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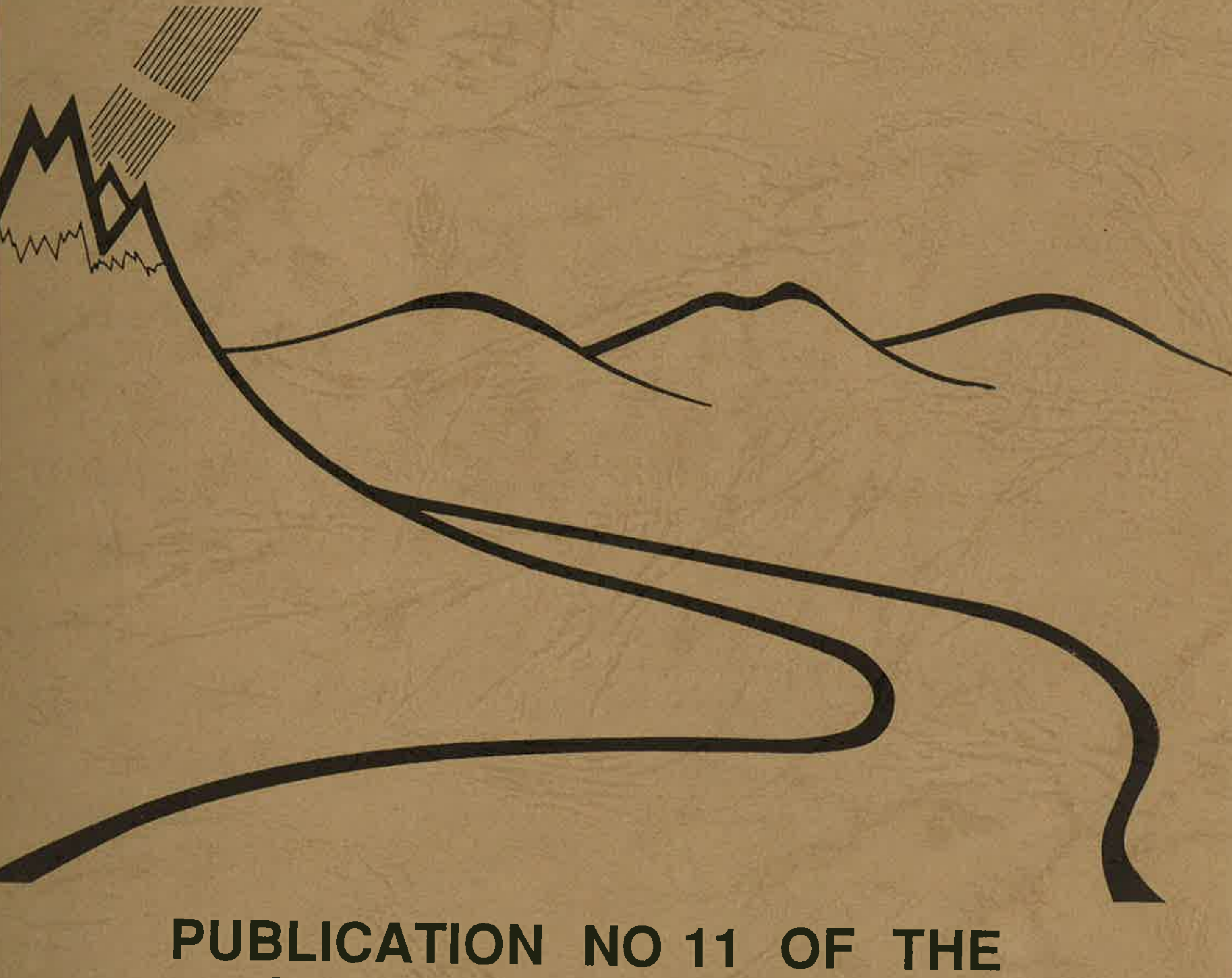
DRAWING AND CHECKING STAGE/DISCHARGE RATING CURVES

A.I. McKERCHAR and R.D. HENDERSON



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DRAWING AND CHECKING STAGE/DISCHARGE RATING CURVES

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Hydrology Centre, Ministry of Works and Development, Christchurch

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Construction of stage/discharge rating curves is detailed. The use of microcomputer software for checking rating curves is illustrated. This software, which displays deviations of ratings from gaugings against time, facilitates identification of deficiencies. Guidelines are given for extrapolating rating curves above the range of existing gaugings.

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CONTENTS

1 INTRODUCTION

The correlation between stage and discharge is called the stage/discharge relation or rating and when plotted provides a curve, called the stage/discharge, or discharge rating curve. Preparation of ratings following recognised procedures is an essential part of a hydrometric programme.

The importance of ratings in hydrological work in New Zealand has long been recognised. At a meeting of design engineers concerned with hydrological works, Burt (1959) drew attention to the need for a systematic gauging programme to maintain rating curves. Other contributions were concerned with hydraulic conditions governing the selection of recording sites. Following this meeting, a provisional procedure for drawing rating curves was prepared by Toebes and Morrissey (1961). Understandings of hydraulic principles necessary to develop ratings have not changed in recent years. The main developments have been a greatly expanded number of recorder stations, an associated increase in the gauging effort, and the adoption of computers for data checking, manipulation and storage.

Beds in alluvial river channels frequently degrade through scour and aggrade through sediment deposition. Each transition can change the stage/discharge rating. In these circumstances, several interpretations of observations may be valid. Rather than presenting a standard procedure to be applied in all cases, we describe here tools and facilities that are useful for the hydrologist in preparing ratings for the widely varying conditions that will be encountered. Initially we describe controls on levels of water in flowing channels as understanding of these is essential for the construction of ratings. We suggest how ratings may be drawn and extrapolated to high stages beyond the range of discharge measurements, using stage/velocity and stage/area curves. We suggest a convenient way to deal with sites subject to scour in the control section by vertically offsetting a standard (type) curve.

We emphasise computer-aided methods for checking ratings. We view checking and revision as integral parts of the task of preparing ratings. We have drawn on the Toebes and Morrissey provisional procedure and from other unpublished notes. The details given here are intended to supplement the recommendations of the international standard ISO 1100/2-1982 ("Liquid flow measurement in open channels - Part 2: Determination of the stage/discharge relation").

Archived hydrological data in New Zealand are accessed through a database management program called TIDEDA (**ti**me **de**pendent **da**ta). This system is implemented on a large computer at the Vogel Computer Centre (VCC). A derivative of this program (micro-TIDEDA) operates on microcomputers located with each Ministry of Works and Development (MWD) hydrological field party. This manual refers mainly to processes available in the micro-TIDEDA program (Thompson and Rodgers, 1985); associated office procedures are described in McMillan (1985).

2 CONTROLS OF WATER LEVELS IN RIVERS

An appreciation of the factors controlling the stage (water level) at a cross-section of a river is essential for drawing ratings.

In long straight channels, flowing water assumes a depth and velocity depending on channel slope, cross-section geometry and channel roughness. A commonly used relationship for this uniform flow is the Manning equation;

$$v = R^{0.67}.S^{0.5} / n$$

where: v is mean velocity (m/s),
R is hydraulic radius (m)
= A/P, where A = cross-section area (m^2)
P = wetted perimeter (m)
S is channel slope (m/m)
n is Manning roughness

Typical values for the Manning roughness 'n' are in standard hydraulics textbooks and range from 0.02 to more than 0.10. In typical river channels where the width usually exceeds 20 times the maximum depth, the wetted perimeter P is effectively equal to the water surface width (i.e. within 5%).

The dimensionless Froude number is defined as;

$$\mathbf{Fr} = v / (gy)^{1/2}$$

where: g is gravitational acceleration (9.8 m/s^2),
y is water depth (m).

Fr is the ratio of fluid velocity to wave speed in the fluid. In most natural channels it is found to be less than unity: then flow is said to be "subcritical" or "tranquil", and depth is controlled by downstream geometry and roughness. In contrast, "supercritical" or "rapid" flow (**Fr**>1) occurs mainly over spillways and in steep flumes. In subcritical flow (**Fr**<1), waves and disturbances in a river will propagate upstream against the current. In supercritical flow, waves and disturbances are swept downstream. Where **Fr** is near unity, waves and disturbances move neither upstream nor downstream, but form into the standing waves that are often encountered in flooded rivers.

Features such as free over-falls cause a drawdown in depth and an increase in velocity (Fig 1) such that **Fr** increases to unity. **Fr** is unity at the crest, enabling the velocity and hence discharge to be calculated, given a measurement of depth. In practice these ideal conditions are encountered at dam spillway crests and weirs. Constrictions also change **Fr** of a flow. Fig 2 illustrates the effect on water level for a flow in a flume with a gentle contraction and expansion, and indicates the corresponding ranges for **Fr**. In the case illustrated, the constriction controls the upstream depth.

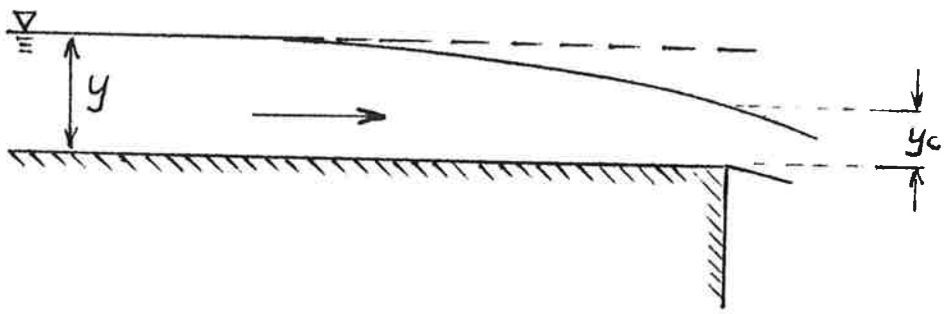


Fig 1: Drawdown of uniform flow approaching a free overfall. y is depth for uniform flow and y_c is critical depth at overfall.

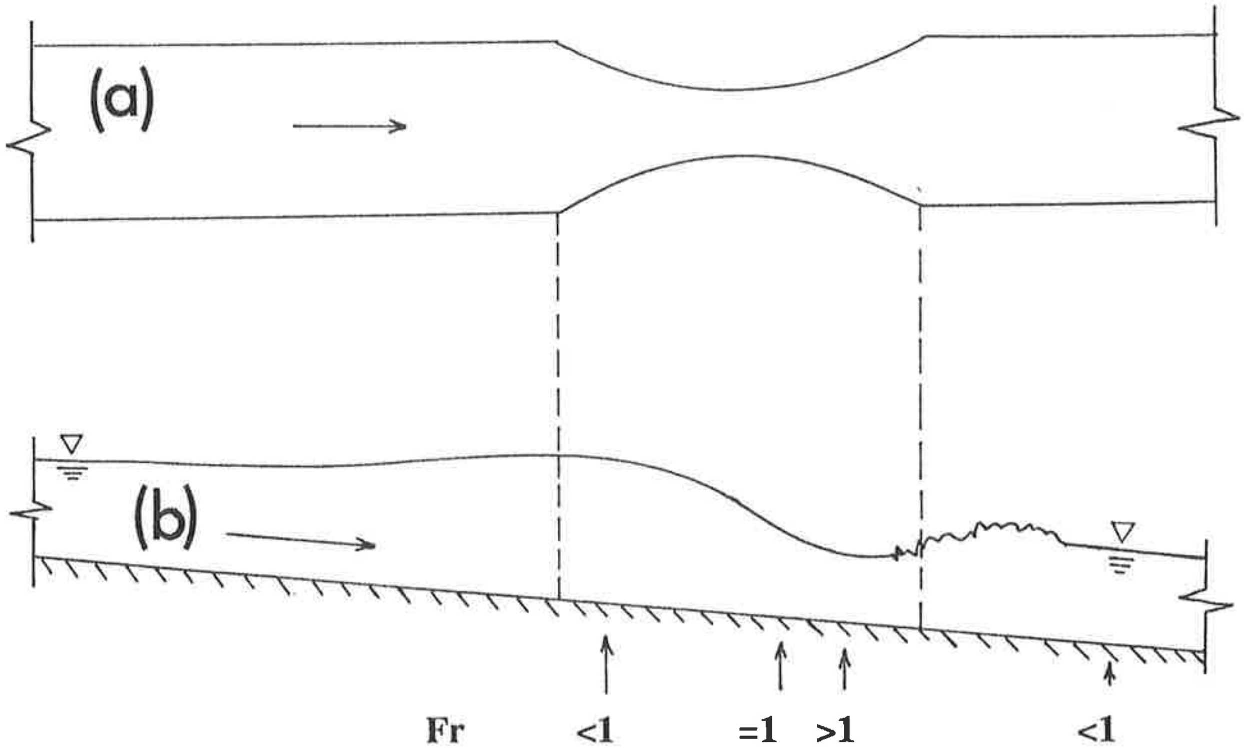


Fig 2: Sketch of flume with a gentle contraction and expansion; (a) plan view; (b) elevation; showing the effect on flowing water of the contraction and expansion. Note the turbulent water just downstream of the constriction; this is termed an hydraulic jump. Expected values for Froude number are given beneath the sketch.

