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HYDROLOGICAL DATA STANDARDS, PROCEDURES AND QUALITY ASSURANCE

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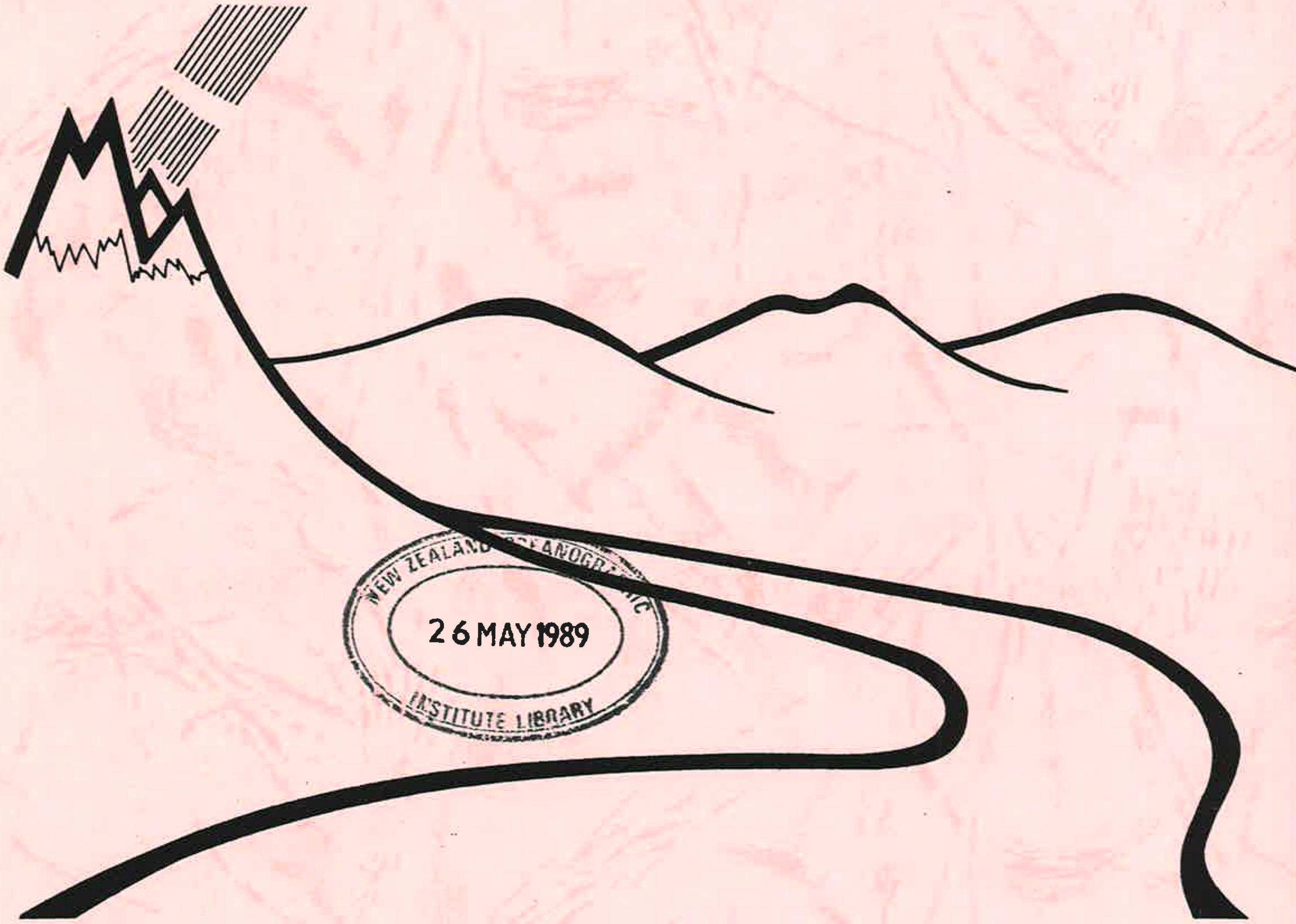

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The current standards and procedures used within the New Zealand hydrological survey for the collection and archiving of hydrometric data are reviewed. Shortcomings and areas where improvements are needed are identified. Appropriate standards and procedures are defined and a quality assurance programme to ensure they will be met is proposed.

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1 INTRODUCTION

Hydrometric data have been collected in New Zealand for over 80 years, but only in the last 20 years have systematic records been gathered into a national hydrological archive. Over this period, the number of stations has expanded many times, and many groups now collect data formerly gathered by one small, highly trained group. It is thus necessary to formalise standards and procedures to ensure that the quality of the data is such that they can be applied with confidence by a wide range of potential users.

The concepts of quality assurance, developed in engineering and manufacturing, are now being applied in many diverse fields. Quality assurance has been defined as "... an independent check to verify that commitments for achievement of quality are met, with a report to management on any significant deviations or failures." (Poling, 1978, p. 32). In the context of hydrometric data collection, quality assurance is the activity of providing to all concerned the evidence needed to establish confidence that the data are of the standard required for their intended uses. A quality assurance programme is the set of procedures and activities that define a pattern of work habits necessary to achieve this confidence. Once the characteristics of the resource to be measured have been determined, a quality assurance programme then comprises four components:

1 setting standards of measurement commensurate with the purposes for which the data are gathered;

2 defining, disseminating and implementing methods of measurement and data processing capable of achieving those standards;

3 implementing within-party and between-party quality control programmes which will provide checks on data quality, such that any deficiencies are flagged and remedied;

4 implementing regular, independent inspections (audits) to determine whether the standards are being met and methods are being applied correctly, and to draw attention to any shortcomings.

Consultation with potential data users is necessary to establish the kinds of data to be measured. Although in hydrology many kinds of data may be required, this report deals with only water level, discharge and rainfall data.

This report reviews current New Zealand practice, with particular reference to the Ministry of Works and Development (MWD) hydrological survey, on the four topics listed above, identifies areas of concern, indicates where improvements are needed, and recommends how they should be achieved.

1.1 BACKGROUND

The first discharge records in New Zealand were made by hydro-electric engineers who began recording the levels of Lakes Taupo and Rotoiti in 1906, and the Wairua River in Northland in 1911. In the 1920's, hydrological interest widened to Lake Waikaremoana, and the Waikato, Clutha and Waitaki Rivers, as well as most South Island lakes. By the 1930's, there was a regular return of hydrological data which has continued to provide the base for studies of major hydro-electric schemes. With a widening interest in hydrological data, specialist hydrological survey parties based in Blenheim, Palmerston North and Hamilton were set up in 1949. In 1985, there were 148 water level recording sites maintained for power operations or investigations throughout the country. As hydro-electric engineers are interested in floods, mean flows and droughts, reliable measurements over the whole spectrum of flow conditions are required. The hydrological records thus gathered are the longest and most reliable in the country.

Irrigation development in the 1930's led to the installation of recorders on many Canterbury rivers. Presumably interest centred mainly on low flows during irrigation seasons. Rating curves, if established, were rarely supported with a regular gauging programme, in part because many staff entered military service during World War II. The original charts, laboriously gathered, now occupy valuable shelf space, but in many cases provide little useful information.

Catchment boards, formed under the Soil Conservation and Rivers Control Act 1941, were initially concerned with erosion and flooding problems. Their hydrological work concentrated mainly on collecting data for flood control work: the measurements were often coarse, and mean and low flows were of little direct interest. Very few continuous discharge records were collected by catchment authorities prior to the Water and Soil Conservation Act 1967. This act established regional water boards as part of catchment boards and required them to issue water rights for the abstraction of water from natural waterways.

In 1959, a meeting of design engineers employed on hydrological works (Soil Conservation and Rivers Control Council, 1959) highlighted the need for a systematic and co-ordinated approach to hydrological data collection. Data to consistent standards were required for the complete range of flows. The consensus achieved at this meeting meant the United Nations Economic, Social and Cultural Organisation proposal for an International Hydrological Decade (IHD) for 1965-74 was readily adopted as an appropriate mechanism for a rational, countrywide approach to necessary data collection. As part of the IHD programme, 90 hydrological regions were identified on the basis of annual precipitation, geology and overland slope, and by January 1983, flow recorder sites were operating primarily as representative basins for 53 of the 90 regions. Each of these basins also contains a network of storage raingauges and at least one recording raingauge.

2 STANDARDS

2.1 REVIEW

The standards for water level measurement adopted in the 1950's for the hydrological survey parties appear to have been those achievable with the existing field equipment and staff resources. A variety of chart-type water level recorders were employed which resulted in a range of level and time resolutions. The main deficiencies in this work were that some chart recorders provided inadequate resolution and that insufficient gaugings, some with insufficient verticals, were made.

During the 1950's and 1960's, there was close contact with the Water Resources Division of the United States Geological Survey (USGS), the principal American hydrological data gathering agency. Copies of their standard procedures (Corbett and others, 1943) were issued to all New Zealand field parties. These procedures set out the standard methods for routine operations, such as the selection of a water level recording site, operation of a recording station, velocity-area and slope-area discharge measurement, stage/discharge rating curve construction, and suspended sediment measurement. Current New Zealand field procedures are also modelled on American practice (Waugh and Fenwick, 1979).

While gauging methods have not changed since the 1950's, several significant developments have occurred.

First was the construction of a current meter rating tank at the Water and Soil Instrument Service Centre (WSISC), in Christchurch, which enabled regular, local calibration of current meters. Previously, it had been necessary to rely on the manufacturers' ratings or to ship the meters to Australia if recalibration was necessary.

Second, during the 1960's and 1970's, American-developed digital recorders, in which water levels recorded at (usually) 15 minute intervals are punched on 16-track tapes, were widely adopted. Resolution was initially 0.01 ft, which was later converted with appropriate gearing to either 1 or 3 mm. These instruments, which have displaced many chart recorders, have contributed to reduced uncertainty in discharge measurement (Ibbitt, 1975). The establishment of a centralised instrument repair depot at the WSISC was crucial to the successful deployment of these recorders. Concurrently, computer-based data processing methods that exploited the improved resolution of digital recorders were being developed to replace tedious manual processing methods.

Finally, more hydrological staff and better understanding of hydrometry resulted in the more regular gauging of rivers with mobile alluvial beds. More gaugings enabled the construction of better rating curves, which led to more accurate flow records. The improvement is evident by examining reach inflows calculated as the difference between flow records for upstream and downstream stations. In a number of cases the calculated inflows are not realistic until recent years.

It is instructive to review the history of data collection at sites of interest for hydro-electric investigations. Regular recording commenced in the 1920's with daily staff gauge readings. Low resolution Littlejohn recorders were installed about 1930, which were replaced by better quality (Lea, Kent) recorders in the 1960's, and by digital recorders in the early or mid-1970's.

In summary, an hydrological survey operation set up in the late 1940's and 1950's has progressively developed in quality and scope. Current field practice varies little from the tentative standards promulgated some 30 years ago, when the then chairman of the Soil Conservation and Rivers Control Council, Mr W L Newnham, commented:

> The data that we are gathering and making available to the organisations who require and use it, is published and will continue to be used for very many years. It is scientific data and our reputations depend on its accuracy and never failing care and fore-thought that must be put into the work of gathering it.
> (Soil Conservation and Rivers Control Council, 1955, p. 121).

2.2 NEED FOR STANDARDS

Water level and discharge data are collected for many purposes. Although many stations are operated primarily for one purpose, for example power investigations, the data are often used for other purposes years later. Uses include studies on:

- land use basins where the whole basin has only one land use
- regional basins which sample different climates and geologies
- water allocation alternatives
- frequency of floods and droughts
- groundwater
- sediment transport.

