original measurement process. Errors in depth assessments may be a consequence of poorly set-up, or poorly maintained, instruments or the use of sensing and recording devices inappropriate for the precise measurement of water level. In addition, inadequate site maintenance may result in water levels, however accurately recorded, being unsuitable for direct conversion into river flow. For instance, a weir may have algal or plant growth along the crest which raises upstream water levels – stage increases exceeding a centimetre are not uncommon – whilst the water level recorder faithfully monitors the river level relative to the crest itself.

A continuing commitment to good practice in the field is the only way to ensure that precise and representative river level data are recorded.

ii. The checking of river stage data

Many hydrometric data processing systems in the United Kingdom now incorporate a facility for the automatic checking of water level data. Early systems provided for the examination of water level sequences to ensure that none fell outside a prescribed range. A refinement of this approach involved checking that the difference between consecutive readings remained below a selected threshold. By choosing a threshold value appropriate to the individual gauging stations, this simple method was able to identify most erroneous data sequences other than those which are essentially systematic in nature. Graphical plots of river level hydrographs are now favoured – often being presented for visual scrutiny immediately prior to the conversion of depth to flow; the need to do this explains the continued popularity of chart recorders in some areas. Powerful editing facilities, including the ability to add, subtract or apply a gradually changing adjustment (for instance, to counter the effect of seasonal weedgrowth) are necessary to allow rectification of the many possible sources of anomalous stage values. More sophisticated techniques are available; most capitalise on the high serial correlation normally found in time series of river stage values but their use has generally been restricted to research applications.

The existence of impressive computer software, alone, does little to guarantee the quality of stage

* The obligations to be placed upon the National Rivers Authority (see page 192) in relation to hydrometric data collection are currently under consideration.

data. Error recognition is a computer assisted - not computer controlled - procedure and the integrity of the final data will reflect the expertise, enthusiasm and commitment of the operator together with priority afforded by management to data validation activities.

iii. The stage-discharge relation

After the measurement of stage, the precision of the stage-discharge relation is the most important influence in determining the quality of river flow data. Both the procedures used to derive a calibration and the form in which it is expressed may limit the accuracy of the computed discharges. A knowledge of the physical characteristics and behaviour of the river concerned together with an appreciation of the hydraulic and statistical principles underlying the calibration exercise is necessary to achieve the most productive interaction with computer based rating programs. A failure to detect significant shifts in the stage-discharge relation may seriously threaten the accuracy of a river flow time series. Such a failure is most likely to result from a decline in local current metering programmes and, inevitably reduces the confidence that can be placed in computed flows. To facilitate reprocessing of stage data when rating changes have been detected, and to permit data users to appreciate how historical flow computations have been effected, it is essential that a register of calibrations be maintained preferably within the computer system.

Artificial controls are not subject to the same degree of scour and fill under high flow conditions which commonly alter stage-discharge relations at velocity-area stations. However, the cross-section of the approach channel may be altered by accretion. Sediment build up in this area will result in increased approach velocities to the structure (the opposite is true in the case of scour). Unless allowed for in the calibration, a systematic error in flow computation will result. An examination of Figure 15 reveals that errors in the computed discharges can be large; however, effective monitoring of the accretion and its removal when a suitable threshold is exceeded can ensure that the weir performance is not seriously degraded.

A less tractable problem concerns the computation of flows in the non-modular range. Drowning may result from a number of causes including weedgrowth or poor channel maintenance downstream. In theory, data from an additional recorder - monitoring the head above the crest or downstream of the structure - should enable a suitable flow reduction factor to be chosen. In practice, it has proved difficult to determine the reduction factor with any certainty and flows are consistently overestimated using the modular flow calibration. This problem is known to affect over 150 gauging stations in the UK and may be considered typical of those which can introduce bias into computed flows. Random uncertainties in stage measurements tend to be of much less significance - with 96 readings normally contributing to the daily mean flow, the residual random error will, in general, be very modest.

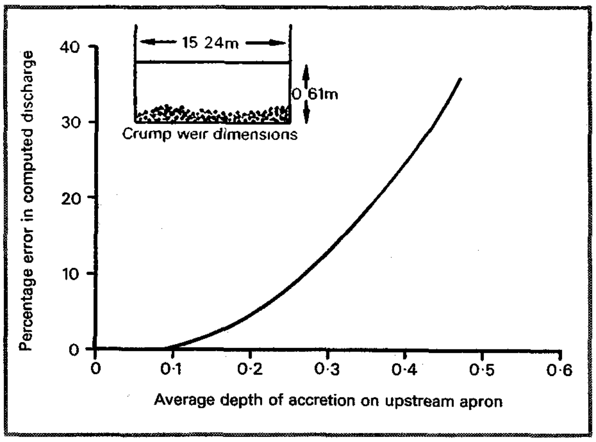

Figure 15. The impact of weir accretion on the accuracy of computed discharges.

iv. The validation and flagging of archived flow data

Hydrological data, along with most categories of environmental data, may be most effectively validated in one, or a combination, of three modes:

a. Temporally: fluctuations in a time series may be examined to ascertain whether they could reasonably be expected in a natural situation given the characteristic behaviour evident from the entire period of record.

b. Spatially: data from adjacent, or analogous, catchments may be examined to check whether they behave sympathetically, within an appropriate tolerance range.

c. By comparison with other related variables. In the case of river flow this is normally rainfall.