In natural rivers, the reach or section controlling the relation between stage and discharge is usually located downstream of the gauge, and is termed the station control. At low flows the control may be at the upstream end of a riffle, at a rock bar across the channel, or at any other physical feature capable of maintaining a fairly stable relation between stage and discharge. At medium and high flows the influence of many riffles and other low flow controls is drowned out (Fig 3). The control becomes all the physical features of the channel that determine the stage of the river at a given point for a given discharge. These features include the size, slope, roughness, alignment, constrictions and expansions, and the shape of the channel. The reach of the channel that acts as a control may lengthen as the discharge increases, introducing new features that affect the stage/discharge relation. An ideal recorder site will have a stable channel control, which is often a constriction found in a gorge or a tight bend, or formed by approach works for a bridge. Constrictions always tend to reduce upstream velocity compared with the velocity from the Manning equation for an unconstricted channel.

In alluvial channels, scour and deposition of gravel in the controlling reach is most active at high discharges; this leads to shifts in the rating curve. Successive cross-section measurements in an alluvial channel (Fig 4) demonstrate the extent of scour that can occur during a flood (Fig 5). If only cross-sections 1 and 6 had been measured (Fig 4), only minor cross-section change would have been noted, whereas in fact up to 2 m of both scour and aggradation occurred near the flood peak (cross-sections 2,3 and 4, Fig 4).

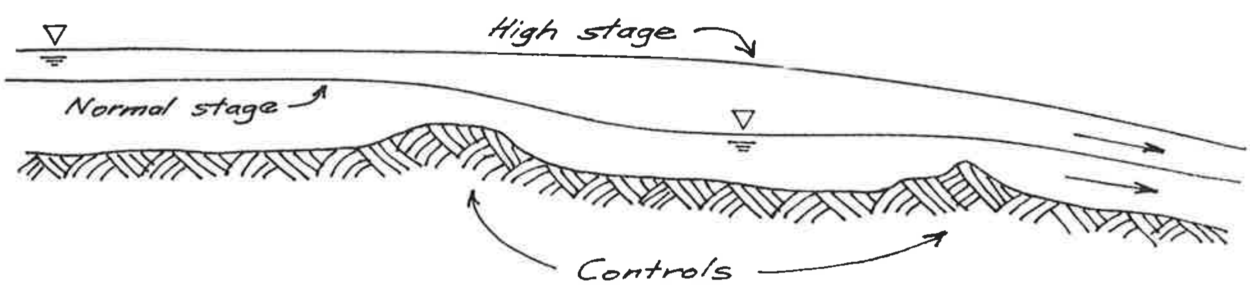


Fig 3: Illustrating the effect of the drowning of a normal control by another control at higher stage.

Downstream tributaries can cause a variable control when they either flood or bring large quantities of sediment into the main channel: an example in New Zealand is the Kawarau River below the Lake Wakatipu outlet where it is joined by the Shotover River (Jowett and Thompson, 1978). In this case, lake discharge is a function of lake level and the extent of blockage of the outlet channel.

On the rising limb of a flood hydrograph the discharge at a given stage exceeds the steady-stage discharge for the same stage, whereas on the falling limb it is less than the steady-state discharge, at least in theory. Sediment transport, especially in sandbed rivers, can cause the same effect. This leads to "loop" ratings which are described in hydrological and hydraulic textbooks (e.g. Henderson, 1966; p392). However, in most New Zealand rivers the channels are so steep that this effect is too small to be measured and so the same rating curve is used on both the rising and falling stages. The PSIM process in the micro-TIDEDA program can be used to handle loop ratings.

3 RATING CURVE CONSTRUCTION

3.1 Scales

Processes in the micro-TIDEDA program that plot gaugings automatically choose the largest scale that will show all the data on a predetermined sheet size. To force choice of scales that will provide space on the plot sheet for extrapolation to the highest stage values, it is necessary to add a dummy gauging to the gauging file. The dummy gauging should give cross-section area for maximum stage, and best but perhaps inaccurate guesses for discharge and velocity. Ordinate scales in the range 1 mm (graph) = 2 mm (stage) to 1 mm (graph) = 20 mm (stage) and abscissa scales in the range 1 mm (graph) = 0.001 m^3/s to 1 mm (graph) = 10 m^3/s (flow) cover most situations.

When ratings are prepared by hand, gaugings should be plotted on an A1 size (841 x 594 mm) sheet of graph paper with graph lines every 2 mm and bolder lines every 20 mm. By convention the stage height (mm) is plotted on the vertical axis (ordinate), the discharge (m^3/s, or L/s for small streams is plotted on the horizontal axis (abscissa). Standard metric scales (1:10, 1:20, 1:50) for the axes should be used. Two A1 sheets should be prepared for each site. The first covers the full stage range, including the extrapolation to the maximum gauge height, and the other covers the lower stage ranges with increased scales. The

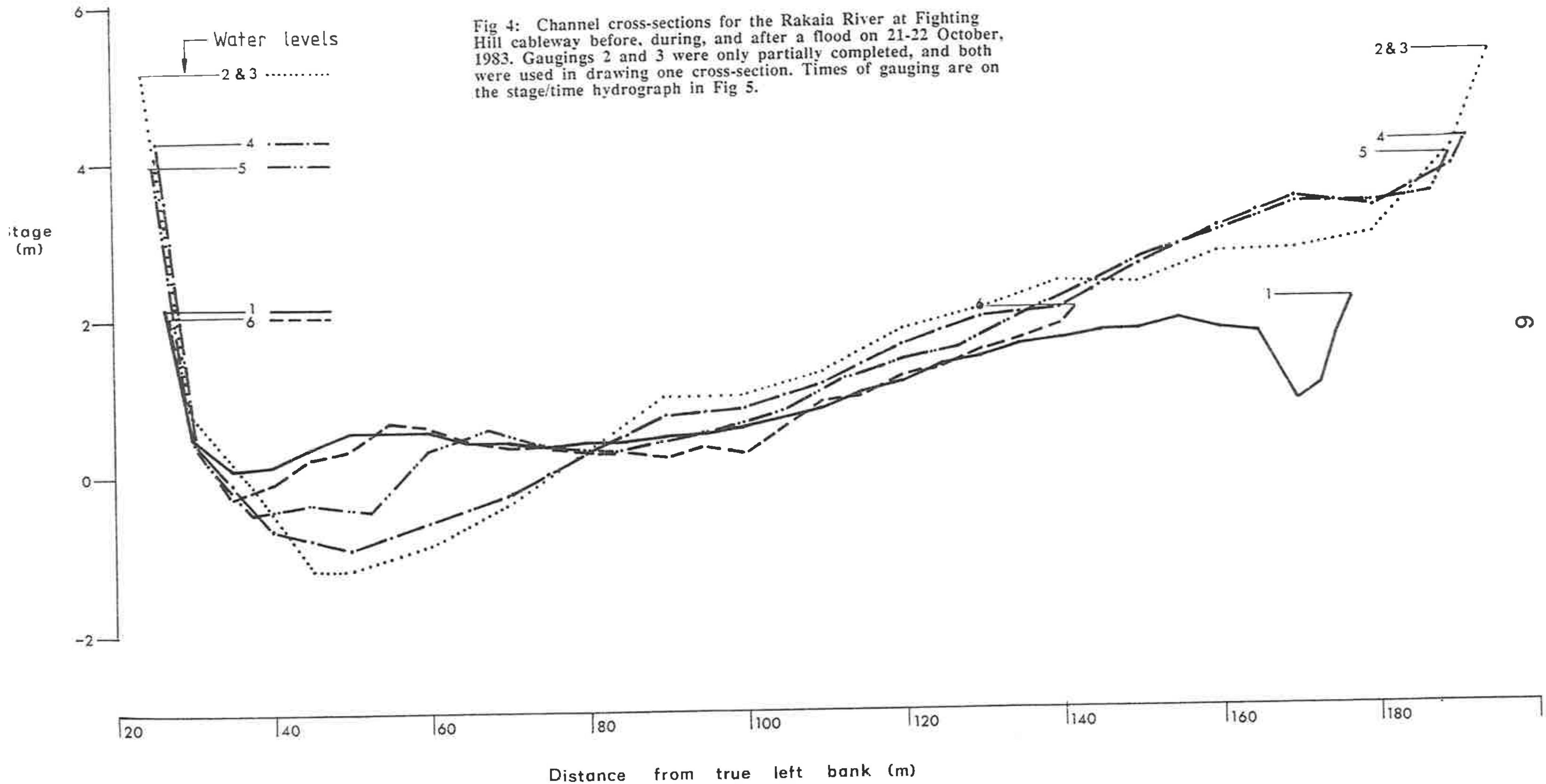


Fig 4: Channel cross-sections for the Rakaia River at Fighting Hill cableway before, during, and after a flood on 21-22 October, 1983. Gaugings 2 and 3 were only partially completed, and both were used in drawing one cross-section. Times of gauging are on the stage/time hydrograph in Fig 5.

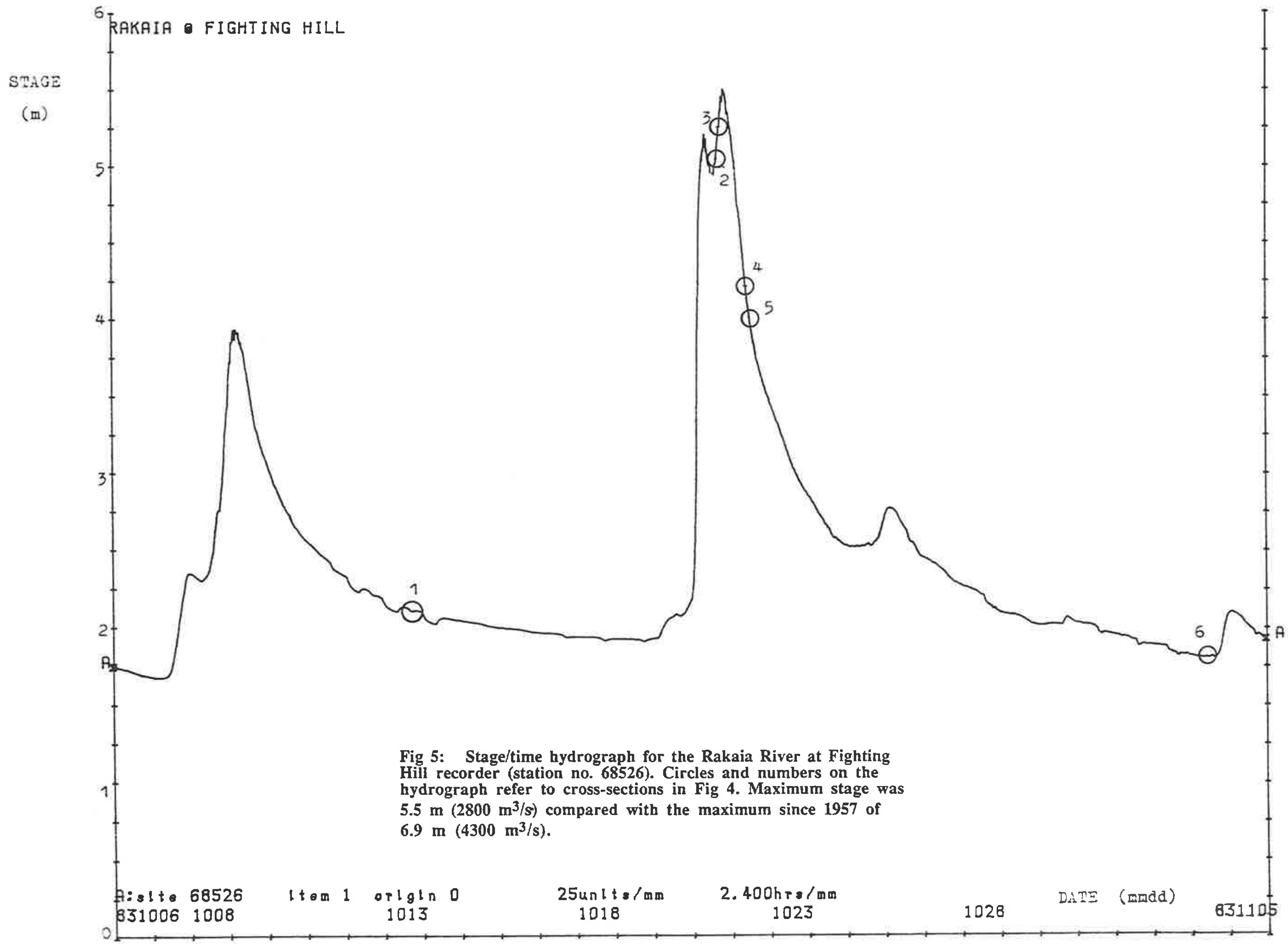


Fig 5: Stage/time hydrograph for the Rakaia River at Fighting Hill recorder (station no. 68526). Circles and numbers on the hydrograph refer to cross-sections in Fig 4. Maximum stage was 5.5 m (2800 m^3/s) compared with the maximum since 1957 of 6.9 m (4300 m^3/s).

latter allows the majority of gaugings to be plotted to a scale large enough that changes in ratings can be identified. Take care to ensure that scale differences do not produce discontinuities in curve shape.