These studies are for the planning, design or assessment of:

- urban development, land improvement or afforestation
- fishery habitat and other in-stream amenities
- hydro-electric power
- irrigation
- flood control
- flood forecasting
- water quality monitoring
- water supply.

Data collection often continues after a development has been completed to provide information to guide its operation. Thus there is a need for one common standard which is sufficient for most potential uses.

Standards for hydrometric data are necessary to:

(a) indicate whether data are suitable for a proposed use;

(b) facilitate comparability of data from different sources;

(c) provide a yardstick for assessing manpower and other resource requirements for field parties involved in data collection;

(d) provide a benchmark for legal purposes (e.g., in water right applications).

Hydro-electricity investigations have demonstrated numerous inconsistencies and oddities in the early records. Many of these can be attributed to uncertainties in datums and reduced levels of staff gauges, insufficient resolution in chart traces, and inadequate detail in digitised chart records. These problems have been largely eliminated through the use of digital recorders and attention to regular programmes of field work and station inspection.

Criteria to be considered in setting standards for hydrometric data are:

(a) are the standards achievable? (i.e., can they be achieved with existing technology? - are there sufficient labour, financial and infrastructural resources available?)

(b) are the standards verifiable? (i.e., are the means available to test that the standards are being achieved?)

(c) are the standards appropriate for potential users of the data? - would the data still satisfactorily meet their requirements, in terms of quality, if less resources were expended on their collection?

(d) are the standards in conformity with international usage?

In recent years, international standards have been promulgated for most aspects of hydrological work (appendix 1). Because much of the hydrological work done in New Zealand follows American procedures, it falls within the scope and recommendations of these standards. However, only two of the standards have been approved by the Standards Association of New Zealand, namely: ISO 555/1-1973 ("Dilution Methods for Measurement of Steady Flow Part I: Constant Rate Injection Method") and ISO 3455-1976 ("Calibration of Rotating-element Current-meters in Straight Open Tanks"). The others should be considered for adoption in New Zealand.

2.3 ERRORS, UNCERTAINTY AND RESOLUTION

Total error is the difference between the measured and true value; it is the sum of the random and systematic errors (figure 1). Spurious errors (figure 1) are clear mistakes or blunders that are not amenable to analysis and must be discarded. Uncertainty is the interval within which the value of a measured quantity can be expected to lie with a stated probability (figure 1). International standards recommend that the probability for stating uncertainties should be 95%.

Random errors can be quantified by repeated measurements and the uncertainty range calculated. The literature (e.g., Herschy, 1978; Kinghorn, 1982) cautions that systematic uncertainties are much more difficult to quantify and are almost always underestimated. The very existence of some sources of systematic uncertainties may be unrecognised. Systematic error may be assessed using independent measuring techniques. If this is not possible, all that can be done is to choose, largely on the basis of experience, limits that are very rarely exceeded and then state that the uncertainty is at a level of at least 95%.

International standards (e.g., ISO 748-1979) recommend that percentage uncertainty from different sources be combined by the root sum-of-squares method. In a technical sense, accuracy is inversely proportional to systematic error; precision is inversely proportional to random error. However, this distinction is not evident in standard dictionaries, and presumably for this reason the terms are not used in the ISO standards.

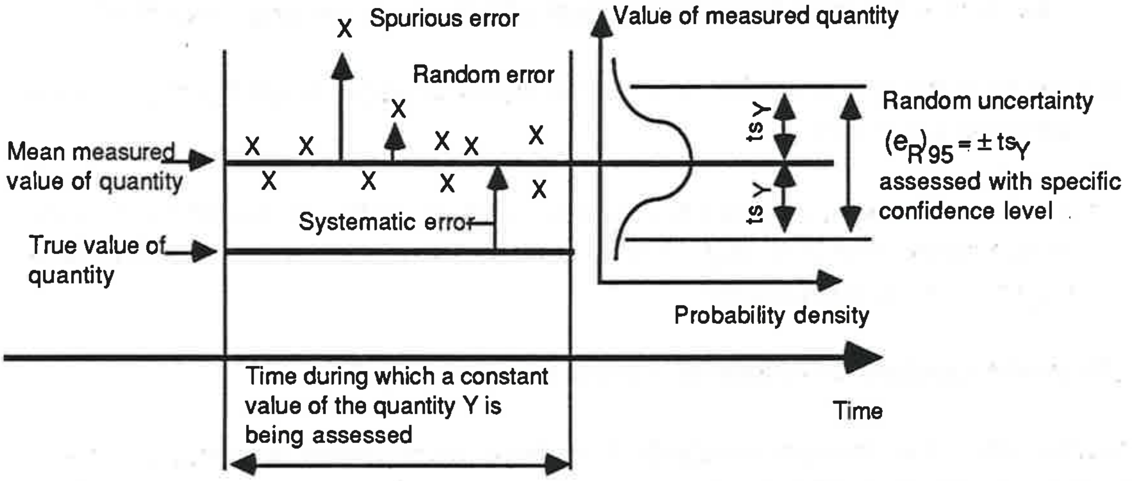

Figure 1 Diagrammatic definition of errors and uncertainties (from ISO 5168 1978 "Measurement of Fluid Flow - Estimation of Uncertainty of a Flow-rate Measurement")

Resolution is the smallest change in a physical variable that can be confidently detected in the response of a measuring system. For example , a 5 m range Foxboro pressure bulb recorder tracing on a circular chart has a full-scale deflection of 100 mm. The trace might be read to the nearest 0.5 mm, which implies a resolution in water level measurement of 25 mm. This provides a base value for random error: zeroing errors, thermal, frictional, inertial and other effects will contribute further error. It is reasonable to accept the 25 mm resolution as a minimum estimate of random uncertainty for a 5 m range Foxboro recorder. In contrast, most digital recorders (i.e., those with 100 mm pulleys) have a resolution of 1 mm. Other error sources contribute to total random error: Herschy (1978) suggests that for digital recorders initially zeroed using a standard engineer's level, a random uncertainty of ± 3 mm is appropriate (uncertainties defined at the 95% confidence interval).

Specfications for accuracy of stage measurement are given in clause 7 of ISO 4373-1979 ("Measurement of Liquid Flow in Open Channels - Water Level Measuring Devices"):

> For the measurement of stage, in certain installations an uncertainty of ± 10 mm may be satisfactory; in others an uncertainty of ± 3 mm or better may be required; however, in no case should the uncertainty be worse than ± 10 mm or 0.1% of the range whichever is greater.

It is assumed that standard digital recorders (with 100 mm pulleys) installed at most of our long term recording stations meet the higher order specification set out above, and digital recorders with 300 mm pulleys meet the lower order specification. The conformity of chart recorders to these standards depends on the instrument range and the standard to which the chart is digitised: from the example given above, it is clear that a Foxboro recorder with a range as great as 5 m does not meet these standards.

2.4 JUSTIFICATION FOR STANDARDS

Because of the variety of uses to which data are put, a common standard sufficient for all potential uses is essential. Studies for land use assessments and hydro-electric investigations demand the highest quality data, and they account for about 33% of the stations operating in New Zealand.

Costs of running a hydrometric network include expenses incurred for servicing, recorder inventory maintenance, data processing and operator training. Given the scope and complexity of a national network, it can be cheaper to standardise on particular recorders, rather than use one appropriate for a specific intended use of the data. The benefits of this optimisation of total costs, as distinct from optimisation for each purpose at each station, are achieved through simplifying operator training, minimising inventory costs, and facilitating the relocation of equipment.

In land use basin studies, levels of uncertainty in measured discharge parameters determine the period of operation necessary to verify, with stated confidence, an hypothesis about the effects of land use on runoff. In a review of a major land use basin programme (MWD, unpublished data), it was found that uncertainties in 55% of recorded data were excessive. Reasons were:

(a) levels recorded with insufficient stage resolution;
(b) levels recorded with insufficient frequency;
(c) levels digitised from charts with inadequate detail;
(d) levels archived with excessive compression.

Situations (c) and (d) could be retrieved by reprocessing the original field records, whereas (a) and (b) could not.

Water level data collected to the ISO standards of ±3 mm and ±10 mm are necessary for land use basin studies and hydro-electric investigations. Although data to lower standards may still be used, they will present increased difficulties in analysis because additional uncertainties are introduced into the data. The sensitivity of the discharge estimates to uncertainties in field measurements is analysed in section 3.2.

Standards for velocity-area gauging with current meters specify criteria for the design and rating of current meters (ISO 2537-1974 and ISO 3455-1976), the selection of a gauging site, and the conduct of a gauging (ISO 748-1979). Given that appropriate equipment is used, the principal determinant of the level of uncertainty in a velocity-area gauging will be the number of verticals used in making the velocity measurements. ISO 748-1979 recommends that at least 20 verticals be used to reduce random uncertainties below stated percentages.

Given that both stage and gauging data have been collected to specified standards, uncertainties in discharge data derived from stage records via the stage/discharge rating curve can be assessed (ISO 1100/2-1982). This assessment is subject to restrictive assumptions about stability of the river channel and extrapolation beyond the range of measured discharge. It leads to discharge data with uncertainties of the order of 5 to 10%. In theory, target levels of uncertainty for derived discharge data could be used to define the instrumentation and methods necessary for the measurements. In practice, this is not done because data users are rarely able to specify in quantitative terms the levels of uncertainty they require in their data. In the absence of target levels, the ISO recommendations for hydrometric measurements present a compromise that is both achievable and appropriate, and (*ipso facto*) in conformity with international usage. Tests to verify that standards are being achieved are outlined in section 4.

3 METHODS

3.1 MEASUREMENT OF WATER LEVELS

Historically, water level measurement has progressed from:

(a) a peg at the water's edge providing a reading at one time;
(b) to a staff gauge which is read every visit;
(c) to an automatic water level recorder which reads all the time.

Today, investigations at a particular site often progress through this same sequence.

From the range of water level recorders (table 1), electronic storage is favoured because it facilitates data telemetry, and has recently become much less expensive than a punch-tape. However, a rugged recorder with the reliability and accuracy of a float actuated punch-tape recorder has not yet been demonstrated convincingly.

Table 1 Water level recording mechanisms

Sensor	Mechanism	Storage	Features
1 air pressure sensor	Bourdon tube	chart	reliable/inexpensive
2 float-in-well	pulley	chart	accurate
3 float-in-well	pulley	punch-tape	machine readable
4 two vertical wires	capacitance	electronic	under development
5 sound-in-air	echo sounder	electronic	under development
6 bubbler	gas meter	electronic	under development
7 pressure transducer	ohm meter	electronic	under development

Standardisation of recorders simplifies the training of operators; facilitates the relocation of equipment to new applications; and minimises inventory costs.

The two "standard" recorders used extensively by MWD field parties are:

(a) reliable inexpensive air pressure bulb chart recorders which do not need special structures for support (1 in table 1);
(b) accurate, machine readable float-in-well punch-tape recorders used at sites ranging from small V-notch weirs which require 1 mm resolution to controlled lakes with a 17 m range (3 in table 1).

Currently under development by MWD are two electronic recorders which require special structures:

(c) vertical wire capacitance recorders having a quick response suitable for measuring surface waves, which are inexpensive and easily relocated, but which are not rugged enough for long term unattended recording (4 in table 1);

(d) echo sounding in air above the water which requires a bridge or other structure for support (5 in table 1).