Any comprehensive quality control system should attempt to provide for the routine screening of all submitted data to identify obviously erroneous figures. It has been widely recognised that a measure of hydrological validation, involving inter-station comparisons, should form an essential component of any such system[31]. However, a number of data validation systems have met with limited success in the past primarily because they have been too ambitious. A common failing has been the continuing detection of trivial errors which then occupy precious staff time during the error rectification phase. No system will ever identify all possible errors; what is required is a practical, efficient set of procedures designed to minimise the volume of significant errors on the river flow archive. In the more sophisticated systems, data flagging options may complement the validation procedures in order to better assess the suitability of particular data sets for given applications.

The Surface Water Archive Validation System

River flow data will often have been subjected to differing degrees of initial validation in local and regional offices before they are transferred to a regional or national centre. Additionally the validation applied is likely to vary significantly between contemporary and historical data sets. Such is the case with data submitted to the Surface Water Archive. To handle all categories of data a suite of validation programs and procedures has been developed. The Institute of Hydrology's validation procedures aim to complement those employed in the regions and to provide a systematic check prior to entry onto the national archive. Upon receipt, data are compared with any already held for the same period – it is normal practice for some authorities to forward magnetic tapes containing their entire archive at suitable intervals. Where this comparison reveals differences exceeding a threshold percentage, the new data are automatically queried and the source of the difference investigated prior to archiving. This serves to prevent the overwriting of valid data by corrupted, or inappropriate, data sequences. Although not strictly a component in a validation system, painstaking quality control arrangements may be wasted if attention is not paid to the data security aspects of archive management – it is too easily forgotten that a hydrological database is an irreplaceable resource with a value far outweighing that of the computer system that houses it.

Following security and reference information checks to determine the status of the submitted data the initial quality control phase involves a comparison between the incoming data and a selection of statistical parameters derived from the the historical record for individual gauging stations. Each flow value which falls outside one, or more, of the reference ranges is automatically flagged for subsequent investigation[32]. To avoid querying an unreasonably high proportion of valid daily flows – for instance when flooding occurs extensively – several filters are used to allow the reference limits to be overridden when, say, similar flow patterns are registered by more than 25 per cent of the gauging stations in a given area.

Many of the queries can be rapidly resolved by calling upon the expertise of regional representatives familiar with river behaviour supported by hydrometric and hydrological information collated in a series of complementary computer and manual files. Where further investigation is merited, several hydrographs – normally for the same river system – may be displayed simultaneously in order to better determine the cause of unusual data sequences. Visual checking of flow hydrographs is, perhaps, the most effective method of isolating sequences of dubious flows and is a valuable aid to correcting the queried data.

The considerable effort devoted to data validation by Surface Water Archive staff of the Institute of Hydrology at Wallingford is underpinned by the hydrometric and hydrological expertise – much of it acquired through field visits and regional office discussions – of the team of regional representatives which is responsible for liaison with the gauging authorities. Error rectification normally involves an initial inspection by the appropriate representative prior to the despatch of query forms to the measuring authorities for their comment and, where necessary, the provision of revised flow figures.

Data Dissemination

River flow data archiving is not an end in itself. The value of any archive is, perhaps, best reflected in the volume of usage and the breadth of its application. Data dissemination – to provide for the information needs of a wide spectrum of data users – may be achieved in various ways. In relation to the Surface Water Archive, data are made available through a comprehensive suite of retrieval options (see page 137) and through the Hydrological data UK series of publications.

Effective dissemination facilities allow the data user to concentrate on analysis and interpretation; this requires not simply a sophisticated retrieval system but, also, ready access to specialised advice and guidance regarding the availability, and suitability, of particular data sets for given applications. Without such guidance, the potential of the basic data may go unrealised or, even worse, result in misleading deductions being drawn. Assessments of drought severity, for instance, may be severely jeopardised if the uncertainties associated with low flow measurement at individual gauging stations are not considered and if allowance is not made for the net effect of upstream abstractions and discharges.

A continuing dialogue with the user community is essential to ensure that means of access, and forms of presentation, remain relevant and appropriate to user requirements which may change substantially with time; there is, for instance, a far greater need to address the problem of water quantity and quality interactions than was recognised a decade ago. Equally, continuing development of the national hydrological database is the necessary cornerstone of any attempt to measure the impact of climatic change on water resources and, thence, to assess the implications for water management.

Conclusion

The two decades since the initial computerisation of the national river flow archive have witnessed, perhaps, as much change in methods of hydrometric data acquisition and handling as in the previous two thousand years. The coming twenty years is likely to witness a revolution in the way hydrological data are handled, presented and analysed with particular emphasis placed on the co-ordinated exploitation of a broad range of environmental data. Digital cartography and geographical information systems offer exceptional potential and the growth of microcomputer based analytical packages will greatly increase the power of water managers, and others, to marshall and utilise a formidable amount of environmental data. Faced with such a beguiling prospect it is necessary to remind ourselves that, ultimately, the benefits will only be fully realised if attention is not diverted from the humbler virtues upon which hydrometric monitoring is grounded: accurate field measurements, station maintenance and instrument performance, careful derivation and monitoring of stage discharge relations, and due emphasis on data quality control. Equally it is only by recognising that river flow data have a great intrinsic, and enduring, value with a potential for application extending far beyond the operational requirements of individual collecting agencies[33] that the costs, and the benefits, of data acquisition and archiving can be considered in an appropriate perspective.

Acknowledgement

A review of this type would not have been possible without the help and advice of many individuals engaged upon the collection and archiving of hydrometric data. A source of particularly valuable information was a questionnaire circulated by the Institute of Hydrology to the measuring authorities in connection with the development of a British Standard for hydrometric data management.

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