3.2 Gauging errors

Errors in stage measurements are usually small compared to errors in discharge measurement and can be ignored for plotting purposes. When stage changes during the gauging, a mean stage value should be used. It is essential to identify each gauging with a reference number or date, and it may be helpful to show with each gauging, horizontal error bars that indicate the assessed gauging error. At low to medium stages, it may be reasonable to assume that 95% of all gaugings give the measured discharge to within +5% of the true value. At high stages, where errors result from difficulties in measuring depths and in applying air and wet line corrections, a figure of 10% may be justified. Slope area estimates may have errors of up to 30%, or more where sediment transport is significant.

On rivers which have loop ratings, separately identify rising and falling limb gaugings.

3.3 Drawing the rating curve

Steps necessary in manually preparing rating curves are:

1 Assemble the gauging cards in chronological order, ensure that the calculations have been checked, and note remarks relevant for any gaugings.

2 Decide the scales to be used and label and annotate the axes.

3 Plot the gaugings and label each point with either the date, or a reference number. If the latter is used, the reference and the corresponding date are entered in a key on the sheet. When all the gaugings have been plotted, the minimum and maximum stages for the period of the rating are marked (e.g. Fig 6a). These will need to be predicted for a rating that is still current. Other levels at which changes in the cross-section occur, (e.g. at bankfull), or at which changes in control occur (if identifiable) should also be marked on the stage axis.

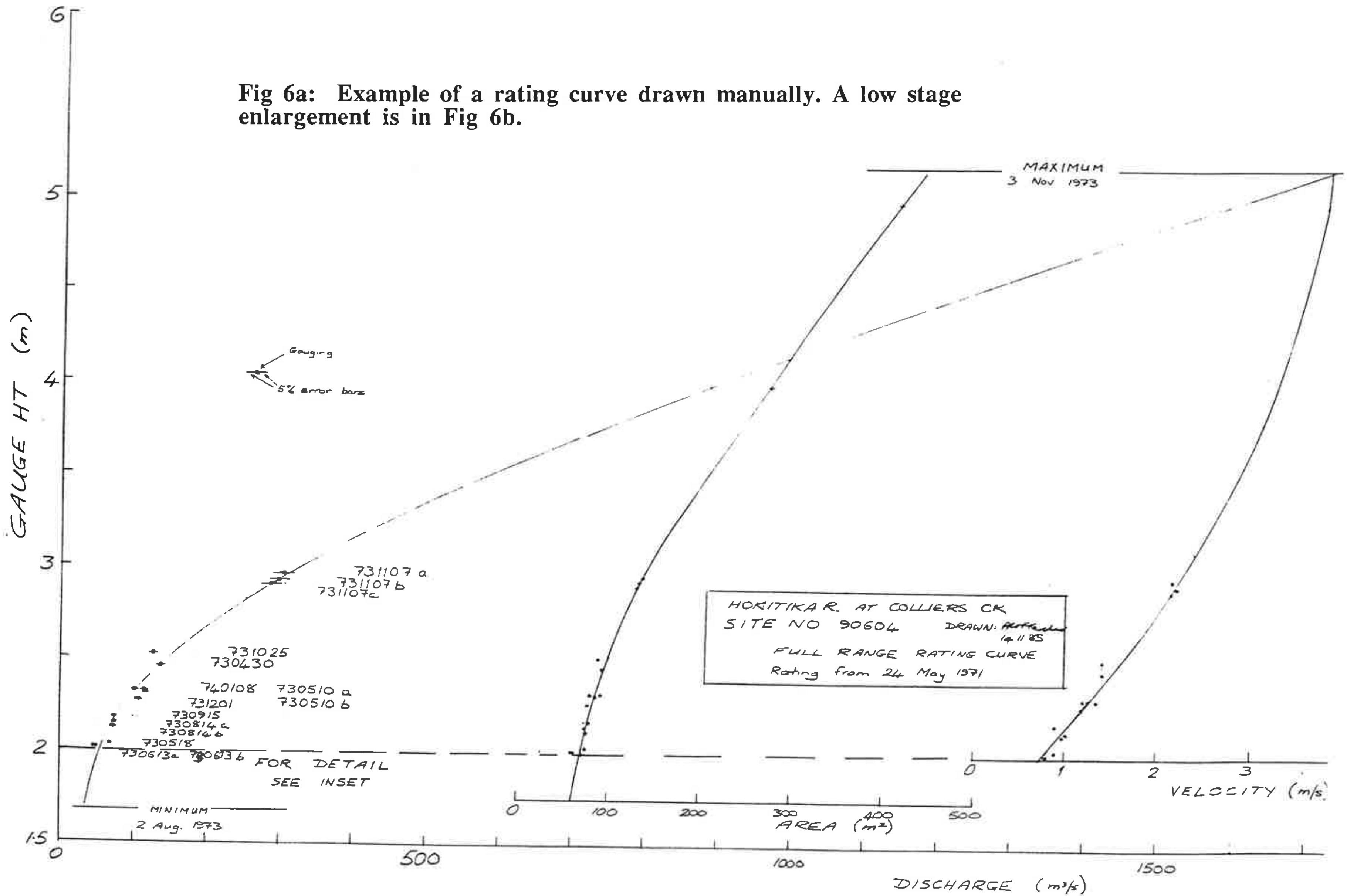
4 Identify a period with frequent gaugings and eye-fit a curve to as many gaugings as possible, recognising likely errors in gaugings (Fig 6a). A template formed to a parabolic curve may be used to get a smooth curve. If the gaugings indicate discontinuities in the slope of the curve, these should only be accepted if they can be assigned a definite reason (e.g. bank overflow).

5 Extend the curve to the highest expected stage value (see section 3.5).

6 Complete a title block which includes the station name and number, the period covered by the rating, the rating curve number, your name and the date.

7 Plot gaugings for the lower part of the curve on a separate sheet, and fit a curve through these points (e.g. Fig 6b). The maximum stage for the enlarged plot depends on the density of points to be plotted and is chosen so that individual gaugings can be distinguished. A useful guide is to use the maximum discharge as five times the mean, and the corresponding stage.

Fig 6a: Example of a rating curve drawn manually. A low stage enlargement is in Fig 6b.



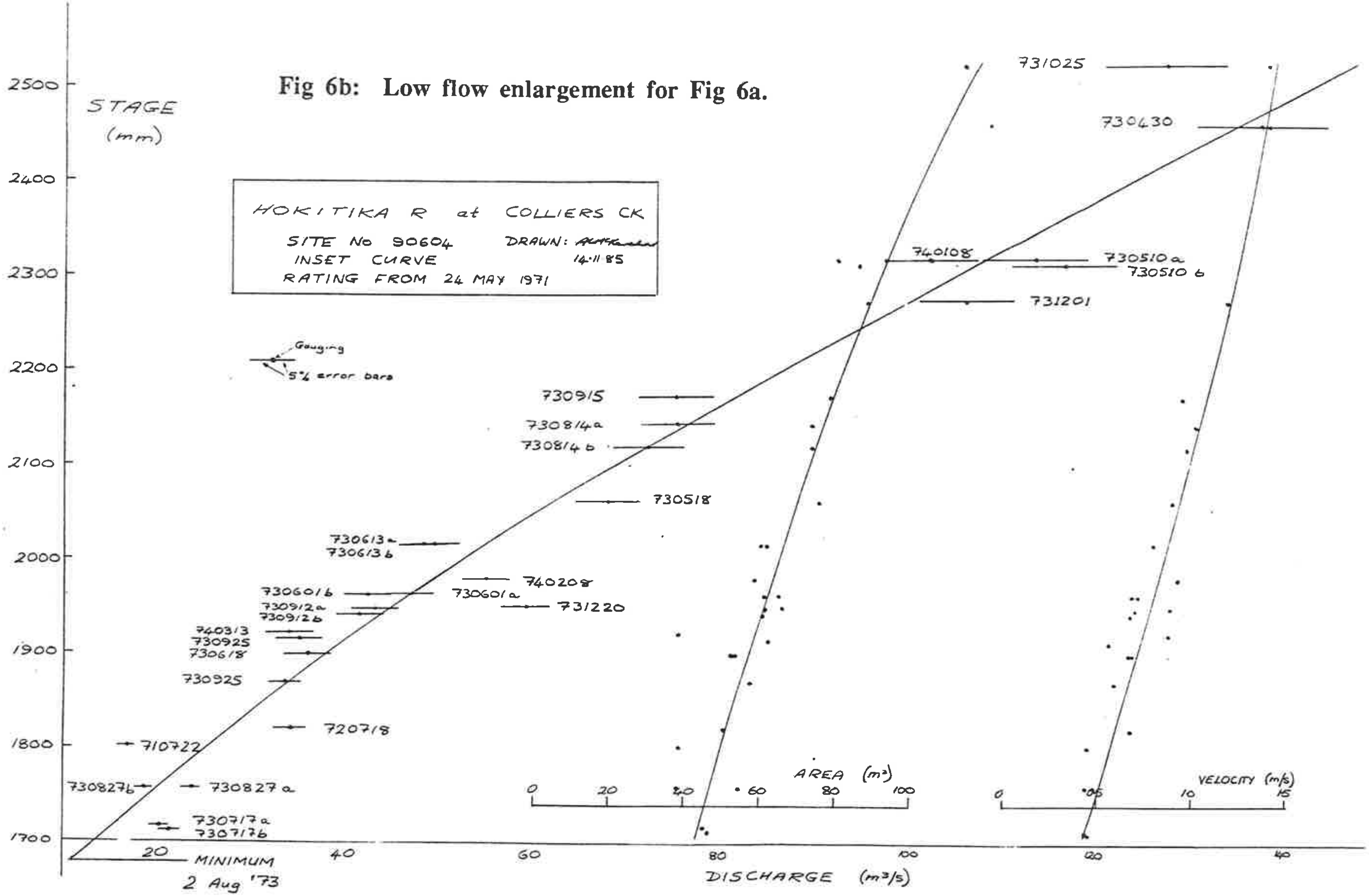


Fig 6b: Low flow enlargement for Fig 6a.

8 Identify rating shifts by examining deviations of successive gaugings from the curve. Further curves are drawn through the gaugings that so deviate.

9 Successive ratings are often merged together at their highest point, but sometimes it may be valid to offset the first curve vertically (Section 3.7).