Two other electronic recorders under development offer the promise of becoming the future standard, but the present commercial versions suffer from uncompensated temperature effects which reduce the resolution to ± 10 mm. The bubbler gas meter recorder (6) requires a gas bottle and the pressure transducer ohm meter recorder (7) requires a power supply, but for both it is possible to arrange for a year of operation without mains power or a visit. Prospects for improved temperature compensation to obtain ± 1 mm resolution seem less promising with (6) than with (7).

3.2 MEASUREMENT OF DISCHARGE

The current meter velocity-area method for discharge measurement is standard work for all field parties and accounts for probably more than 99% of all discharge measurements made in New Zealand rivers. It involves the division of a stream cross-section into m segments, measuring width (b_i) and depth (d_i) for each segment, and velocity at sufficient points in each vertical, such that a satisfactory estimate of mean velocity in the vertical (v_i) can be made. Total discharge is then obtained from:

$$Q = \sum_{i=1}^{m} b_i d_i v_i \qquad (1)$$

It is usual in gauging to choose vertical spacings such that discharge through each segment is approximately equal. Denoting by X'_Q, X'_b, X'_d and X'_v the random uncertainty in Q, b, d and v, respectively, is given by:

$$X'^2_Q = X'^2_m + (X'^2_b + X'^2_d + X'^2_v)/m \qquad (2)$$

where X'_m is the random uncertainty due to taking a limited number of verticals in the cross-section. Random uncertainties X'_b and X'_d arise from random errors in length measurement. Sources of the random uncertainty X'_v are uncertainties caused by pulsations in flow (turbulence) (X'_e), taking a limited number of points in the vertical (X'_p) and random uncertainty in current meter rating (X'_c). Thus, X'_v can be estimated from:

$$X'^2_v = X'^2_e + X'^2_p + X'^2_c \qquad (3)$$

Similarly, the systematic uncertainty in discharge measurement, (X''_Q) is given by:

$$X''_Q{}^2 = X''_b{}^2 + X''_d{}^2 + X''_c{}^2 \tag{4}$$

where X''_b and X''_d are systematic uncertainties in width and depth measurements, and X''_c is the systematic error in the current meter rating. Total uncertainty can be calculated from:

$$X_Q{}^2 = X'_Q{}^2 + X''_Q{}^2 \tag{5}$$

International standards recommend that results be presented as either:

discharge = $Q \pm X_Q$, random uncertainty = $\pm X'_Q$
or discharge = Q, random uncertainty = $\pm X'_Q$
systematic uncertainty = $\pm X''_Q$

Herschy (1978) gives typical values for random and systematic uncertainties attributable to the number of segments (m) and length and velocity measurements. With 20 verticals and the current meter calibrated to ISO standards, gaugings in shallow water (less than 760 mm deep), where velocity is measured at 0.6 of depth, have a coefficient of variation for random errors of 4.3%, and gaugings in deeper water (more than 760 mm), with velocity measured at 0.2 and 0.8 of depth, have a coefficient of variation of random errors of 3.0% (Carter and Anderson, 1963). Gauging with at least 20 verticals is recommended in ISO 748-1979 and in published standard procedures.

The sensitivity of velocity-area gaugings to random uncertainties in the constituent measurements can be assessed from equation 2 (ISO 5168-1978 "Measurement of Fluid Flow - Estimation of Uncertainty in a Flow-rate Measurement"). Table 2 shows the sensitivity of X'_Q to a range of values for m. Typical values for uncertainties in other quantities are assumed for mean velocity in the vertical greater than 0.5 m/s.

Comparing X'_m with X'_Q in table 2, and noting the divisor m in equation 2, it can be seen that the number of verticals is the prime source of random uncertainty in velocity area gauging, and that other sources of uncertainty are of secondary importance. Remembering that uncertainties are approximately twice the coefficient of variation, it can be seen that uncertainties suggested by Carter and Anderson (1963) are slightly greater than those of table 2 for 20 verticals.

Checking the random uncertainty of velocity-area measurements by repeated gauging is rarely done because natural river flow is generally unsteady. However, repeated measurements of steady flow, by different parties using separate sets of instruments, have been required for power station commissioning tests. Repeated gaugings of flows between 100 and 600 m^3/s on the Pukaki and Ohau power canals in 1979 and 1980 had

Table 2 Effect of the numbers of verticals and velocity observations in the vertical on the random uncertainty of a gauging. Typical figures (%) for the uncertainties are from Herschy (1978, tables 10.15 to 10.23)

Number of verticals	X'_m	X'_b	X'_d	X'_c	X'_e	X'_p	X'_Q (eqn 2)	X'_p	X'_Q (eqn 2)
						One point at 0.6 depth		Two points at 0.2, 0.8 depth	
5	20	0.5	3	1	7	15	21.3	7	20.5
10	10	0.5	3	1	7	15	11.3	7	10.5
15	7	0.5	3	1	7	15	8.2	7	7.5
20	5	0.5	3	1	7	15	6.3	7	5.5
30	3	0.5	3	1	7	15	4.3	7	3.6

an average coefficient of variation of 1.4%. These gaugings were to a higher standard than usual because a depth was measured midway between each velocity measurement vertical, and the power canals have stable cross-section shapes which present exceptionally favourable conditions for velocity-area discharge measurement. The variation was, therefore, less than the figures in table 2 for gaugings in natural river channels. They indicate that velocity-area gauging techniques as practised by our field parties can provide results which meet ISO standards. Repeated gaugings by separate parties using separate sets of instruments are a useful between-party quality control check (see section 4.4).

Systematic uncertainty in velocity-area gauging results from errors in calibrating tapes, cables and winches for width and depth measurements, and current meter calibration. Herschy (1978) recommends percentage uncertainties (95% confidence level) of 0.5, 0.5 and 1.0, respectively, for these quantities, leading to a combined systematic uncertainty of 1.2% in discharge measurement. This implies a coefficient of variation for randomised systematic error of 0.6%, which is almost an order of magnitude less than the corresponding figures for random errors. Demonstration of systematic errors in gaugings requires alternative discharge measurements using independent methods. For very small flows this can be done with weirs or flumes, or with volumetric methods. Unfortunately, for large flows, alternative measurements tend to be made only when the results for one of the independent measurements are in doubt. Thus, it was concluded from gaugings on the Manapouri power station tailrace that the turbine power output was 5% less than the design specification: the comparison of gauged discharge and discharge deduced from the turbine ratings provided no information about systematic gauging errors.

3.3 PRECALIBRATED WEIRS AND FLUMES

Discharge measurement on many small streams is facilitated by the use of precalibrated weirs or flumes (e.g., 120° V-notch weirs which are used extensively in the land use basin programme). In theory they enable a more accurate discharge record to be gathered than is possible with a rated natural channel reach, where regular gauging is necessary. Such accuracy is essential for the measurement of the effects on discharge of changing land use on small (less than 10 km^2) basins. Careful attention to levelling the recorder zero to the weir invert is necessary (Ackers *et al.*, 1978; ISO 1438/1-1980).

Theoretically, for such structures, field gauging is unnecessary because the rating determined by laboratory calibration is more accurate than ratings constructed from current meter gaugings if the weir geometry and approach conditions conform to the relevant specifications. In practice, sediment accumulation in the weir pond which can result in modified approach conditions, altered downstream conditions causing backwater influences, increased vegetation growth, leakage under the weir and deterioration of the weir sharp edge, can change the stage/discharge rating curve. Since the changes can occur imperceptibly over a period of years, it becomes necessary to occasionally measure discharge through the structure to check that the specified rating still applies. Under low flow conditions the measurements may be volumetric gaugings, where discharge is deduced by measuring the time required to fill a container of known volume. Even if the measurements confirm the existing ratings, it is essential that they be archived for reference purposes. Dilution gauging is a useful way to test assumptions about weir underflow.

3.4 MEASUREMENT OF RAINFALL

Approximately 300 automatic raingauges and a large number of manually read storage gauges are operated throughout the country, primarily for hydrological purposes. Automatic gauges provide rainfall intensity data for flood hydrograph studies; storage gauges measure rainfall for water balance and water resource studies. These gauges, often in remote basin headwaters, complement those in the meteorological network, which are mostly located in populated lowland areas. Many of the meteorological gauges are read manually at daily intervals.

While the meteorological literature on errors in rainfall measurement deals mainly with manually read and chart gauges, more than 70% of the automatic gauges in the hydrological network are tipping bucket gauges. These record on punched-tape, with 6 minute resolution, the time of occurrence of each 0.5 mm tip. The automatic gauge total is checked from an adjacent manual storage gauge, with the totals being corrected to the check gauge totals.

A raingauge standing above the ground disturbs the wind flow around it, causing it to undercatch total liquid precipitation by as much as 10%, depending on wind speed, and by much larger amounts for snow. For most meteorological purposes this systematic error is acceptable; however water balance studies, which are concerned with the differences between rainfall and runoff, require that the systematic error in rainfall be a minimum. Corrections can be applied to the data (Sevruk, 1982), or the gauges can be shielded or set in pits with their rims and surrounding anti-splash grids set level with the ground surface. These ground level gauges are used in land use basin studies.

As rainfall records do not have the property of continuity inherent in streamflow records, the best checking technique is comparison with other rainfall records for the same time, or with runoff records from nearby streams. Such comparisons may indicate storm events which have not been correctly recorded. Because electronic data processing facilities have not been readily available to do this, much of the filed rainfall data are unchecked.

3.5 DATA HANDLING

In this report, archiving refers to the operations applied to the data after capture in the field. For water level and rainfall, capture is (in 1985) mainly on 16-track punched-tapes. New technology may eliminate these and records will be held in solid state memories. The standard database facilities used by MWD to transfer these data to archives are called TIDEDA, and a microcomputer version called microTIDEDA (Thompson and Rodgers, 1985) is available to all field parties.

If the correct field procedures have been followed, the office practices necessary to archive data are also standard (McMillan, 1985). It is necessary to check that appropriate operations have been applied to the data. Folders are maintained in MWD field party offices to provide documentation for the collection, interpretation, archiving and checking of gauging cards and tapes and charts from water level recorders and raingauges. When gaugings are done on rapidly rising or falling rivers, a weighted mean stage should be filed with the gauged discharge. The use of an incorrect stage value in these circumstances is a subtle source of systematic uncertainty. Allowance for a time of travel is necessary when the gauging site is some distance from the recorder station. Stage-time plots are inspected, and if considered correct, the data are said to be "certified", which is a somewhat subjective assessment of data quality. Automatic data checking routines, which are currently under development at the Hydrology Centre (e.g., Henderson, 1984), are expected to improve this aspect of archiving.

Most questions in archiving revolve around what to do when field records contain errors (e.g., as a result of silting) or are missing through recorder failure, and how to construct and extend rating curves. There is no entirely satisfactory procedure for dealing with gaps in records. Some analysts simply mark gaps in the record, and users requiring data for the missing periods must construct their own according to their own criteria. Where the continuity of record is important (e.g, for the production of monthly and annual summaries), the insertion of synthetic records, usually constructed by a variety of correlational methods, is done temporarily: however, these should not remain in the archive as if they were "observations". Interpolation across short gaps in recessions may be acceptable if only monthly or annual summaries are required. If continuity of record is particularly important, a backup chart recorder should be installed.

3.6 RATING CURVES

Construction of rating curves that convert stage records to discharge is a key part of hydrometry, and it requires careful attention if the full advantage of improved stage measurement instruments is to be realised. The procedure should be to plot gaugings on arithmetic graph paper with axes scaled for the full range of stage and discharge. Separate plots with larger scales, either inset or on separate sheets, are used for the lower 20 to 30% of the range. Best fit lines, generally smooth and parabola shaped, should be drawn through the data.

Poor quality record can often be a result of poor initial site selection and much expense can be incurred if the rating curve alters because the hydraulic control on the water level is unstable. Field observation, supplemented with a knowledge of open channel hydraulics, are necessary to identify stable sites. The dominant criteria for selecting a water level recording site are stability and sensitivity of the hydraulic control. Other factors, such as access and suitability for radio transmission, are secondary. As uniform flow is the prime requirement for a gauging site, the site may not necessarily be adjacent to the recorder.

When the hydraulic control on water level at a recorder site is unstable and changes during floods, it becomes necessary to shift the rating curve to allow for these changes. This is done by identifying a series of successive gaugings that plot consistently to one side of the existing rating. However, it is difficult to do this when the gaugings have been infrequent and are insufficient to identify the timing and amount of the shift necessary. Recent work on rating curves for the unstable Rakaia River shows that in low flows of less than 90 m^3/s, errors are typically 20% (MWD unpublished data). Much of this is attributed to an inability to monitor rating shifts because of insufficient gaugings. Radio telemetry systems can enable field parties to better schedule their visits to sites so that gaugings can be done as flow conditions require them.

Usually it is necessary to extrapolate the curves fitted to measurements to high stage values, where the corresponding flood flows have not been measured. Thus, the need for flood gaugings is stressed repeatedly, but because floods are transitory events, gauging them at remote locations is often very difficult. Nevertheless, progress in recent years has been encouraging, and telemetry is now assisting field parties in this work.

Slope-area estimates of flood peaks are also helpful, especially if a high stage/Mannings 'n' relationship has been established. The recommended procedure for extension beyond measured points is to extrapolate stage/area and stage/mean velocity curves and use the product of the extrapolated points for extending the stage/discharge curve.

The TIDEDA facility includes a process for plotting gauging information which removes much of the labour necessary in manual plotting. Published analyses of uncertainties in stage/discharge rating curves (Ibbitt, 1975; Herschy, 1978) enable the calculation of uncertainty in discharge resulting from uncertainty in stage measurements and the lack of fit of gaugings about a rating curve. Uncertainties in discharge are also attributable to the extrapolation of rating curves beyond the range of measured discharge and to undetected shifts of the hydraulic control. A significant advantage of TIDEDA for archiving is that rating curves are easily revised retrospectively, as new measurements of extreme flows come to hand. In fact, rating curve construction, checking and revision are done as an iterative process.

3.7 SENSITIVITY OF DISCHARGE RECORDS TO RANDOM MEASUREMENT UNCERTAINTIES

The random uncertainty in an estimate of instantaneous discharge from a rating curve results from uncertainties:

(a) in stage data due to recording instrument error;
(b) due to compression of archived data;
(c) from lack of fit of the rating curve, mainly attributable to uncertainty in velocity-area measurement of discharge;
(d) due to rating curve extrapolation;
(e) due to the hydraulic control changing with time (e.g., through scour or deposition of sediment, or weed growth).

The relative magnitudes of errors due to (a), (b) and (c) can be demonstrated using the method described in Ibbitt (1975). The errors in a discharge record, where levels were recorded with a 12 m range Foxboro recorder, were compared with those from a digital recorder where levels were recorded with ±3 mm resolution. The analysis is repeated here using the methods recommended in ISO 1100/2-1982. Taking the 26 gaugings from

Ibbitt's table 1 and using his equation 5, a rating curve fitted by least squares regression in log-log space is:

$$Q = C(h - a)^B \tag{6}$$

where $a = 0.16$, $B = 2.107$, $C = 1.195$, and $0.8 \text{ m} < h < 8.0 \text{ m}$

Using section A.3.2.4 of ISO 1100/2-1982 with the above values, standard error of discharge, $S_e(Q) = 9.72\%$. Using a standard result of least squares regression (e.g., Draper and Smith, 1966, p. 22), $S_e(Q)$ can be used to obtain the standard error (S_{mr}) of an estimate of Q for the value of stage at the centroid of the gaugings when they are plotted in log-log space:

$$\begin{aligned} S_{mr} &= S_e(Q)/N^{1/2} \\ &= 9.72/26^{1/2} \\ &= 1.9\% \end{aligned} \tag{7}$$

and rating uncertainty $X'_{Qr} = 2.S_{mr} = 3.8\%$

Uncertainties increase away from the centroid. For Ibbitt's data, the minimum stage is $h = 0.866$ m, and the corresponding uncertainty is $X'_{Qr} = 7.38\%$, which is attributable mainly to the lack of fit of gaugings on the rating curve. Additional uncertainties occur from the errors in water level measurement (X'_{Qi}) and as a consequence of compressing the time series of recordings (X'_{Qc}). The analysis given in table 3 shows the contribution of uncertainty in stage to uncertainty in discharge. The values selected for uncertainties in

Table 3 Analysis of the random uncertainty in discharge (X'_Q) read from a rating curve in Ibbitt (1975) for $h = 0.866$ m. Sources of random uncertainty are rating uncertainty (X'_{Qr}) and uncertainty in the water level recording instrument (X'_{Qi})

Meas uncerty (mm)	X'_{hi} (%)	X'_{Qi} (eqn 8) (%)	X'_{Qr} (%)	X'_Q (%)
0	0.00	0.00	7.38	7.38
3	0.43	0.90	7.38	7.43
10	1.42	2.98	7.38	7.96
25	3.54	7.46	7.38	10.50
50	7.08	14.90	7.38	16.60

stage are ±3 mm and ±10 mm (ISO standards), ± 25 mm and ±50 mm. (The 50 mm value is the uncertainty from reading 12 m range Foxboro chart records to ±0.25 mm.) Values for h = 0.866 m, (h - a) = 0.706 m, and B = 2.107 are from Ibbitt (1975). Note that the uncertainty in discharge due to uncertainty in water level (X'_{Qi}) can be estimated from uncertainty in water level (X'_{hi}) by differentiating the rating function (equation 6),

$$\partial Q/\partial h = C.B.(h - a)^{B-1}$$

$$\partial Q/Q = B.\partial h/(h - a) \tag{8}$$

hence

$$X'_{Qi} = B.X'_{hi} \tag{9}$$

In figure 2, the total random uncertainty in discharge (X'_Q) is plotted as a function of the instrument uncertainty. For low flows, instrument uncertainty becomes a significant factor in determining total uncertainty, but has little influence for medium and high flows. Further, figure 2 shows that uncertainties due to rating curves are more important for extremes, both low and high, than for values near the mean.

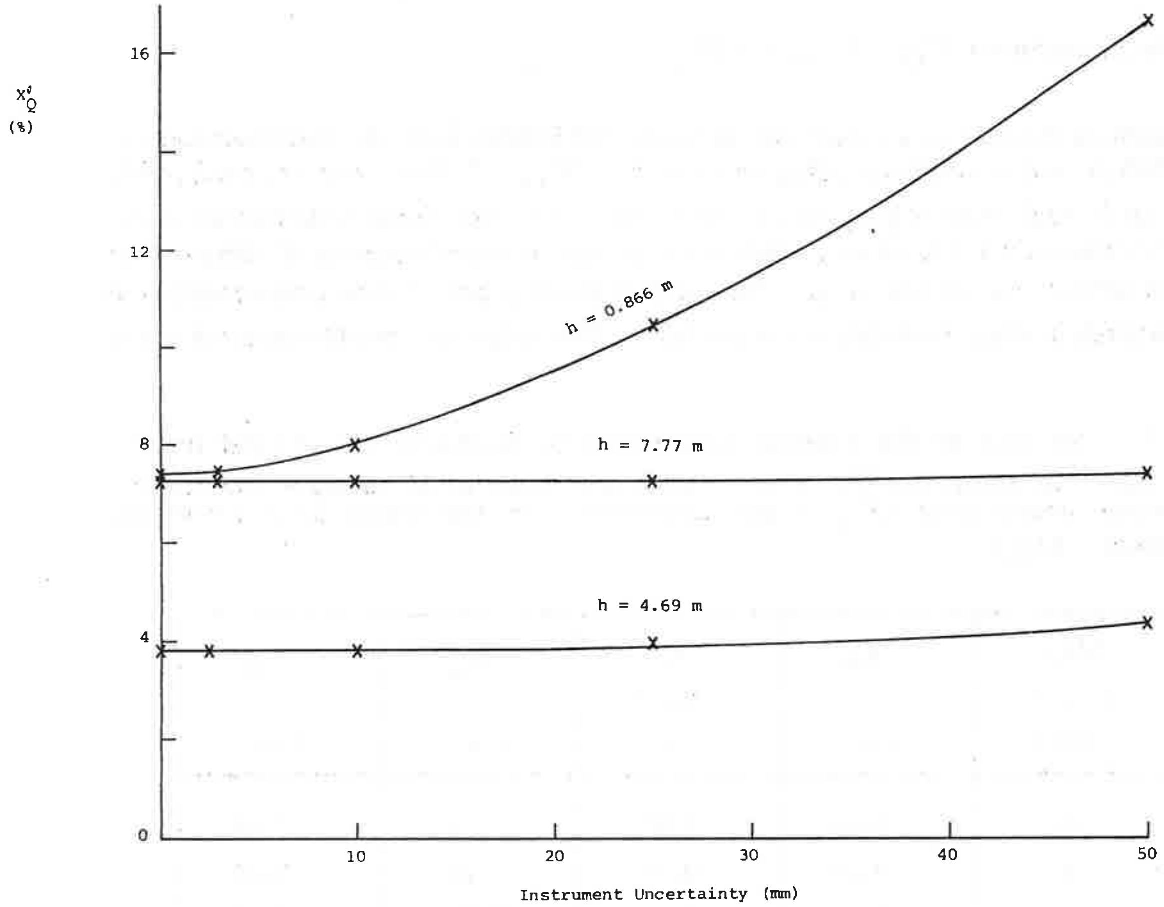

Figure 2 Total random uncertainty in discharge (X'_Q) as a function of instrument uncertainty for low (0.866 m), medium (4.69 m) and high (7.77 m) stage values (h)

Thus, it can be seen that rating uncertainty (X'_{Qr}) dominates discharge uncertainty (X'_Q) for instrument uncertainty (X'_{Qi}) of ±10 mm or less (ISO recommendations). These uncertainty estimates are for estimates of instantaneous discharge read from a rating curve. For random uncertainties in daily and monthly mean discharges, ISO 1100/2-1982 recommends that a weighted mean of uncertainties of instantaneous values be calculated. Thus, during a recession, when discharge through a day would change very little, the random uncertainty in the daily mean would be similar to that in the instantaneous value.

The effect of compression (X'_{Qc}) on discharge uncertainty can be readily assessed by including it as an additional term in table 3. It can be safely applied up to the point where it is, say, 25% of the uncertainty from the rating. It should be this large to make any subsequent data processing efficient. This rule-of-thumb suggests that $X'_{Qc} = 1.90\%$, and hence the uncertainty in water level due to compression, $X'_{hc} = 0.90\%$ (equation 8). At $(h - a) = 0.706$ m this leads to an uncertainty range of ±6 mm.

The major limitation of this analysis is that it applies only for stable permanent hydraulic controls and does not deal with uncertainties due to either rating curve extrapolation or change to hydraulic control. While uncertainties attributable to the former can be reduced by extra effort in gauging extremes, further attention to uncertainties for sites with unstable controls is necessary.