10 Read pairs of stage and discharge coordinates from the curves for entry into data archives.

Rating changes are most evident at times of low flow. They are identified from several successive gaugings which consistently plot away from previous gaugings and may be caused by bed scour or sediment deposition at or downstream of the recorder site in a previous flood. Other possible influences are seasonal weed growth and bank slumping. The effect of such changes is less significant at high discharge and may not be evident. This permits the few high stage gaugings that might have been executed over a station's period of operation to be pooled. Therefore, high discharge points prior to the expected start of a new rating should be plotted, preferably using a different colour or symbol to indicate that they were measured in a different time period.

3.4 Stage/velocity and stage/area curves

To the right of the main rating and to the same stage scale, cross-section area and mean velocity curves for the gauging cross-section are drawn (e.g. Fig 6a). Velocity and area scales are chosen in a similar manner to the discharge scales. First the area curve is drawn using cross-section survey data for the gauging cross-section. Cross-section area values measured for all available gaugings are then plotted. Points on the velocity curve are calculated by dividing the discharge for each gauging by the corresponding area. Finally, a curve is drawn through these points. Where all the gaugings are done for a single cross-section (e.g. from a cableway), velocities and areas measured in gauging may be expected to plot on their curves, but values measured at other gauging sites (e.g. wading, boat, or slope area), will obviously vary from the curves. Reference to the original gauging cards may be necessary.

These two additional curves will be useful for:

(a) helping with the extrapolation of ratings;
(b) helping to identify causes of sudden changes in rating slopes, eg, the cross-section area curve will flatten above bankfull stage;
(c) checking for mistakes; for example when the area plots satisfactorily, a deviation of a measured mean velocity away from the curve may be caused by use of an inappropriate current meter rating table;
(d) identifying when scour or aggradation has occurred because the measured area for the gauging will plot away from previous area measurements for the same stage. When the gauging site is some distance away from the recorder, and a shift in the gauging cross-section has been identified, then the master cross-section at the recorder may need to be resurveyed to check whether a change in the control has occurred.

3.5 Extrapolation of ratings

Extrapolation of ratings is necessary when a water level is recorded above the highest gauged level. Log-log plots are sometimes used to establish the preliminary shape of the extrapolated rating curve, but generally overestimate flow at high stage. Where the cross-section is stable, a recommended method (ISO 1100/2, Annex D) is to extend the stage/area and stage/velocity curves, and for given stage values, take products of velocity and cross-section area to give discharge values beyond the gauged values.

Extension of the stage/area curve above the active channel can be completed by standard survey methods. However, where the active channel scours during high flows as shown in Fig 4, or aggrades, the area during floods can be estimated by gauging in the bed section and merged into the surveyed section above the active zone.

Extrapolation of the stage/velocity curve requires an understanding of the high stage controls. Where the flow is confined within a regular channel section of constant roughness, the Manning Equation $v = R^{0.67}.S^{0.5}/n$ is sometimes used to assist the extrapolation by assuming that the factor $K = S^{0.5}/n$ tends to a constant value at high stage. The Manning Equation is thus $v = K.R^{0.67}$ which specifies the shape of the extended velocity curve (see ISO 1100/2. Annex D, and also Rantz and others, 1982; p334). However where fine sediment cloaks the bed and temporarily reduces roughness, or transport of boulders and gravel temporarily increases roughness during floods, then the velocity during floods can only be determined by gauging.

In extending velocity curves, an upper bound is imposed by the fact that **Fr** rarely exceeds unity in natural channels and is probably always less than about 0.8 where the channel bed is erodible. With **Fr** = 0.8,

$$v < 0.8\ (g.y)^{0.5}$$

For some typical values of depth , this criterion yields the following maximum velocities;

mean depth y (m)	mean velocity v (m/s)
1	2.5
2	3.5
3	4.3
4	5.0
5	5.6

In New Zealand, mean velocities in the cross-section exceeding 4.0 m/s have been measured rarely. Gaugings implying high mean velocities should be carefully scrutinised.

Extrapolation of stage/discharge curves by taking the product of area (from surveyed stage/area curves) and velocity (from extrapolated stage/velocity curves) is preferred to extrapolation of stage/discharge curves on log-log graph paper.

Velocity measurements at high stage are the only way to reduce the uncertainty inherent in extrapolation of the stage/velocity curve. If a full current meter gauging is not possible, then surface velocity measurements with either current meters or floats are better than no measurement at all. If these measurements come to hand subsequently, the stage/velocity curve and the extrapolated part of the ratings may need to be revised.

Rating curves are often represented by equations of the type

$$Q = K.(h + e)^{m}$$

where K, e and m are constants. In channels that are long, straight, and uniform such that the Manning equation can be applied reliably, values of m for different cross-section shapes are:

rectangular	m = 1.67 (assuming width > 20 x depth)
parabolic	m = 2.17 (assuming width > 20 x depth)
triangular	m = 2.67

In the micro-TIDEDA program, ratings are stored as pairs of stage and discharge coordinates, and an equation of the above form is used to interpolate between coordinate pairs. The micro-TIDEDA software assumes e = 0 and m = 2.0 to extrapolate above the largest filed h, and m = 0.5 to extrapolate below the lowest filed h.

3.6 Time of rating change

In natural channels, most rating changes result from erosion or deposition of sediment at or downstream of the recorder. A regular programme of gaugings will be necessary to confirm that the existing rating still applies, or to indicate that a change has occurred. Rating changes will be needed when levels for successive gauged flows deviate in a consistent way from the level read from the rating curve for the same discharge. Examination of successive level differences enables the interval in which a rating change occurs to be identified.

Sometimes a change in rating can be related to a specific flood which gives the time of introduction of the new rating. Often it is not possible to say which of several floods caused the rating to change. In this situation stage-time plots should be examined because a definite shift in recession levels may indicate the event which caused the change. If, having examined stage-time plots, no decision can be made as to which of several flood peaks might have caused the change, then assigning the rating change to the highest flood is as good a compromise as any. It is recommended that a new rating be introduced progressively over a period of time starting halfway up the rising limb of the chosen flood hydrograph, and ending halfway down the falling limb. This smooth transition from one rating to another avoids artificial jumps in the flow series. Details of the progressive introduction of new ratings are given in the micro-TIDEDA manual.

3.7 Use of type curves

Rating curves that change frequently because of scour and fill are often drawn to converge at a high flow (e.g. Rantz and others, 1982). Where the control section is confined by steep sides to the channel, the labour of constantly drawing new ratings can be reduced by using a single master curve, called a "type curve" (Ibbitt, 1979), that has been built up from gaugings over a period of time. An intensive gauging effort mounted over a short period while the channel is in a quasi-stable state will provide the data necessary to establish this curve. When a shift in control occurs, it may then be sufficient to shift the curve up or down by a suitable value of stage. Regular gauging will still be necessary to establish whether a shift has occurred, but only a few gaugings are needed to establish the size of the shift. The ratings are thus a set of identical curves offset vertically. The idea is not new; it is described in Liddell (1927, p200).

The shape of a type curve may change when a noteworthy flood completely alters the geometry of the channel. In this case it will be necessary to derive a new type curve.

4 ARCHIVING AND CHECKING RATINGS AND GAUGINGS

4.1 Computer software

This section describes the computer software available to MWD field parties to load gauging and rating data to archives and to present these data in formats that expedite data checking, as well as construction of rating curves. The software also provides useful means for illustrating inherent uncertainties in rating curves and hence in derived discharge data.

The software that is additional to micro-TIDEDA is currently (July, 1986) available only for CP/M operating system machines, but it is intended that equivalent software for all machines that run micro-TIDEDA will be produced. It comprises two programs called PGAUGE and PDEV. The PDEV program can be run either in sequence after the PGAUGE program, or separately.

4.2 Archiving gaugings

Entry of current meter gauging data into micro-TIDEDA files is a three-step process involving three computer files. First, all details of a current meter gauging (measurements of depths, widths, and velocities at points in a cross-section, date and details to identify the gauging) are loaded into a computer text file (name.DTA) using the program for handling gauging details. Second a program called RGAUGE calculates the discharge and writes this with other summary information (area, mean velocity, stage height, date) into a second text file (LIST.ED) in a format acceptable to the micro-TIDEDA program. Third, the micro-TIDEDA program (process TLIST) translates data from the text file (LIST.ED) into a micro-TIDEDA file called TIDEDA.0nn (00<nn<100) (see Fig 2-1 of Thompson and Rodgers 1985). The measurement details loaded into the text file in the first step are kept for other purposes.

Clearly, maintenance of integrity of files requires that any errors detected in gauging data should be corrected in the original text file (name. DTA) and the translation steps RGAUGE, TLIST) repeated. Otherwise, if a text editor is used to edit data in the intermediate LIST.ED file, inconsistencies between the gauging details (in the name.DTA text file) and the summary data in the micro-TIDEDA files will be created.

Slope/area and dilution gaugings can be entered with the micro-TIDEDA program (process ADDATA).

4.3 Archiving ratings

Rating curve co-ordinate pairs are entered into the LIST.ED file using the micro-TIDEDA program (ADDATA) and then translated into a TIDEDA.0nn file with the micro-TIDEDA program (TLIST).

Where the rating curve is smooth and approximately parabolic, between 5 and 10 pairs of coordinates may suffice. However, more are necessary when a transition in the cross-section shape occurs, for example when a V-notch weir is overtopped.

Where type curves are used, the vertical offsets are readily applied with the micro-TIDEDA program (process TRANSFORM); however to alter dates, a text editing program is used on ratings that have been listed into a text file (LIST.ED) by the micro-TIDEDA program (process LIST).

4.4 Plotting gaugings

Gaugings may be plotted in the following ways:

1 against stage, using the PGAUGE program, or the micro-TIDEDA program (process PLGRAPH);
2 as deviations from a particular rating, using the PDEV program or the micro-TIDEDA program (PLBED);
3 on a stage hydrograph or flow hydrograph, using the micro-TIDEDA program (process PLGRAPH).

The PGAUGE and PDEV programs draw printer plots, and are equivalent to the processes PLGRAPH and PLBED in the micro-TIDEDA program which present most of the same information using a pen plotter.

4.5 PGAUGE program

The PGAUGE program produces a plot on a printer of one item against another item from a micro-TIDEDA file of gaugings. For the purposes of the PGAUGE program (and the PDEV program), a gauging is a set of measurements of two or more parameters, that were made at the same time. If rating curves are filed, it offers the option of displaying the ratings on the same plot.

For example, consider the use of a current meter to measure water velocity, and thereby estimate discharge through a cross-section. The stage at the time of the gauging is noted, and other features of the cross-section can be calculated, e.g. mean velocity and cross-sectional area. The set of values for stage, discharge, mean velocity etc, are in micro-TIDEDA as a multi-item element (section 4.2). After a number of such measurements at a range of stages, a rating curve can be constructed, relating discharge (Item 2) to stage (Item 1). The PGAUGE program can be used to produce plots of the gaugings (e.g. Fig 7a, Fig 8), plus plots of cross-sectional area and mean velocity (Items 3 and 4) versus the stage (e.g. Fig 7b). A list of gaugings, each identified by the symbol used to display it on the plots, is also printed (e.g. Fig 7c). If ratings for the same site are loaded in the file, they also can be plotted (e.g. Fig 10a).

On the first plot, up to 400 gaugings, together with any rating coordinates from up to nine ratings, can be displayed. Rating coordinates are shown as a digit from 1 to 9 (see Fig 10a). For each gauging the letters A-Z then a-z are used in order, then reused if there are more than 52 print positions used on the plot.