An intensive gauging effort over a short period while the control is presumed stable is used to establish the shape of the rating curve. (Hydraulic theory assists: for the practical case of uniform flow in a channel with an approximately parabolic cross-section, it can be shown that the rating curve is also approximately parabolic.) Once the shape of the rating curve has been determined, shifts in the hydraulic control caused by scour or aggradation may be allowed for by shifts in the rating curve, while retaining the shape. Shifts are detected by regular gauging. Ibbitt and Pearson (MWD, Christchurch, pers. comm.) show that the regularity of gauging necessary to detect significant shifts with stated confidence, varies from less than 2 weeks to more than 6 months, depending on the river.

Where standard laboratory determined rating curves are applicable, an analysis similar to that described above can be used to estimate random uncertainty for discharge data measured with weirs and flumes. As an example, consider an 120° V-notch weir (these are widely used in land use basin studies). The standard equation for a thin plate V-notch weir with notch angle A ($0 < A < 100$) is (ISO 1438/1-1980):

$$Q = C_e \,(8/15)\, \tan(A/2)\, (2g)^{1/2}\, H_e^{5/2} \qquad (10)$$

where: C_e is the discharge coefficient,
g is the acceleration due to gravity,
H_e is the effective head.

It is presumed in this analysis that equation 10 is applicable without significant error for $A = 120°$. With $C_e = 0.588$ and $A = 120$,

$$Q = 2.406\, H_e^{5/2} \tag{11}$$

ISO 1438/1-1980 recommends that uncertainty in Q be calculated as:

$$X'_Q = (X'_{Ce}{}^2 + X'_{\tan(A/2)}{}^2 + 2.5^2\, X'_{He}{}^2)^{1/2} \tag{12}$$

where: X'_{Ce} is uncertainty in the discharge coefficient (=1%, ISO 1438/1),
$X'_{\tan(A/2)}$ is uncertainty in notch angle (=0.5%, Herschy (1978)),
X'_{He} is uncertainty in the effective head.

In turn, X'_{He} is attributed to error in head measurement (E'_h) and error in setting the gauge zero (E'_g), and is estimated from:

$$X'_{He} = 100\,(E'_g{}^2 + E'_h{}^2)^{1/2}/2 \tag{13}$$

Taking E'_g and E'_h as 3 mm, $X'_{He} = 0.424/h$. With these uncertainties, X'_Q for a range of h is given in table 4. The conclusion from this table is that X'_Q becomes increasingly sensitive to X'_{He} for $h < 0.300$ m.

Table 4 Random uncertainties in discharge (X'_Q) for an 120° V-notch weir resulting from the random uncertainties in the head measurement (X'_{He}) discharge coefficient (X'_{Ce}) and notch angle ($X'_{\tan(A/2)}$)

h (m)	X'_{He} (eqn 13) (%)	X'_{Ce} (%)	$X'_{\tan(A/2)}$ (%)	X'_Q (eqn 12) (%)	Q (eqn 11) (m^3/s)
0.03	14.10	1	0.5	35.40	0.000375
0.06	7.07	1	0.5	17.70	0.00212
0.10	4.24	1	0.5	10.70	0.00761
0.20	2.12	1	0.5	5.42	0.0430
0.30	1.41	1	0.5	3.71	0.119
0.40	1.06	1	0.5	2.88	0.243
0.50	0.848	1	0.5	2.40	0.425

On some basins of approximately 5 km^2, the discharge exceeded 95% of the time (which may be of the order of 0.002 m^3/s) is used as an index for land use studies. Table 4 shows that the random uncertainty in this quantity measured with a 120° V-notch weir will be approximately 18%, or 0.0004 m^3/s. Uncertainties calculated in this way must be anticipated when discharge data are collected on small basins to test hypotheses about the hydrological impact of land use. In practice, the theoretical ratings are discarded in favour of curves that are eye-fitted to field gaugings because the approach conditions required for equation 10 are often not fulfilled over the range of flows to be measured. The method illustrated in table 3 should therefore be used to calculate random uncertainties for the expected range of stage values.

From a sample of recorder stations throughout the country, Freestone (1983) lists the errors in mean, median and 95% percentile discharge which can be attributed to selected levels of E'_h. However, in assessing total random uncertainties for weirs where theoretical ratings are used, uncertainties due to X'_{Ce}, $X'_{tan(A/2)}$ and E'_g also need to be considered. In other cases, uncertainties due to lack of fit of the rating curve need to be included (table 3).

4 QUALITY ASSURANCE

4.1 INTRODUCTION

The concept of quality assurance has developed in diverse fields and has become an essential component for success in many business enterprises. The New Zealand Organisation for Quality Assurance, formed in 1977, has more than 700 individual and corporate members and conducts a vigorous programme promoting quality assurance. In close co-operation, the Testing Laboratory Registration Council (TELARC) offers a quality assurance accreditation scheme as an independent verification of an organisation's quality assurance procedures. British Standard 5750 (Parts 1 to 6, 1979-1981, "Quality Systems"), for example, provides guidelines for establishing quality assurance systems. Key elements include the clear documentation of the organisation's tasks, structure, lines of responsibility and reporting procedures.

In water quality testing, quality control has developed through the need to ensure that the standard methods of analysis are being used correctly in different laboratories. The Department of Scientific and Industrial Research Chemaqua programme is a between-laboratory quality control programme which entails sending standard samples to each laboratory for analysis. Results indicate those laboratories where analyses deviate from the expected values.

In the field of hydrological data collection and processing, quality assurance seems to have received little explicit attention. A search of abstract material (*Geo Abstracts*, 1975-1982), using the keywords hydrologic data, hydrological data, quality assurance and quality control, elicited few useful references. Two directly relevant items were found. The first was prepared for the Nordic Hydrological Working Group for Data Processing and Quality Control (Roald, 1981). It supports many of the findings herein relating to the indentification of sources of errors and mistakes in the data, but does not deal with the issue of setting up quality assurance programmes for hydrological data collection. The other item is an unpublished report by the British North West Water Authority Hydrological Projects Group "Report on a Quality Assurance System". Much of this report is concerned with defining appropriate computer hardware and software that would facilitate hydrological data checking. In New Zealand, this has been largely established by the TIDEDA software.

For hydrological field parties, the use of established procedures by appropriately qualified staff to ensure standards are met is the prime means of within-party quality control. Responsibility for the correct application of procedures rests with field party leaders. Independent evaluation of each party's field work, office procedures and results is a key between-party quality control mechanism. Between-party checks should include simultaneous gaugings by separate parties with their own equipment. Uniformity in the application of procedures will be promoted by interchange of staff between field parties.

4.2 PROCEDURES AND TRAINING

Within MWD, field party staff are encouraged to use methods of measurement and data processing that will meet appropriate technical standards by the provision of suitable reference books, workshops and training courses to develop the necessary understanding of procedures and skills in applying them. Documenting procedures and providing training in their applications are prerequisites for any quality assurance programme.

A major effort was made in the 1960's by the Water and Soil Division of the Ministry of Works to produce a set of New Zealand procedures. At least 38 provisional procedures were written (appendix 2) but the effort seems to have lapsed in the early 1970's: only 15 were published (appendix 3). Those on current meters and servicing and inspecting automatic water level recorders and gauging stations (Nos 16, 29, 30, 31 and 41) have proven particularly useful; they are still relevant, but need updating. Unpublished notes have been circulated at departmental hydrology courses to complement these procedures. Procedure No. 45, on metrication, has served its purpose and is now really only of historical interest. A major deficiency in the published series has been the lack of a procedure on constructing rating curves (correctly drawn rating curves are essential for recording discharge). Some guidance is given in Provisional Procedure No. 4, and in a two volume hydrological text (Toebes, 1963) which includes a section on the subject. The current lack of a series of up to date, relevant, published procedures available for reference is a deficiency in the operation of the New Zealand hydrological survey.

The revision and updating of standard procedures are a current concern because they are essential for the maintenance of standards. The following New Zealand publications have recently appeared:

R.J. Curry and J.K. Fenwick (1984): Hydrologists Safety Manual
R.D. Henderson (1984): Automatic QA of Quickflow Records
D.A. McMillan (1985): Hydrology Field Office Practice
S.M. Thompson and M.W. Rodgers (1985): microTIDEDA User's Manual

Titles of MWD publications in preparation include:

Hydrological Field Manual
Telemetry Operating System User's Manual
Preparation of Stage-Discharge Rating Curves

The procedures of the USGS, originally a collection of booklets, have now been consolidated into a two volume publication (Rantz and others, 1982), superseding the widely used manual of Corbett and others (1943). The World Meteorological Organisation (WMO) "Manual on Stream Gauging" (WMO, 1980) contains substantial reproductions of the USGS material, but cannot be recommended because it contains many typographical and editorial errors.

A Hydrological Observational Multipurpose Subprogramme (HOMS) has been initiated by the WMO, and a manual lists items available from national reference centres that may assist other countries. A very useful reference obtained from this source is a four volume Australian produced "Manual of Hydrometric Practice" (Bureau of Water Resources, 1975). A series of Canadian booklets (e.g., Halliday and Terzi, 1983) is also available as an HOMS item.

A series of eight 20 minute video tapes (appendix 4) has been prepared by MWD covering stream gauging and the operation and maintenance of instruments. Although now five to seven years old, the series is still up to date and provides an excellent training aid. Copies are held by the district training officers in each MWD District Office. Although the videos have been used extensively by some field parties, more publicity is needed to encourage their wider use. The preparation of videos on other aspects of hydrological work (e.g., flood gauging, suspended sediment collection, and rating curve construction and checking) should also be considered.

Excessive, undiscriminating reliance on standards and procedures can lead to the use of inappropriate methods or equipment, or to no measurements at all of interesting or unusual situations. The people doing the work, their experience, training, and ability, are the key to a successful quality assurance programme. The challenge for hydrological survey managers is to capitalise on the interest and enthusiasm of their staff for their work. In New Zealand, the introduction of microcomputer based dataloggers to field parties, which enabled the dismantling of the field party/data processor demarcation, has been a positive step in this direction. Discussions in the literature on the qualities necessary for technical staff in hydrological surveys (Corbett *et al.*, 1943, pp. 6-7; Speight, 1953) have been aptly summed up by Thomas (1976). His list of requirements for the accurate measurement of streamflow for design of dams includes "... meticulous attention to equipment by operators who should be men of high integrity and initiative."

Some background of open channel hydraulics theory is particularly appropriate and useful for hydrological field party staff, as it assists in understanding the mechanics of what is being measured, and in preparing rating curves. Within MWD at present there is no requirement for technical staff to undertake such training. It was available in the ETC (Engineering Technician Certificate) course, and is available in courses for NZCE (New Zealand Certificate of Engineering) and NZCS (New Zealand Certificate of Science) in water technology. However, only 7 of 62 (11%) hydrological survey staff held one of these qualifications, as at 31 March 1983. A further 23% held NZCS in other subjects (mainly geology), New Zealand Certificate of Data Processing, or a university degree. Since 1984, training in hydraulics has been included in the MWD short courses offered for field staff, with practical demonstrations in a flume at the hydraulics laboratory at Canterbury University.

4.3 WITHIN-PARTY QUALITY CONTROL

For field parties, quality control should be built into standard field procedures. The MWD has achieved this by using carefully designed forms (Forms WS 4 and 4A) for recording information on velocity-area gaugings. Omissions are self-evident, and errors in recording in the field are minimised by repeating aloud the observations as they are written down. Blunders are screened by checking procedures during subsequent archiving which provides plots of the cross-section and velocity in each vertical for visual checking. The cross-section area measured during a gauging can often be compared to a standard cross-section for the gauging site. This can reveal gross errors in depth or distance measurements, as well as errors incurred through not correctly applying the air and wetline corrections. The immediate plotting of gaugings on rating curves (upon return to the office) should be done to rapidly check for poor or faulty gaugings and changes in rating resulting from a shift in the hydraulic control.

Current meters used for velocity-area gauging are precision instruments. Performance to specification requires both care in handling and correct maintenance, although the latter is generally limited to the daily cleaning and oiling of the finely machined bearings. Performance to specification is checked in the field by the spin test. This requires that the time that a meter takes to stop rotating, after being set in motion by a flick of the fingers (or by blowing for small delicate instruments), exceeds a stated value, depending on meter type. Although space for spin test data is provided on the gauging card (Forms WS 4 and 4A), its omission is an unsatisfactory aspect of much field practice. Although the appropriate spin test figures are given in the training videos, there does not seem to be any document in which they are set down for reference. The practice of specifying spin test data on the instrument case should be re-established.

In annual inspections of recorder stations, all critical features of the installation should be checked. For MWD stations, reduced levels for the staff gauges, plumb bob and benchmarks are surveyed, the recorder well and static tubes are checked for silting and flushed, and the gauging structure is checked for safety and clarity of the vertical markings. Details are recorded on a standard form (Form SCC 5). Levelling checks are also necessary after earthquakes.

At present, regular station inspections at two to four week intervals are necessary to check the operation of water level recorders. The standard procedure in MWD for these inspections sets out the checks to be made. Instrument times and level readings are checked against clock time and staff gauge readings and recorded in standard log books (Form WS 67). A key requirement is to check the water levels read from the staff gauge, the plumb bob in the stilling well, and the recorder. If discrepancies occur, the reasons for them need to be identified and the appropriate corrective action taken, preferably before leaving the site. This may not always be straightforward, as there are at least 38 possible reasons for such discrepancies. In effect, this inspection provides an independent observation to identify any systematic uncertainty in water level measurements.

Sources of systematic uncertainty in float operated punched-tape recorders include float lag, line shift, submergence of the counterweight, and temperature effects. However, these uncertainties are negligible in most field installations (Halliday and Terzi, 1983).

The most common cause of discrepancies, and hence of systematic uncertainties, in water level measurement is silting. Silt blocking stilling well static tubes means that the water level in the well cannot respond quickly to changes in river level. With digital recorders, it is a difficult field problem to detect, as it is often only apparent when flows are changing quickly, and may not be detected if the station is inspected in low flow conditions. (If suspected, the appropriate check is to measure the rate of drainage of water poured into the stilling well). Silting causes systematic error in calculated flows and can be detected by the absence of realistic recession curves or through cumulative mass curve analysis. If silting is detected, the record can sometimes be corrected, although in severe cases it may be best to discard the affected record. In the field, the usual remedy is to flush the tower. Although difficult, removal of accumulated silt in the well below the static tubes is also useful. Provided the reduced level of the lower static tube invert is known, the electric plumb bob can be used to check the level of silt in the well.

Provided the recorder matches the external staff gauge, and the recorder time is correct, the error in recording water level will be consistent with the resolution of the recorder.

The archiving of data is a new task for most MWD field parties. They are now expected to process 16-track tapes, check and correct the records, calculate gauging cards, and send copies of their data on floppy disk to the Hydrology Centre's Quality Assurance Section (QAS) (McMillan, 1985). An automatic procedure maintains a history of all QAS transactions in receiving and testing each batch of data.

The maintenance of stage/discharge rating curves on rivers where water level recorders are installed is a major component of field party work. Regular discharge gaugings are necessary to either confirm the validity of an existing rating curve, or identify the size of the shift that has occurred in the rating. The required frequency of gaugings depends on the frequency of rating shifts, and ranges from less than two weeks to greater than six months. Gauging of discharge extremes during floods and droughts reduces the need to extrapolate rating curves.

Several criteria can be devised to assist field parties in monitoring their performance in maintaining rating curves. Three illustrated here (see figures 3 and 4) are based on:

(a) comparison of the size of gauged discharges relative to the mean and extremes;
(b) the time between successive gaugings;
(c) the deviation between gauged discharge and the corresponding discharge read from the rating curve.

For the first criterion an index value of -50 is allocated to the lowest gauged discharge, 0 to the mean, and +50 to the highest. A logarithmic scaling is then used to determine

For the first criterion an index value of -50 is allocated to the lowest gauged discharge, 0 to the mean, and +50 to the highest. A logarithmic scaling is then used to determine indices for the intermediate gaugings. This index has been plotted against time in figure 3a. It shows a slight seasonal pattern, in that most high flow gaugings were done in the latter half of the years. The number of index values at ±50 indicates success in the measurement of extremes.

To illustrate the second criterion, let t_{n-1}, t_n be times of successive gaugings filed by a field party. Plotting $(t_n - t_{n-1})$ against t_n will then provide an indication of the regularity of gaugings undertaken by a field party (item 2, figure 3a). High values of $(t_n - t_{n-1})$ might be expected to correspond to the Christmas-New Year summer shutdown, staff shortages or resources being directed to other priorities. For the field party of figure 3a, over almost two years, only two intervals greater than 200 hours (8.33 days) occurred between successive gaugings, and one of these was the summer shutdown. Low values might be expected during a period of intensive gauging effort, such as during an extreme event.

Deviations between gaugings and ratings can be examined as follows: let Q_g be a gauged discharge and Q_r be the corresponding discharge read from the rating curve. The index

$$I = 100 \times |Q_g - Q_r| / Q_g$$

provides an index of a party's performance in executing the gaugings, constructing and checking rating curves, and archiving the data. Values of I might be classed as in table 5.

Table 5 Index of field party performance

Value of I (%)	Action/Cause
Low (0-10)	Gauging and rating acceptable
Medium (10-100)	Gauging error Error in calculation or filing of gauging Error in rating curve Shift in rating curve
High (>100)	Gross mistake (e.g., gauging in ml/s and rating in l/s)
No data	Gaugings not archived

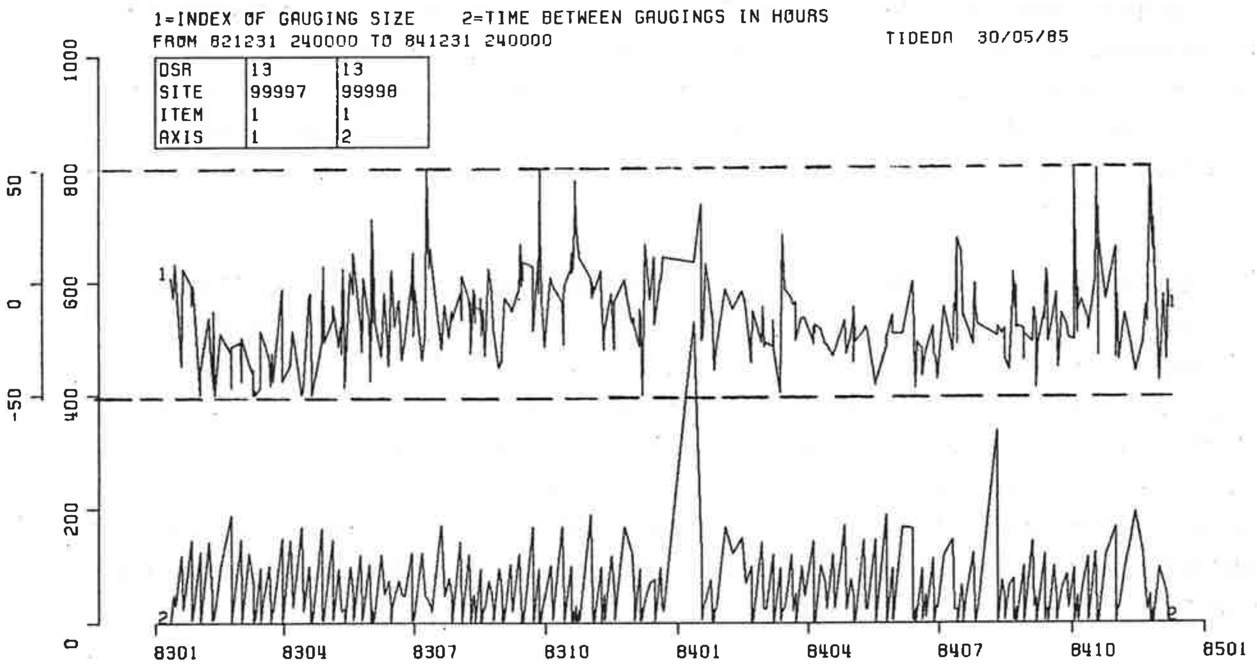

Figure 3a Item 1, index of gauging size (-50 min., +50 max.) and Item 2, time between successive gaugings (hours), for the period January 1983 to December 1984 (Christchurch field party data)

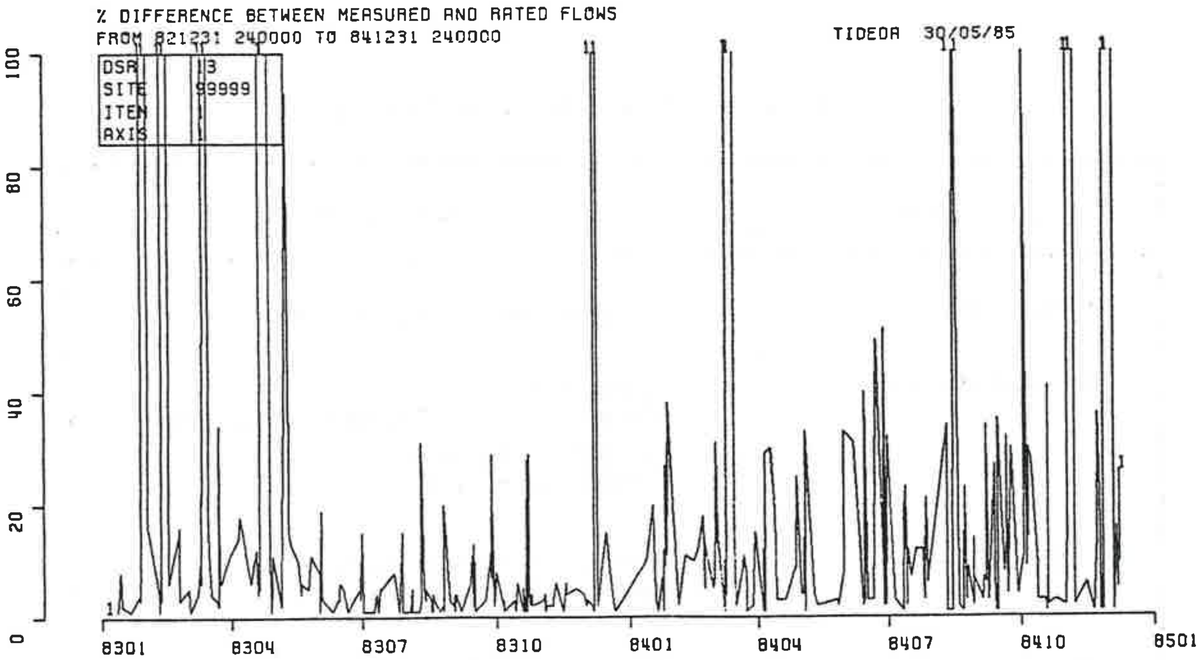

Figure 3b Percentage difference between gauged and rated discharge for the period January 1983 to December 1984 (Christchurch field party data)