When ratings are filed, PGAUGE also produces plots which enable the stage deviation of each gauging from its rating curve to be investigated. Each rating is projected onto a line across the page, and the relevant gaugings are printed above,

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""" PGAUGE """ VER 2.4  05-11-85

B:TIDEDA.001 Site    90604   710524   144500 to    740404  240000
HOKITIKA RATINGS
Rated versus unrated
               units/mm  resolution         low        high   spans(mm)
Rated          10000.00    15393.94           0     1980000        198.
Unrated           20.00       42.33        1500        5200        185.
  33 gaugings plotted       :    0 outside limits
```

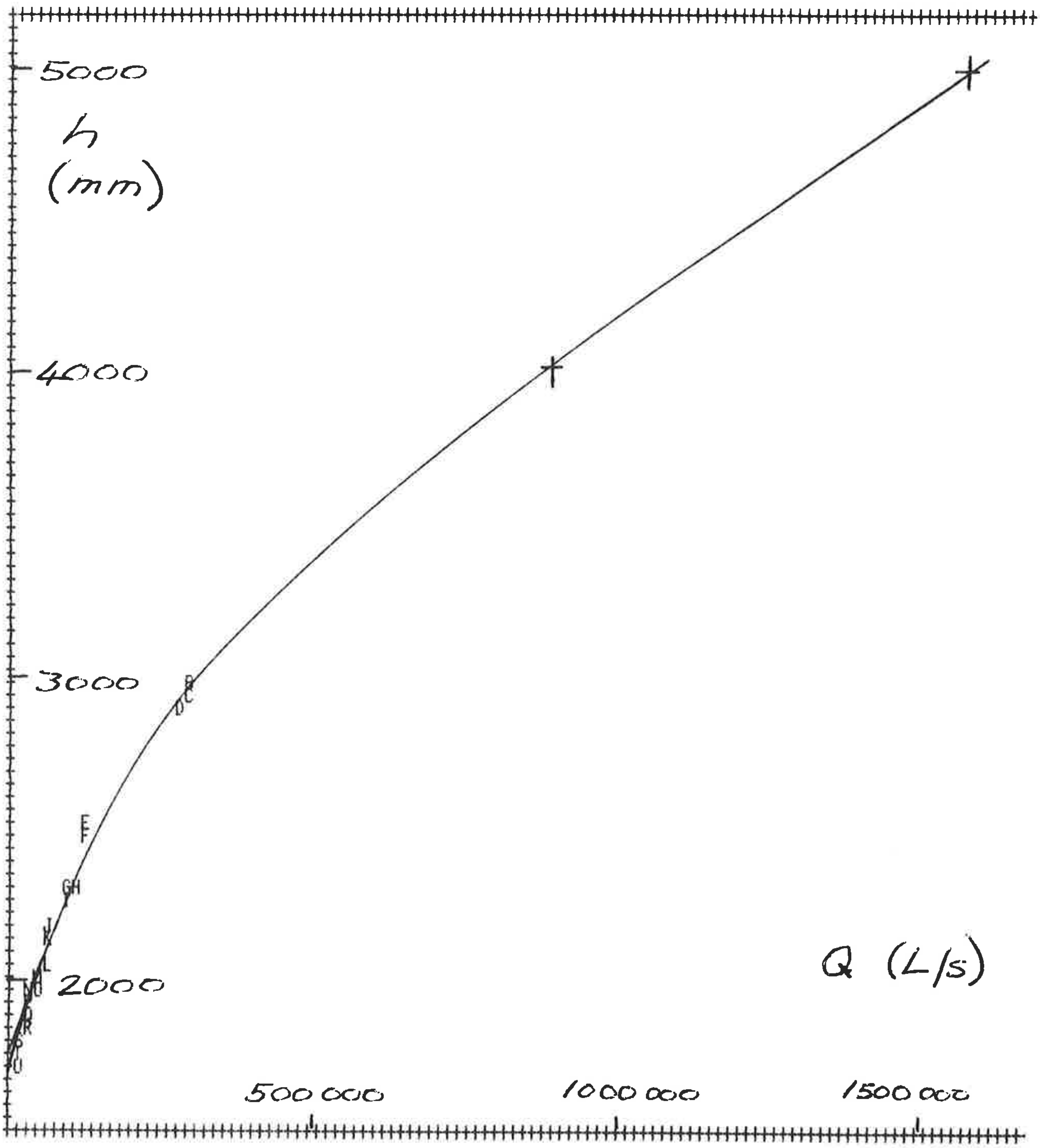


Fig 7: (a) Stage/discharge data for Hokitika River with suggested rating curve drawn in. The curve is extrapolated through points which are the products of values read from the stage/velocity and stage/area curves (Fig 7b). Dummy gauging "A" has been deleted.

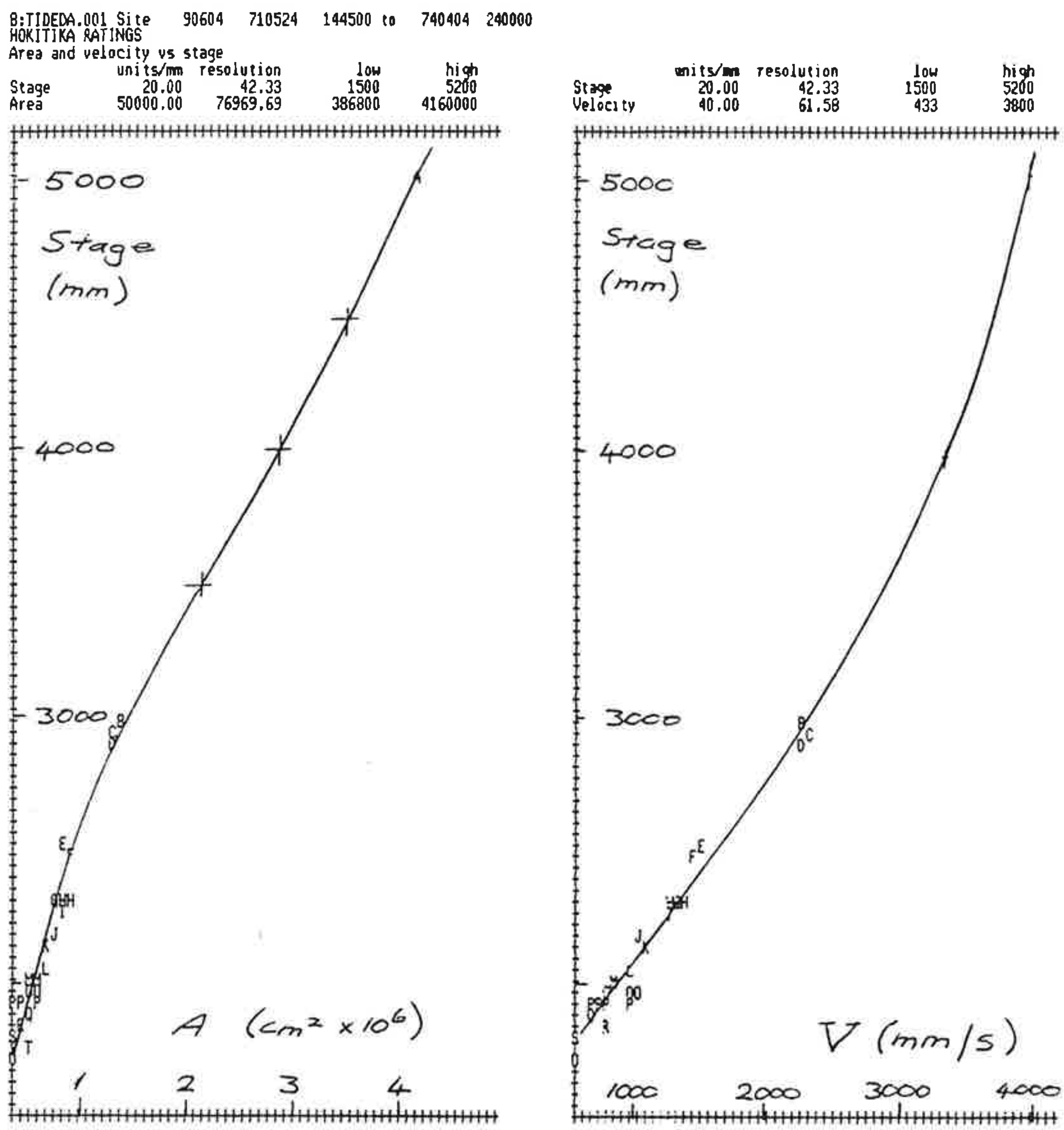


Fig 7: (b) Stage/area and stage/velocity data for Hokitika River. The curves are eye-fitted to the points. Note on the stage/area curve the dummy gauging "A" to force the scale size, and the data from cross-section survey marked "+".

B:TIDEDA.001 Site 90604 710524 144500 to 740404 240000
HOKITIKA RATINGS
Gaugings in symbol order

Read Qi : XXXXX00

	Si	Qi	Vel.	Date	
A	5000	16000	3800	710524	2400
B	2968	3043	2185	731107	1225
C	2935	2995	2231	731107	1430
D	2909	2853	2167	731107	1555
E	2525	1275	1421	731025	1150
F	2460	1375	1418	730430	910
G	2318	1022	1265	740108	1315
H	2320	1135	1214	730510	1410
H	2312	1167	1354	730510	1540
I	2275	1061	1191	731201	1508
J	2174	752	953	730915	1215
K	2145	753	1015	730814	1230
K	2120	722	988	730814	1350
L	2063	680	900	730518	1345
M	2018	483	801	730613	1430
M	2018	495	798	730613	1603
N	1963	414	681	730601	1435
N	1948	432	704	730912	1324
N	1943	415	681	730912	1445
O	1964	470	721	730601	1315
O	1951	594	881	731220	1545
O	1981	550	927	740208	1222
P	1900	360	689	730618	1410
P	1900	361	673	730618	1520
P	1916	351	563	731010	1400
P	1922	341	882	740313	1510
Q	1870	337	585	730925	1450
R	1821	343	680	720718	1410
S	1802	169	433	710722	1630
T	1759	239	436	730827	1308
T	1759	186	481	730827	1428
U	1712	207	459	730717	1340
U	1717	203	437	730717	1530

Gaugings in date order

Read Qi : XXXXX00

	Si	Qi	Vel.	Date	
A	5000	16000	3800	710524	2400
S	1802	169	433	710722	1630
R	1821	343	680	720718	1410
F	2460	1375	1418	730430	910
H	2320	1135	1214	730510	1410
H	2312	1167	1354	730510	1540
L	2063	680	900	730518	1345
O	1964	470	721	730601	1315
N	1963	414	681	730601	1435
M	2018	483	801	730613	1430
M	2018	495	798	730613	1603
P	1900	360	689	730618	1410
P	1900	361	673	730618	1520
U	1712	207	459	730717	1340
U	1717	203	437	730717	1530
K	2145	753	1015	730814	1230
K	2120	722	988	730814	1350
T	1759	239	436	730827	1308
T	1759	186	481	730827	1428
N	1948	432	704	730912	1324
N	1943	415	681	730912	1445
J	2174	752	953	730915	1215
Q	1878	337	585	730925	1450
P	1916	351	563	731010	1400
E	2525	1275	1421	731025	1150
B	2968	3043	2185	731107	1225
C	2935	2995	2231	731107	1430
D	2909	2853	2167	731107	1555
I	2275	1061	1191	731201	1508
O	1951	594	881	731220	1545
G	2318	1022	1265	740108	1315
O	1981	550	927	740208	1222
P	1922	341	882	740313	1510

End of Process

Fig 7: (c) Listing of gaugings for the Hokitika River (710524-740313). Gauging "A" is a dummy to force scales on the stage/area curve.