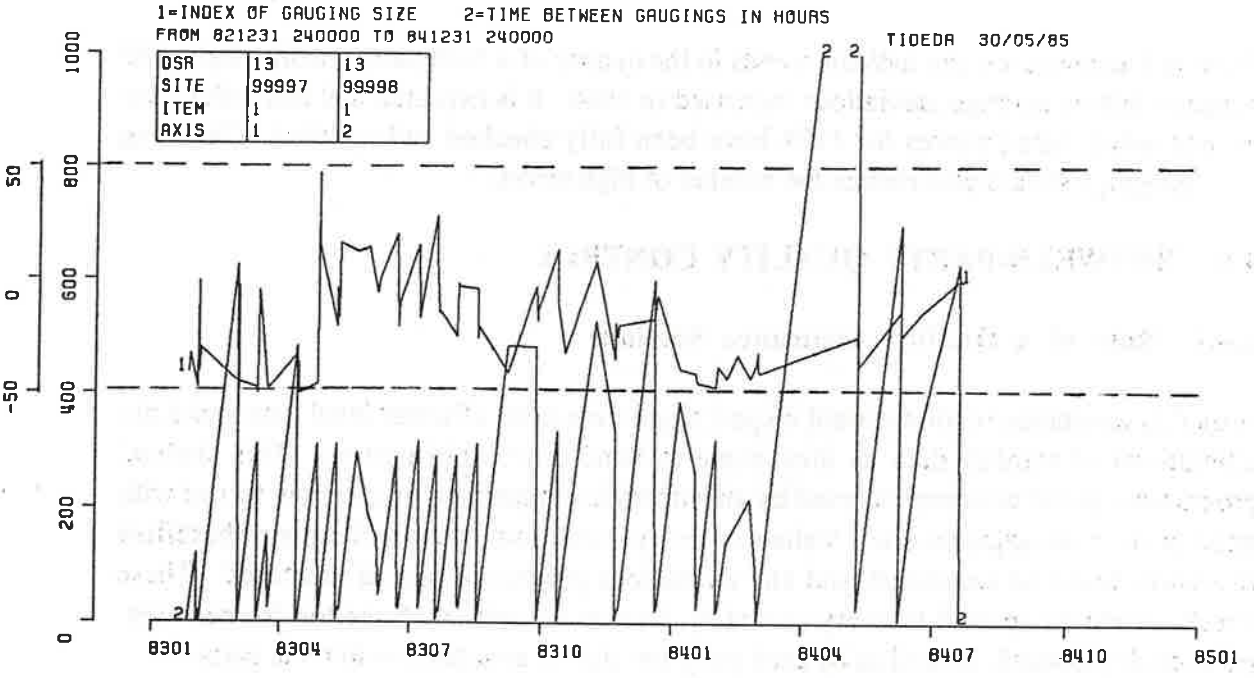

Figure 4a Item 1, index of gauging size (-50 min., +50 max.) and Item 2, time between successive gaugings (hours), for the period January 1983 to December 1984 (Wanganui field party data)

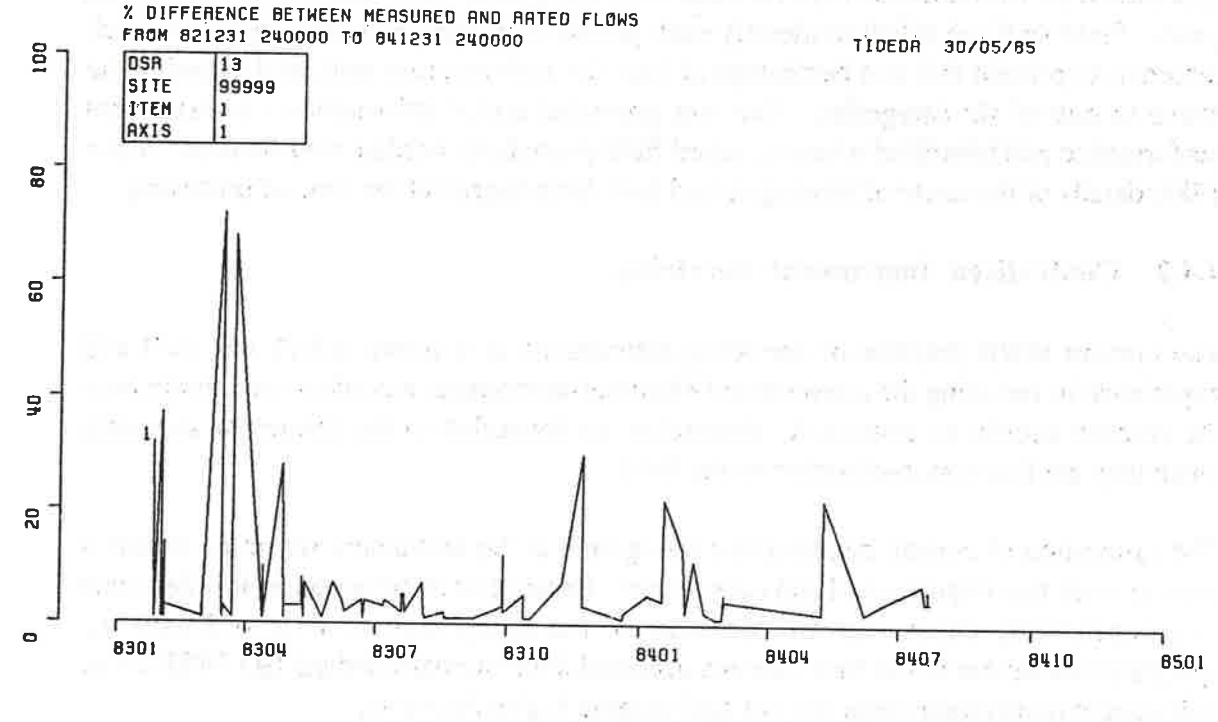

Figure 4b Percentage difference between gauged and rated discharge for the period January 1983 to December 1984 (Wanganui field party data)

Plotting I against time can indicate trends in the quality of a field party's work: figure 3b suggests that on average, deviations increased in 1984. It is expected that this index may change when rating curves for 1984 have been fully checked and updated. Checking filed gaugings should also reduce the number of high errors.

4.4 BETWEEN-PARTY QUALITY CONTROL

4.4.1 Role of a Quality Assurance Section

A quality assurance section should inspect stage-time plots of water level data and daily tabulations of rainfall data as they come to hand from field parties. This skeletal programme could be complemented by an automatic comparison of one flow record with another from an adjacent site. Values of every quickflow event and rates of baseflow recession could be examined, and any anomalous periods of record identified. These checks could be applied to every record by the quality assurance section for between-party quality control, as well as by each party for quality assurance within the party.

The current MWD practice of visiting field parties to inspect recorder installations, field work, and office procedures complements examination of recorded data. Such visits are followed up with reports back to the local field party administrators. This should be expanded by arranging for the evaluation of a field party to be undertaken by staff from another location.

Equipment performance surveys for each field party have been undertaken for several years. Field staff are asked to identify each period of missed or wrong record for each recorder, to present this as a percentage of time for each recorder type, and to assign the cause to one of six categories. This has provided useful information on instrument performance and identified where standard field procedures needed modification. Since 1984, details of the cause of missing record have been logged at the time of processng.

4.4.2 Centralised Instrument Servicing

The current MWD practice of servicing instruments at a centre which has skill and experience in servicing the conventional electrical-mechanical recorders used throughout the country should be continued. Recorders are fowarded to the centre for servicing when they are found to malfunction in the field.

The calibration of current meters at the rating tank at the instrument servicing centre is routine work that requires skill and consistency. Because of its importance, it is desirable to independently check that the operation of the rating tank is in accord with the specifications set out in the New Zealand accepted international standard ISO 3455-1976. Subsequent registration under the TELARC scheme is also desirable.

4.4.3 Reporting

The monitoring of automatically generated summaries of the quality and timeliness of data coming to hand, such that deficiencies and backlogs can be quickly identified, is a prime between-party quality control technique. Within the MWD, as a first step, summaries of backlogs of water level and rainfall data transmitted to the QAS are prepared at regular intervals and appended to Quarterly Reports (see appendix 5). The performance indices suggested in figures 3 and 4 for within-party quality control can also be used for between-party quality control. For example, figure 3 can be compared with figure 4, which presents comparable information for another field party. While variations in site conditions and numbers of sites may account for some of the differences between parties, management's attention can be focused on the differences so that relevant questions are asked about party activities.

4.4.4 Comparison Gaugings

Discharge measurements by a field party are not normally checked for random error. A programme of comparison gaugings by separate parties with their own equipment is necessary to monitor this source of uncertainty. Suggested guidelines are that each party should do at least one per year. The sites used should have an up to date rating curve. At each site, each party should do a gauging, discharge should then be calculated on-site, and estimates compared and plotted on the rating. If differences for a two-party comparison exceed 6.3% for 0.6 depth gaugings, or 5.5% for 0.2 and 0.8 depth gaugings, the measurements should be repeated with gauging equipment exchanged. (These target values are derived from a Chi-square test for sample variances that is applicable for the case of n parties.) If differences persist, then the cross-section areas and mean velocities should be compared. Differences in the cross-section areas indicate that winch counters and width measurement equipment should be checked; differences in the mean velocities indicate that the current meters require re-rating.

Independence of technique is essential: the work done by one party must not be influenced by the decisions of previous parties (e.g., the choice of meter, number and location of verticals). Therefore, the second and subsequent parties should remain off-site until preceding parties have completed their measurements. An independent referee is necessary. Results for each party (date, time, site, party, stage height, number of verticals, area, mean velocity, discharge) should appear in routine reports (e.g., Hydrology Centre Quarterly Reports).

4.4.5 Staff Interchange

Interchange of staff between field parties is desirable to promote job interest, understanding and uniformity in the application of methods. A suggested guideline is that each party member should have at least one exchange per year of one week's duration with another field party. Where this exchange is between MWD parties, it should be between, not within districts.

4.5 AUDIT

The final part of a quality assurance programme is an independent examination of the measures established under the programme. The audit should seek evidence that specified procedures are documented and being applied, instruments are calibrated, quality control procedures are in operation, and independent checks are being made on the data to verify them. Identified deficiencies are then brought to the attention of the management. In New Zealand, such an audit is available through the TELARC organisation.

5 SUMMARY

(1) Because the ultimate uses of much hydrological data are not known at the time of recording, a common standard should continue to be used for most hydrological survey and archiving work in New Zealand.

(2) International standards cover most aspects of hydrological data collection and appear to be appropriate for New Zealand conditions and requirements.

(3) Various overseas handbooks and manuals on procedures are useful, but need to be complemented by locally prepared manuals that deal in greater detail with particular problems which have not been adequately covered (e.g., frequently changing rating curves in unstable rivers).

(4) The MWD set of video films on instruments should be maintained and updated, and made available for use by all field parties. Preparation of video material on other subjects needs promotion.

(5) Besides procedures, staff with experience and ability are necessary to ensure that standards are achieved. Formal training in open channel hydraulics, to the level of NZCE/NZCS courses, is appropriate and desirable for field party staff. Because many technical staff are in their thirties and are unlikely to take these courses, hydraulics should feature in refresher courses. It is also a suitable subject for a video film.

(6) Gaps in water level records should be marked in the record. General purpose synthesis of records, especially for small basins, should usually be discouraged. If continuity of records is essential, then backup recorders should be installed.

(7) Spin tests to check meter peformance must become routine, and the practice of appending the appropriate specifications to the instrument case reinstated.

(8) The WSISC current meter rating function needs to be independently checked with a view to confirming that the rating procedures conform to ISO 3455-1976. This is a necessary preliminary for TELARC registration.

(9) (a) International standards provide a framework for assessing the random uncertainty in discharge as a consequence of uncertainty in constituent measurements.

(b) The prime source of uncertainties for velocity-area discharge measurements is the number of verticals used. However, this is well recognised in field practice, where it is reduced to a level consistent with other uncertainties by using at least 20 verticals.

(c) For discharge read from a rating curve, a sensitivity analysis indicates the levels of uncertainties attributable to errors in recording stage, data compression, and lack of fit of the rating curve. Uncertainties due to rating curve extrapolation and shifts in hydraulic control are not easily quantified.

(10) The following between-party quality control activities, currently operated by the Hydrology Centre, could be expanded to cover all hydrological surveys in New Zealand:

(a) standard procedures for checking and archiving data;

(b) visits to field parties to check that both field and office procedures are being correctly applied;

(c) maintenance of equipment performance records to identify the causes of significant loss of record;

(d) inspection of data to be archived;

(e) courses and workshops to promote approved procedures.

(11) An additional between-party quality control should be the operation of a programme of interchange of staff between field parties, designed to promote job interest and the standardisation of procedures. A suggested target is that each member should have one week per year on exchange.

(12) A programme of occasional comparison gaugings by two or more field parties at the same site to check for discharge measurement errors is necessary. As an interim target, each party should aim for at least one such gauging per year.

(13) Ultimately, it is intended that this quality assurance programme should receive an independent audit.

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APPENDIX 1

INTERNATIONAL STANDARDS FOR OPEN CHANNEL FLOW MEASUREMENT

(Source: ISO Catalogue 1983)

REFERENCE	TITLE
ISO 555/I-1973	Liquid flow measurement in open channels - Dilution methods for measurement of steady flow - Part I : Constant-rate injection method
ISO 555/II-1974	Liquid flow measurement in open channels - Dilution methods for measurement of steady flow - Part II : Integration (sudden injection) method
ISO 555/3-1982	Liquid flow measurement in open channels - Dilution methods for measurement of steady flow - Part 3 : Constant-rate injection method and integration method using radioactive tracers
ISO 748-1979	Liquid flow measurement in open channels - Velocity-area methods
ISO 772-1978	Liquid flow measurement in open channels - Vocabulary and symbols (bilingual edition)
ISO 1070-1973	Liquid flow measurement in open channels - Slope-area method
ISO 1088-1973	Liquid flow measurement in open channels - Velocity-area methods - Collection of data for determination of errors in measurement
ISO 1100/1-1981	Liquid flow measurement in open channels - Part 1 : Establishment and operation of a gauging station
ISO 1100/2-1982	Liquid flow measurement in open channels - Part 2 : Determination of the stage-discharge relation
ISO 1438-1975	Liquid flow measurement in open channels using thin-plate weirs and venturi flumes
ISO 1438/1-1980	Water flow measurement in open channels using weirs and venturi flumes - Part 1 : Thin-plate weirs
ISO 2425-1974	Measurement of flow in tidal channels Amendment 1-1982
ISO 2537-1974	Liquid flow measurement in open channels - Cup-type and propeller-type current meters

ISO 3454-1975	Liquid flow measurement in open channels - Sounding and suspension equipment
ISO 3455-1976	Liquid measurement in open channels - Calibration of rotating-element current-meters in straight open tanks
ISO 3716-1977	Liquid flow measurement in open channels - Functional requirements and characteristics of suspended sediment load samplers
ISO 3846-1977	Liquid flow measurement in open channels by weirs and flumes - Free overfall of finite crest width (rectangular broad-crested weirs)
ISO 3847-1977	Liquid flow measurement in open channels by weirs and flumes - End-depth method for estimation of flow in rectangular channels with a free overfall
ISO 4360-1979	Liquid flow measurement in open channels by weirs and flumes - Triangular profile weirs
ISO 4363-1977	Liquid flow measurement in open channels - Methods for measurement of suspended sediment
ISO 4364-1977	Liquid flow measurement in open channels - Bed material sampling
ISO 4366-1979	Echo sounders for water depth measurements
ISO 4369-1979	Measurement of liquid flow in open channels - Moving-boat method
ISO 4373-1979	Measurement of liquid flow in open channels - Water level measuring devices
ISO 4374-1982	Liquid flow measurement in open channels - Round-nose horizontal crest weirs
ISO 4375-1979	Measurement of liquid flow in open channels - Cableway system for stream gauging
ISO 4377-1982	Liquid flow measurement in open channels - Flat-V weirs

APPENDIX 2

PROVISIONAL PROCEDURES PROPOSED FOR THE SERIES HANDBOOK OF HYDROLOGICAL PROCEDURES

(Source: Hydrology Annual No.16, Part 1 1968. Ministry of Works, Wellington, p115)

1 The ϕ (phi) Index for Infiltration Rates - C. Toebes
2 Hydrograph Analysis - Separation of Base Flow - C. Toebes
3 Unitgraph Derivation by Electronic Computer IBM 650 - P. Askew and C. Toebes
4 Stage/Discharge Curves - C. Toebes and W.B. Morrissey
5 Calculation of River Flows from Stage Heights - C. Toebes and P. Askew
6 Slope/Area Observations - W.B. Morrissey and C. Toebes
7 Flow-duration Curves - C. Toebes and P. Askew
8 Base-flow Recession Curves - C. Toebes and W.B. Morrissey
9 Suspended Sediment Sampling - A.C. Hopkins and C. Toebes
 - 1st Revision - A.C Hopkins
10 The Determination of Mean Catchment Rainfall - P.J. Grant
11 Regional Data for Publication - C. Toebes
12 Selection of Site for Stream Gauging and Recorder Stations - E.J. Speight
13 Survey of Gauging Station Sites - E.J. Speight
14 Computation of the Potential Evapotranspiration by the Thornthwaite Method - C. Toebes
15 Suspended Sediment Analysis - Determination of Sediment Concentration and Discharge - A.C. Hopkins and R.K. Moreton
16 -
17 Standard Cross Sections - H. Drost
18 Hydrological Observation Programmes, Quarterly Hydrological Returns, Annual Returns of Hydrological Data for Hydrology Annual - C. Toebes
19 Glossary of Terms - C. Toebes
 - 4th Revision - C.Toebes
20 -
21 Infiltration Analysis I - Introduction - C. Toebes
 - 1st Revision - C. Toebes
22 Infiltration Analysis II - Sprinkling Plot Analysis (Sharp and Holtan Method) - C. Toebes
23 Infiltration Analysis III - Runoff Plot Analysis - C. Toebes
24 Infiltration Analysis IV - Natural Catchment Analysis (Horner and Lloyd Method) - C. Toebes
25 Cancelled
26 Rainfall Sampling - P.J. Grant
27 Rainfall Correlation - C. Toebes
28 The Water Balance - C. Toebes and J.R. Forth
29 Automatic Water Level Recorders - Instructions for Chart Changers - E.J. Speight
30 Inspection of Gauging Stations - E.J. Speight and C. Toebes
31 Operation of Fischer and Porter Analog to Digital Recorder - E.J. Speight and C. Toebes
32 Interpretation and Correction of Water Level Recorder Charts - W.B. Morrissey
33 Data Processing for Experimental Basins - Flow - C. Toebes
34 Interpretation and Correction of Automatic Rain Gauge Charts - P.J. Grant
35 Data Processing for Experimental Basins - Rainfall - C. Toebes

36 Data Processing for Experimental Basins - Publication - R.J. Pittams
37 Snow Data - W.B. Morrissey
38 Interpretation and Correction of Fischer and Porter Analog to Digital Water Level Recorder Tapes - W.B. Morrissey and W.J. Fraser
- 1st Revision - H. Hartog
39 Rainfall Stations - R.K. Moreton
40 Morphological Characteristics - R.J. Pittams
41 Instructions for Changing Fischer and Porter Analog Digital Water Level Recorder Tape - H. Hartog

APPENDIX 3

PUBLISHED HYDROLOGICAL PROCEDURES IN THE SERIES HANDBOOK OF HYDROLOGICAL PROCEDURES

Published by the Ministry of Works for the
National Water and Soil Conservation Organisation

5 Measurement of Phytomorphological Characteristics of Trees and Shrubs - C.T. Blake and W.D. Burke, 1972
8 Base-flow Recession Curves - C. Toebes, W.B. Morrissey, R. Shorter and M.Hendy, 1969
14 Computation of the Potential Evapotranspiration by the Thornthwaite Method - C. Toebes, 1968
16 Metric Rating Tables for Current Meters - S. Besley, W.B. Morrissey and R.P. Ibbitt, 1971
19 Glossary of Terms - C. Toebes, 1970
21 Infiltration Analysis I - Introduction - C. Toebes, 1969
22 Infiltration Analysis II - Sprinkling Plot Analysis - C. Toebes and G.D. Mallinson, 1971
25 Hydrological Statistics - F. Scarf, 1971
27 Rainfall Correlation - C. Toebes, 1968
29 Automatic Water Level Recorders - Instructions for Chart Changers - E.J. Speight, 1968
30 Inspection of Gauging Stations - E.J. Speight and C. Toebes, 1968
31 Field Installation and Maintenance of Fischer and Porter Analog to Digital Water Level Recorders - E.J. Speight, 1968
39 Precipitation Records - R.K. Moreton, 1968
41 Instructions for Tape Changers - H. Hartog, 1967
45 Metrication in Hydrology - A.C. Hopkins, 1971

APPENDIX 4

HYDROLOGICAL TRAINING VIDEO TAPES

Available from Ministry of Works and Development District Training Officers

1 Maintenance of propeller meters: large Ott, small Ott, Amsler
2 Maintenance of bucket current meters: Gurley, Watts, Pygmy
3 Using current meters: wading, cable cars, bridges, safety.
4 Chart recorders: Foxboro, Lea, Stevens F, surface follower, Lambrecht raingauge
5 Rainfall event recorders
6 Water level recorders: Fischer and Porter, Leupold and Stevens
7 Water level event recorders
8 Water quality sampling

APPENDIX 5

EXAMPLE OF A BACKLOG STATEMENT

SUMMARY OF DATA BACKLOG AS AT 6 JUNE 1984

(Figures are mean lag (months) between last data archived and 6.6.84, and numbers of recorders)

	FIELD PARTY															
Mean lag for	WHR	AKD	HAM	ROT	TUR	NAP	GIS	WNG	NP	WEL	NEL	GYM	CHC	LTK	ALX	DUN
Digital water level recorders	3.8	4.6	2.2	2.5	2.0	1.7	1.8	2.0	2.0	3.0	3.0*	2.6	2.4	1.1	3.6	3.6
(number operated)	16	10	16	37	17	9	8	13	10	11	21	20	20	12	17	31
Chart water level recorder	24.8	-	5.8	-	?	4.7	8.4	-	2.3	-	-	14.0	-	-	9.0	5.8
(number operated)	3	0	1	0	3	4	7	0	2	0	0	3	0	0	8	1
Digital raingauges	1.8	3.5	4.5	4.9	2.0	5.4	8.9	2.4	5.3	5.7	3.9	13	6	4	3	13

* Excludes 12 event recorders at Moutere FRC