```
~~~ PGAUGE ~~~ VER 2.4  05-11-85

B:TIDEDA.001 Site    90604   710524   144500 to    740404  141500
HOKITIKA RATINGS
Rated versus unrated
              units/mm  resolution         low        high    spans(mm)
Rated           800.00     1231.52       16000      144000         160.
Unrated           5.00       10.58        1600        2600         200.
  29 gaugings plotted      :     4 outside limits
```

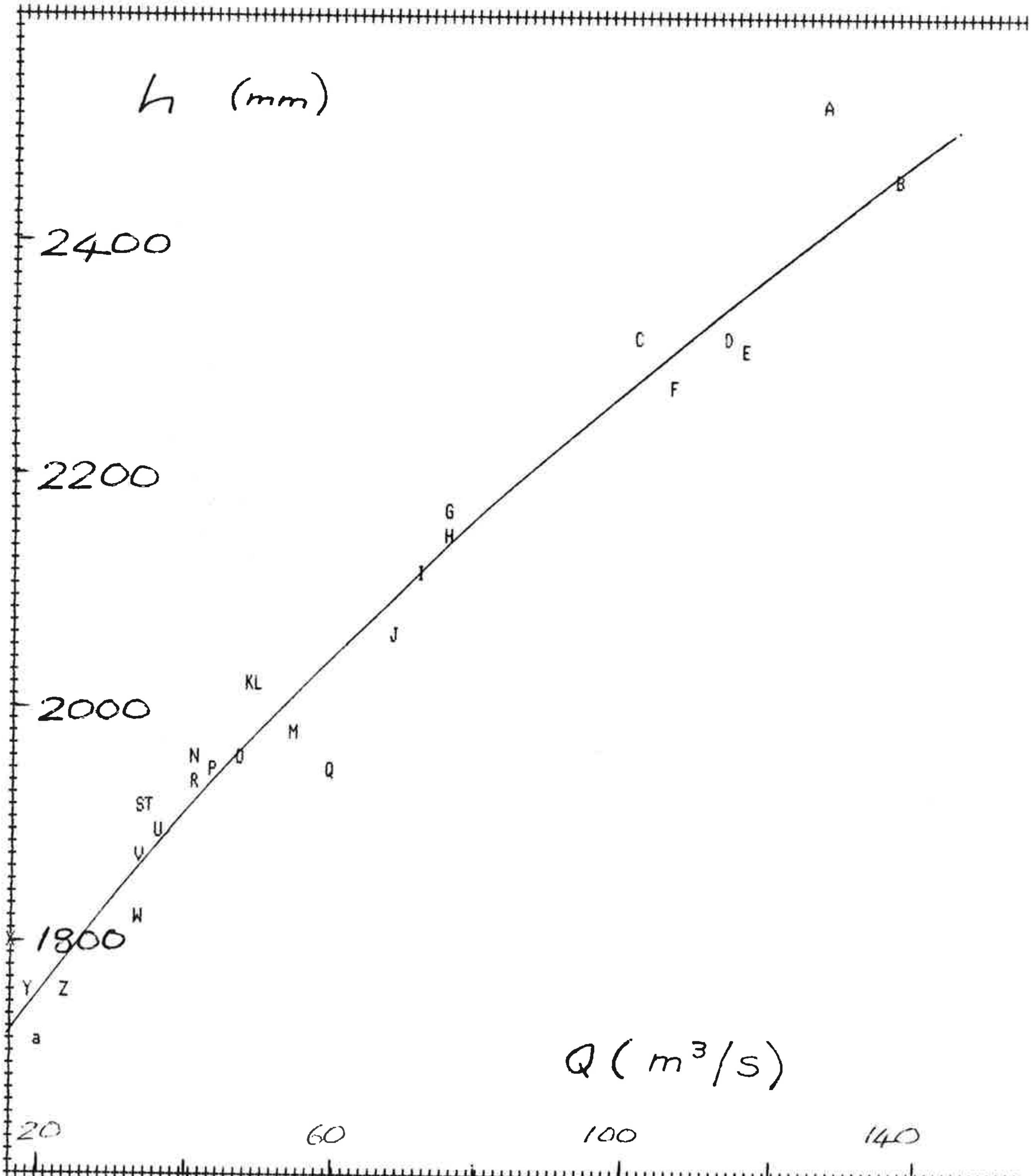


Fig 8: Expanded scale plot of the stage/discharge curve. Note that the plot symbols have changed.

on, or below this line, at the same vertical scale as the first plot (e.g. Fig 10b). This picture identifies any evidence from gaugings that the rating shape is inappropriate, without the complication of the curvature of the rating.

The gaugings are also listed in the order in which they appear on the first plot. The list shows plotting symbol, stage (Si), flow (Qi), mean velocity, date and time (Fig 7c). If ratings had been filed, an extra column is generated containing the deviation of the gaugings from the ratings (Fig 10b). Gaugings outside the limits on the first plot are not tabulated.

4.6 PDEV program

The PDEV program produces a plot on a printer of the deviation of a series of gaugings from their ratings, versus time (Figs 9,10c). It may be run independently of or in conjunction with the PGAUGE program. A list of gaugings and ratings in time order is also produced (Fig 10d).

Up to 400 gaugings and rating points and up to nine ratings can be analysed in one run, and in most cases this quantity of data will cover one or two decades. The line of zero deviation (gaugings on the rating curve) is shown as a line of dots, and gaugings at a particular character position are shown as a letter from A-Z or a-z. Letters appear in sequence across then down the page. A set appearing on one line may thus not be in date order. Ratings are shown by printing the rating number from 1 to 9 at the righthand side of the plot (Fig 10c). If the time resolution allows, a smoothed rating will be indicated by the previous rating number at the start date of the rating, and the new rating number at the effective date. The number of the new rating takes precedence.

The list in Fig 10d gives the coordinates of each rating curve and the gaugings, in date order. The tabulation shows the PDEV plotting symbol, the PGAUGE plotting symbol (if PDEV was preceded by PGAUGE), stage (Si), flow (Qi), velocity, date, time and deviation of gauging from rating. For the rating co-ordinates, effective date and time are shown instead of velocity and deviation. The PGAUGE plotting symbol is an asterisk (*) for gaugings and rating points that did not appear on the preceding PGAUGE plot because of scaling.

5 EXAMPLE

Gaugings for the Hokitika River (site no. 90604) for the period 710524 - 740313 (Fig 7c) are used to illustrate construction of a rating curve. Stage for the highest gauging is 2968 mm and the curve is to be extended to the highest recorded stage of 5200 mm. There was an intensive gauging effort in 1973/74 and a manually-prepared curve for these gaugings is in Fig 6.

The stage/area curve (Fig 6a) is extended by plotting stage/area values measured from site survey data and drawing a curve through the points. The stage/velocity curve has to be extrapolated from the highest gauging (stage = 2968 mm) to stage = 5200 mm. Experience with rivers like the Hokitika suggests that mean velocities in cross-section rarely exceed 4 m/s and this is adopted as an asymptotic value. Products of values read from these curves at higher stages are used to plot discharge on the discharge plot and the discharge curve is drawn through these points (Fig 6a). For example from Fig 6a, at stage = 5.0 m, A =

```
""" PDEV """ VER 1.3  13-06-85

B:TIDEDA.001 Site    90604   710524 144500 to  760603  41500

Deviation of gaugings from each rating vs time.
Given the rating function S(Q,t), and gauging observations (Si,Qi), where i's
correspond to particular times, then the following plot is Si-S(Qi,t) vs time.
                units/mm   resolution          low           high   spans(mm)
Deviation         10.00       15.39            -85            667         75.
Time(days)        10.00       21.17                                       184.
```

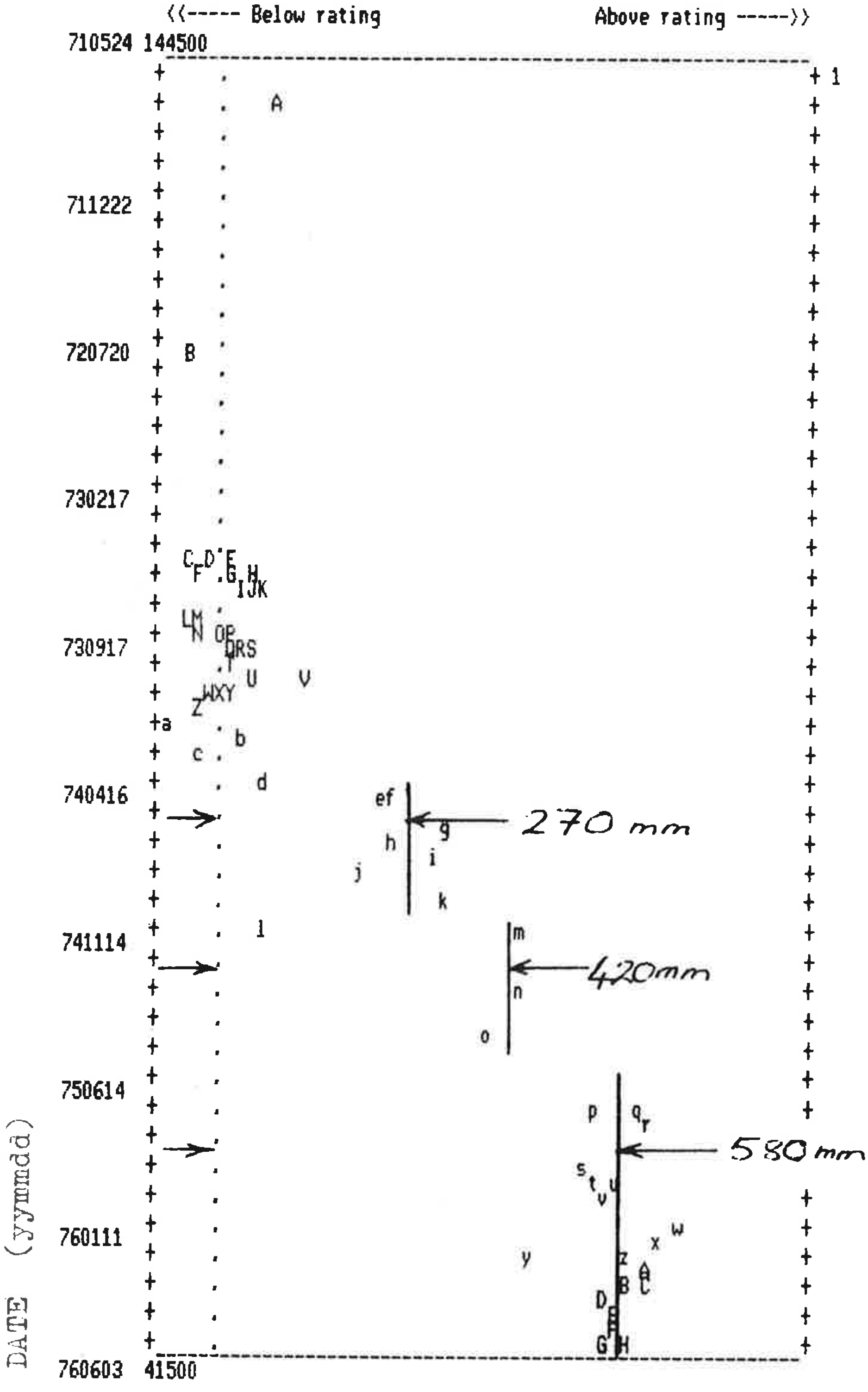


Fig 9: Chronological plot of the difference between gauged stage and stage read from the rating curve for the gauged discharge. Magnitudes of three suggested shifts in the rating curve after 740313 are indicated. Exact dates for the symbols are in Fig 10d.

```
~~~ PGAUGE ~~~ VER 2.4  05-11-85

B:TIDEDA.001 Site    90604   710524   240000 to   760602  240000
HOKITIKA RATINGS
Rated versus unrated
              units/mm  resolution        low        high   spans(mm)
Rated          2000.00     3078.79      16000      376000        180.
Unrated          10.00       21.17       1600        3600        200.
  62 gaugings plotted      :    0 outside limits
   8 rating points plotted :   12 outside limits
```

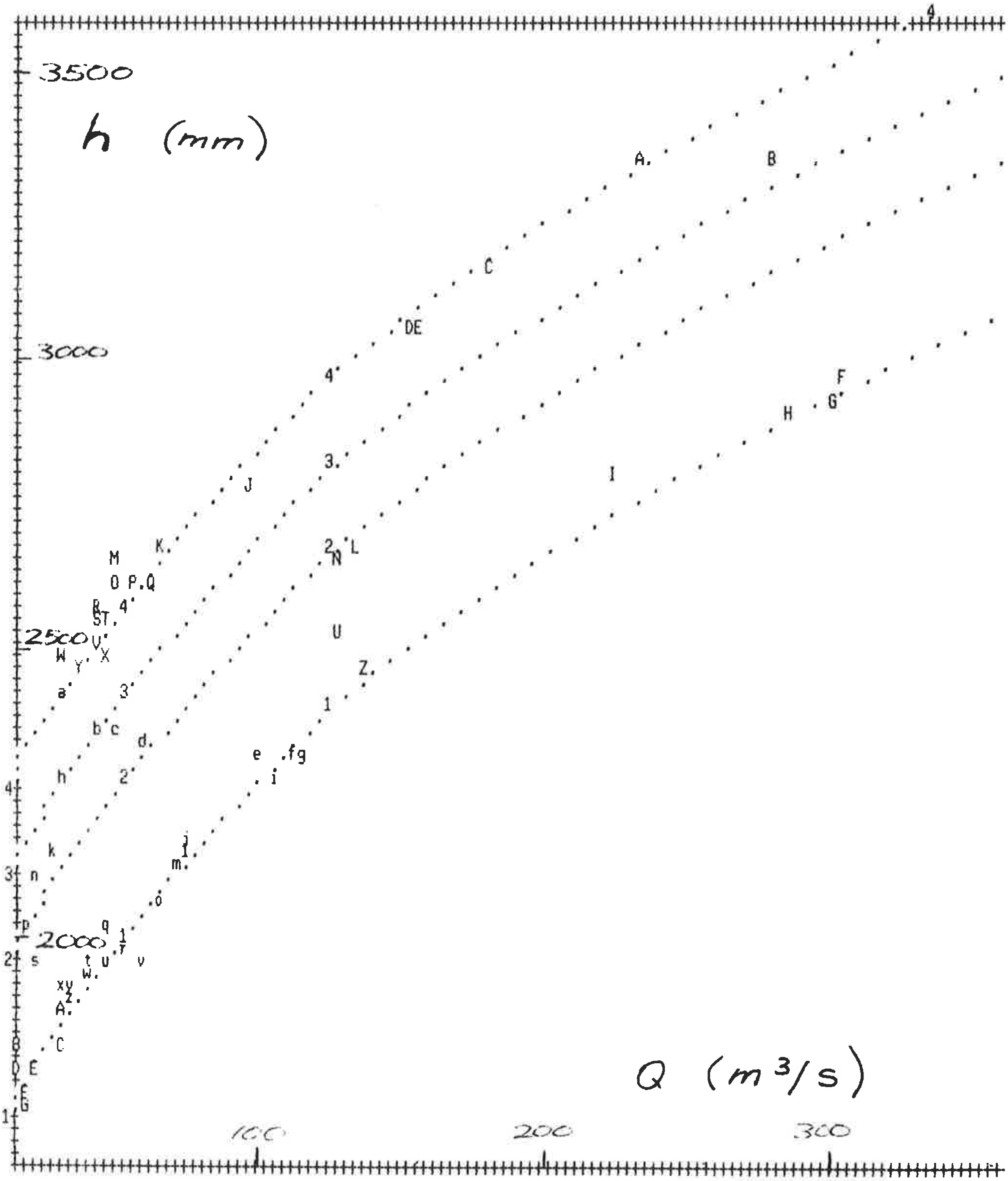
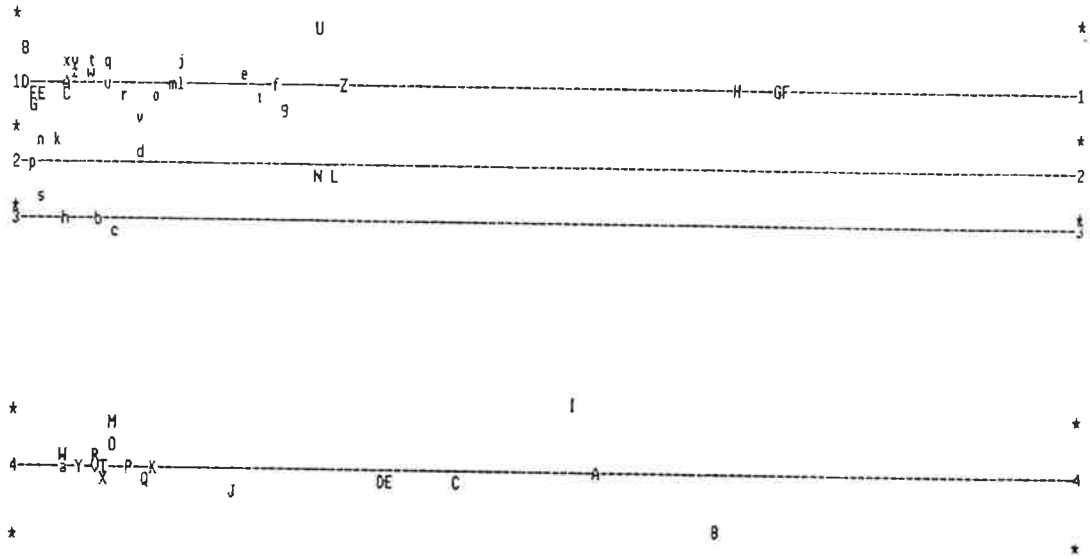


Fig 10: (a) Rating curves fitted to gaugings for the Hokitika gaugings.

B:TIDEDA.001 Site [illegible] 710524 240000 to 760602 240000
HOKITIKA RATINGS
Deviation of gaugings from each rating vs rated values



HOKITIKA RATINGS
Gaugings in symbol order

	Si	Qi	Vel.	Date		Si-S(Qi,t)
A	3351	23381	1755	7[illegible]519	1245	1
B	3350	28012	1864	7[illegible]127	1205	-126
C	3167	18206	1628	[illegible]529	1045	-23
D	3063	15428	1516	7[illegible]128	1422	-30
E	3067	15613	1720	[illegible]015	1530	-33
F	2968	30426	2185	7[illegible]107	1225	11
G	2935	29951	2231	7[illegible]107	1430	-10
H	2909	28525	2167	7[illegible]07	1555	0
I	2813	22516	1878	7[illegible]009	1200	-351
J	2779	9609	1277	7[illegible]922	1345	-49
K	2670	6725	992	7[illegible]120	1320	7
L	2675	13587	1455	741409	1310	-37
M	2652	5169	821	7[illegible]208	1200	98
N	2658	12841	1385	741409	1401	-24
O	2615	5114	774	7[illegible]107	1200	54
P	2620	5876	646	7[illegible]310	1200	9
Q	2617	6497	772	7[illegible]324	1245	-32
R	2564	4619	891	7[illegible]210	1115	38
S	2550	4471	770	7[illegible]227	1300	34
T	2544	4942	708	7[illegible]511	1336	-5
U	2525	12746	1421	7[illegible]025	1150	117

End of Process

	Si	Qi	Vel.	Date		Si-S(Qi,t)
V	2517	4643	968	750930	1245	-11
W	2481	3446	960	750721	1400	39
X	2490	4706	887	750617	1315	-42
Y	2474	3937	740	760408	1333	-4
Z	2460	13752	1418	730430	910	11
a	2434	3163	758	750623	1115	13
b	2359	4412	1156	741024	1120	7
c	2365	5022	753	750310	1230	-29
d	2345	6100	1171	740625	1310	30
e	2318	10219	1265	740108	1315	37
f	2320	11351	1214	730510	1410	-20
g	2312	11669	1354	730510	1540	-44
h	2275	3193	765	750116	1140	12
i	2275	10611	1191	731201	1508	-27
j	2174	7523	953	730915	1215	43
k	2154	2964	795	740521	1425	58
l	2145	7527	1015	730814	1230	14
m	2120	7221	988	730814	1350	7
n	2111	2480	778	740906	1233	52
o	2063	6803	900	730518	1345	-25
p	2016	2188	721	740610	1320	-21

Read Qi : XXXXX0

	Si	Qi	Vel.	Date		Si-S(Qi,t)
q	2018	4834	801	730613	1430	57
q	2018	4953	798	730613	1603	49
r	1981	5498	927	740208	1222	-25
s	1970	2329	681	740718	1230	-78
t	1963	4144	681	730601	1435	50
u	1964	4700	721	730601	1315	12
v	1951	5939	881	731220	1545	-83
w	1948	4321	704	730912	1324	23
w	1943	4152	681	730912	1445	30
x	1922	3413	882	740313	1510	62
y	1916	3508	563	731010	1400	49
z	1900	3603	689	730618	1410	26
z	1900	3615	673	730618	1520	26
A	1870	3374	585	730925	1450	13
B	1802	1685	433	710722	1630	75
C	1821	3429	680	720718	1410	-40
D	1759	1862	481	730827	1429	18
E	1759	2385	436	730827	1308	-23
F	1717	2030	437	730717	1530	-37
G	1712	2070	459	730717	1340	-45

Fig 10: (b) Horizontal projections of ratings in Fig 10a and list of gaugings in order of magnitude. Stars at the side of the plot show the limit of deviations from each projection.

```
~~~ PDEV ~~~ VER 2.3  05-11-85

B:TIDEDA.001 Site    90604   710524   144500 to   760602  240000
HOKITIKA RATINGS
Deviation of gaugings from each rating vs time.
Given the rating function S(Q,t), and gauging observations (Si,Qi), where i"s
correspond to particular times, then the following plot is Si-S(Qi,t) vs time.
                  units/mm  resolution          low          high   spans(mm)
Deviation            6.40        9.85          -351           224         90.
Time(days)          10.00       21.17                                    184.
```

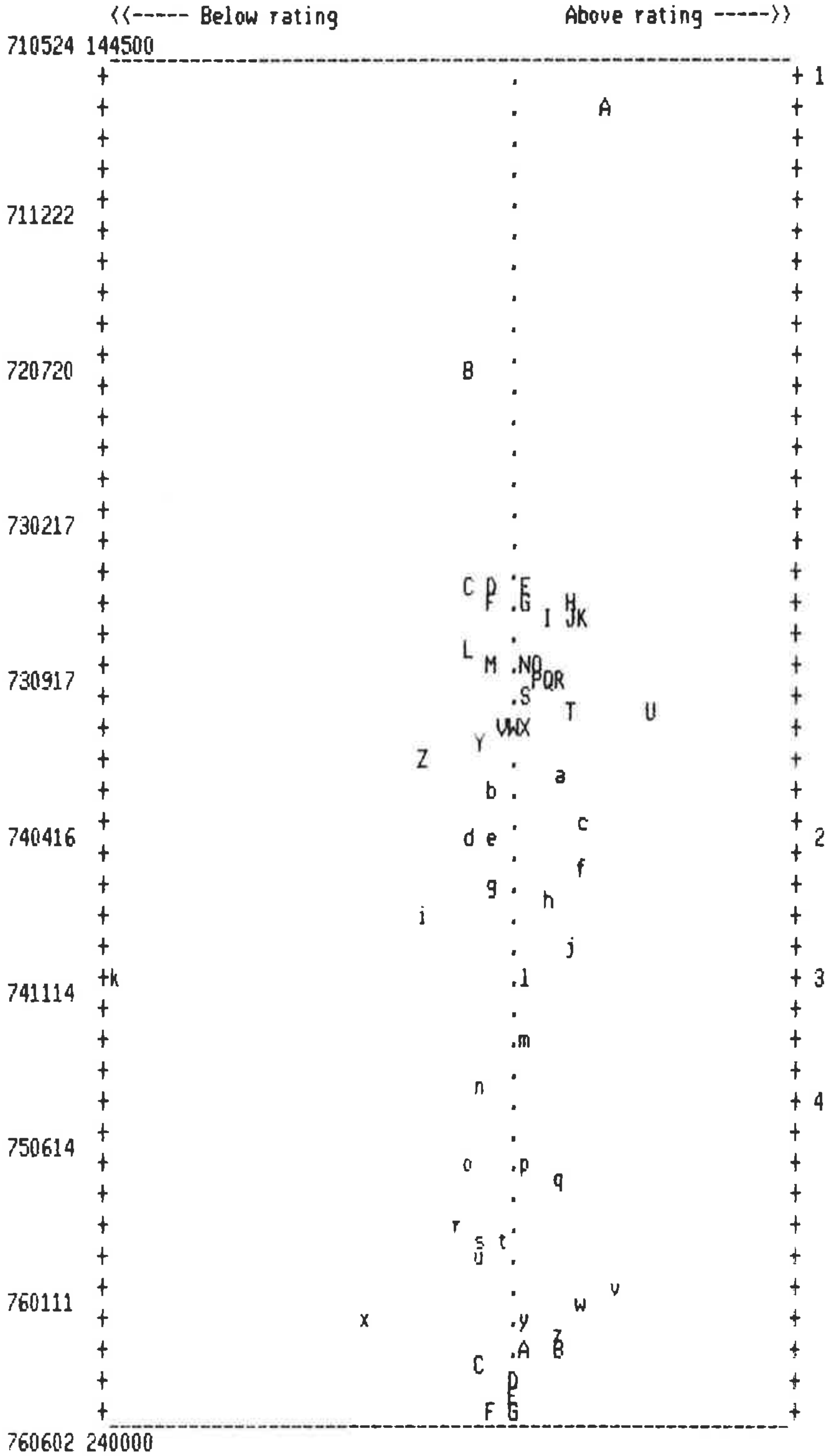


Fig 10: (c) Bed plot for the data in Fig 10a. Dates and magnitudes of the gaugings are in Fig 10d.

```
B:TIDEDA.001 Site    90604   710524   240000 to   760602  240000
HOKITIKA RATINGS
Gaugings and ratings in date order
                                                                Read Qi :      XXXXX0
```

		Si	Qi	Vel.	Date		Si-S(Qi,t)
1	*	1680	1100	710524	1445	710524	1445
1	1	2000	5400	710524	1445	710524	1445
1	1	2400	12550	710524	1445	710524	1445
1	*	4000	88700	710524	1445	710524	1445
1	*	5200	*	710524	1445	710524	1445
A	B	1802	1685	433	710722	1630	75
B	C	1821	3429	680	720718	1410	-40
E	Z	2460	13752	1418	730430	910	11
D	f	2320	11351	1214	730510	1410	-20
C	g	2312	11669	1354	730510	1540	-44
F	o	2063	6803	900	730518	1345	-25
G	u	1964	4700	721	730601	1315	12
H	t	1963	4144	681	730601	1435	50
K	q	2018	4834	801	730613	1430	57
J	q	2018	4953	798	730613	1603	49
I	z	1900	3603	689	730618	1410	26
I	z	1900	3615	673	730618	1520	26
L	G	1712	2070	459	730717	1340	-45
L	F	1717	2030	437	730717	1530	-37
O	1	2145	7527	1015	730814	1230	14
N	m	2120	7221	988	730814	1350	7
M	E	1759	2385	436	730827	1308	-23
O	D	1759	1862	481	730827	1428	18
P	w	1948	4321	704	730912	1324	23
Q	w	1943	4152	681	730912	1445	30
R	j	2174	7523	953	730915	1215	43
S	A	1870	3374	585	730925	1450	13
T	y	1916	3508	563	731010	1400	49
U	U	2525	12746	1421	731025	1150	117
X	F	2968	30426	2195	731107	1225	11
V	G	2935	29951	2231	731107	1430	-10
W	H	2909	28525	2167	731107	1555	0
Y	i	2275	10611	1191	731201	1508	-27
Z	v	1951	5939	881	731220	1545	-83
a	e	2318	10219	1265	740108	1315	37
b	r	1981	5498	927	740208	1222	-25
c	x	1922	3413	882	740313	1510	62
2	*	1950	1100	740405	600	740405	1200
2	2	2270	5400	740405	600	740405	1200
2	2	2670	12550	740405	600	740405	1200
2	*	4270	88700	740405	600	740405	1200
2	*	5470	*	740405	600	740405	1200
d	L	2675	13587	1455	740409	1310	-37
e	N	2658	12841	1385	740409	1401	-24
f	k	2154	2964	795	740521	1425	58
g	p	2016	2188	721	740619	1320	-21
h	d	2345	6100	1171	740625	1310	30
i	s	1970	2329	681	740719	1230	-78
j	n	2111	2480	778	740906	1233	52
3	*	2100	1100	741007	600	741009	600
3	3	2420	5400	741007	600	741009	600
3	3	2820	12550	741007	600	741009	600
3	*	4420	88700	741007	600	741009	600
3	*	5620	*	741007	600	741009	600
k	I	2813	22516	1878	741009	1200	-351
l	b	2359	4412	1156	741024	1120	7
■	h	2275	3193	765	750116	1140	12
n	c	2365	5022	753	750310	1230	-29
4	*	2260	1100	750401	1400	750401	2400
4	4	2580	5400	750401	1400	750401	2400
4	4	2980	12550	750401	1400	750401	2400
4	*	4580	88700	750401	1400	750401	2400
4	*	5780	*	750401	1400	750401	2400
o	X	2490	4706	887	750617	1315	-42
p	a	2434	3163	758	750623	1115	13
q	W	2481	3446	960	750721	1400	39
r	J	2779	9609	1277	750922	1345	-49
t	V	2517	4643	968	750930	1245	-11
s	E	3067	15613	1720	751015	1530	-33
u	D	3063	15428	1516	751028	1422	-30
v	M	2652	5169	821	751208	1200	88
w	O	2615	5114	774	760107	1200	54
y	K	2670	6725	992	760120	1320	7
x	B	3350	28012	1864	760127	1205	-126
z	R	2564	4619	891	760210	1115	38
8	S	2550	4471	770	760227	1300	34
A	P	2620	5876	646	760310	1200	9
C	Q	2617	6497	772	760324	1245	-32
D	Y	2474	3937	740	760408	1333	-4
E	T	2544	4942	708	760511	1336	-5
G	A	3351	23381	1755	760519	1245	1
F	C	3167	18206	1628	760529	1045	-23

End of Process

Fig 10: (d) List of gaugings in date order. Note the ratings identified by numbers and asterisks rather than letters in the second column, and dates and times in the columns headed "Vel. Date Si-S(Qi,t)".

416 m^2, v = 3.8 m/s and Q = 416 x 3.8 = 1580 m^3/s is a point on the extrapolated rating curve.

In this example the suggested procedure of extrapolation with Mannings equation (section 3.5) does not work because the quantity K in the equation $v = K.R^{0.67}$ increases with stage and does not approach a constant value for the gaugings in the period being considered. Clearly the somewhat arbitrary nature of this extrapolation of the stage/velocity curve will be a major source of uncertainty in flood discharge estimates. In this case, a series of gaugings in the range 500 - 900 m^3/s done in the period 1979-1983 support the general form of the extrapolation in Fig 6a.

On a second sheet (Fig 6b) an enlargement is prepared of the lower part of the rating curve. A curve fitted through the gaugings is transferred to the full range plot in Fig 6a. Stage/discharge co-ordinates read from Fig 6 for filing are:

Stage (mm)	Discharge (L/s)
1680	11000
2000	54000
2400	126000
4000	887000
5200	1720000

The PGAUGE program can be used to plot the measured gaugings (Fig 7a) and a dummy gauging at the maximum recorded stage to force scales to cover the full range of the stage data. Corresponding stage/velocity and stage/area plots are in Fig 7b, and hand-drawn curves are fitted to the data and extrapolated as described above. To check the lower part of the curve, the process is rerun with a larger scale to include the bulk of the gaugings (Fig 8), and a curve is hand-drawn through the plotted points. The advantage of PGAUGE is that each gauging can be identified, should that be necessary for subsequent checking. The current (July, 1986) version of this program uses print-plotting on a dot-matrix printer, but better resolution is expected with future versions.

Checks on the fit of the rating curve as represented by the filed coordinates are provided by the PDEV program. Thus Fig 9 is a chronological plot of the difference between stage for each gauging and stage for the gauged discharge as read from the rating curve. This is known as a bed plot because a series of consistent values differing significantly from other values indicates a shift in the mean bed level. Fig 9 includes subsequent gaugings for the Hokitika through to 760529 and three such shifts are suggested for the gaugings for the period 740402 - 760529. Sizes of these shifts are listed below with suggested dates of occurrence determined from examination of stage/time plots.

Rating No.	Start Date (yymmdd)	Shift (mm)
2	740405	270
3	741007	420
4	750401	580

Fig 10a is a PGAUGE plot of the original gaugings and rating, and these additional ratings and gaugings up to 760529; Fig 10b shows projections of these ratings to check that the curves represent the general shape suggested by the gaugings plus a list of all the gaugings in symbol order; Fig 10c is a bed plot of all the gaugings; Fig 10d is a listing of the ratings and gaugings in chronological order.

At this point the shape of the curves may be adjusted if necessary, and gaugings that are outliers to the general trends can be examined. In particular the gauging for date 741009 ("I" in Figs 10a and 10b; "k" in Fig 10c and 10d) shows up as an outlier, but no reason to discard it could be found from examination of the original gauging card. Other gaugings that are to be questioned are "U" and "B" (Figs10a and b); ("U" and "x", Fig 10c and Fig 10d, deviations 117 and -126 mm respectively). Otherwise the maximum deviation of gaugings from ratings is 88 mm (Fig 10d) which seems a satisfactory result considering the wide scatter of the gaugings in Fig 10a, and the fact that one type curve shifted three times, has been used.

This example could be presented using other processes in the micro-TIDEDA program. For example, Fig 11 drawn with the PLRATE process repeats, with different scales, the rating curves of Fig 10a. Fig 12 shows for the period 740312-741030; a) a stage/time plot, with stage corresponding to a flow of 16 m^3/s drawn below; b) a discharge/time plot with gaugings overplotted; (c) a bedplot truncated at +/- 100 mm. Dates for the rating shifts were determined from examination of the stage/time hydrograph recessions: the two shifts chosen are illustrated by the steps in the stage line in Fig 12a which corresponds to a discharge of 16 m^3/s. Note that the outlier gauging of 741009 occurs on a rapidly receding hydrograph limb (Fig 12b).

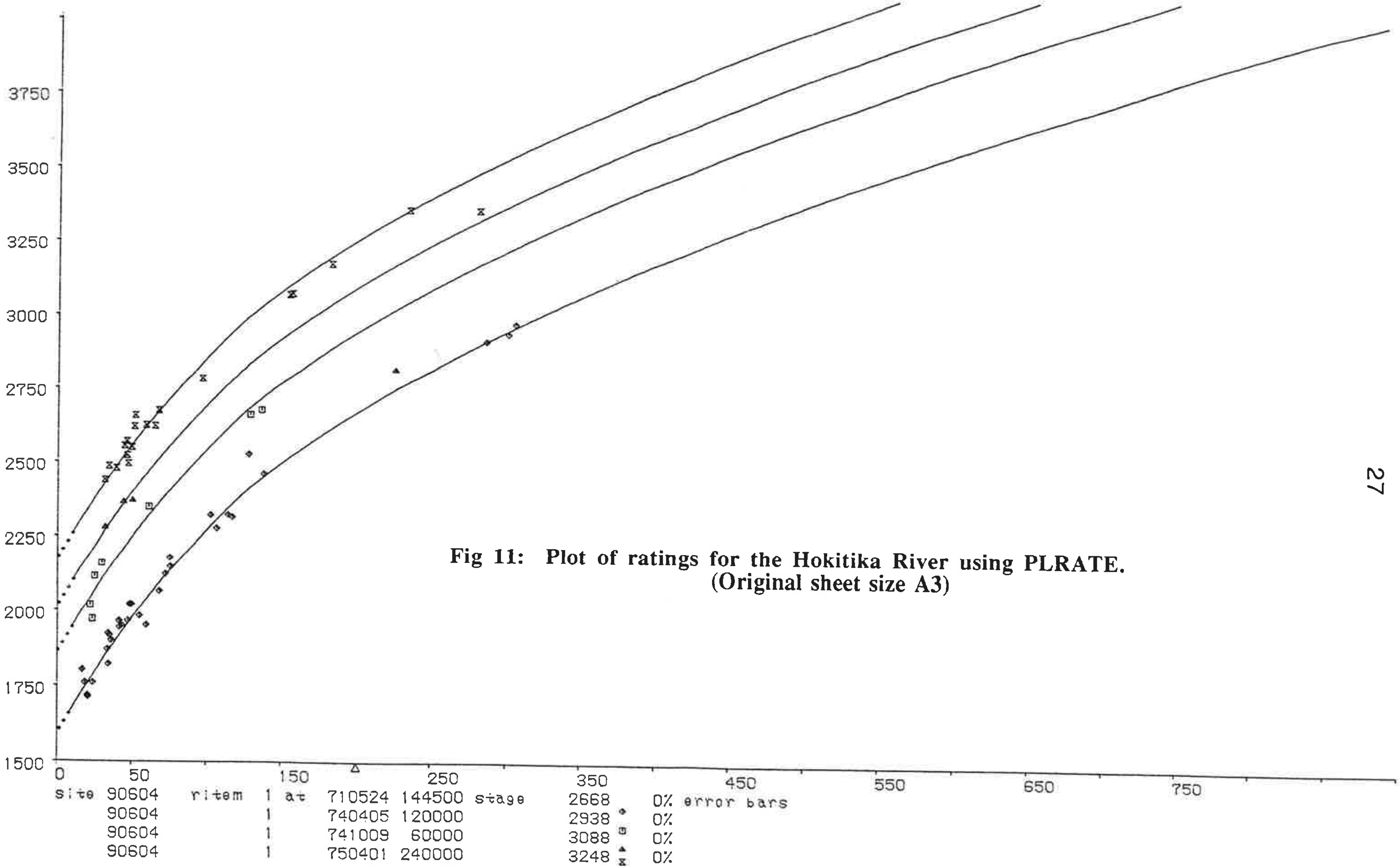
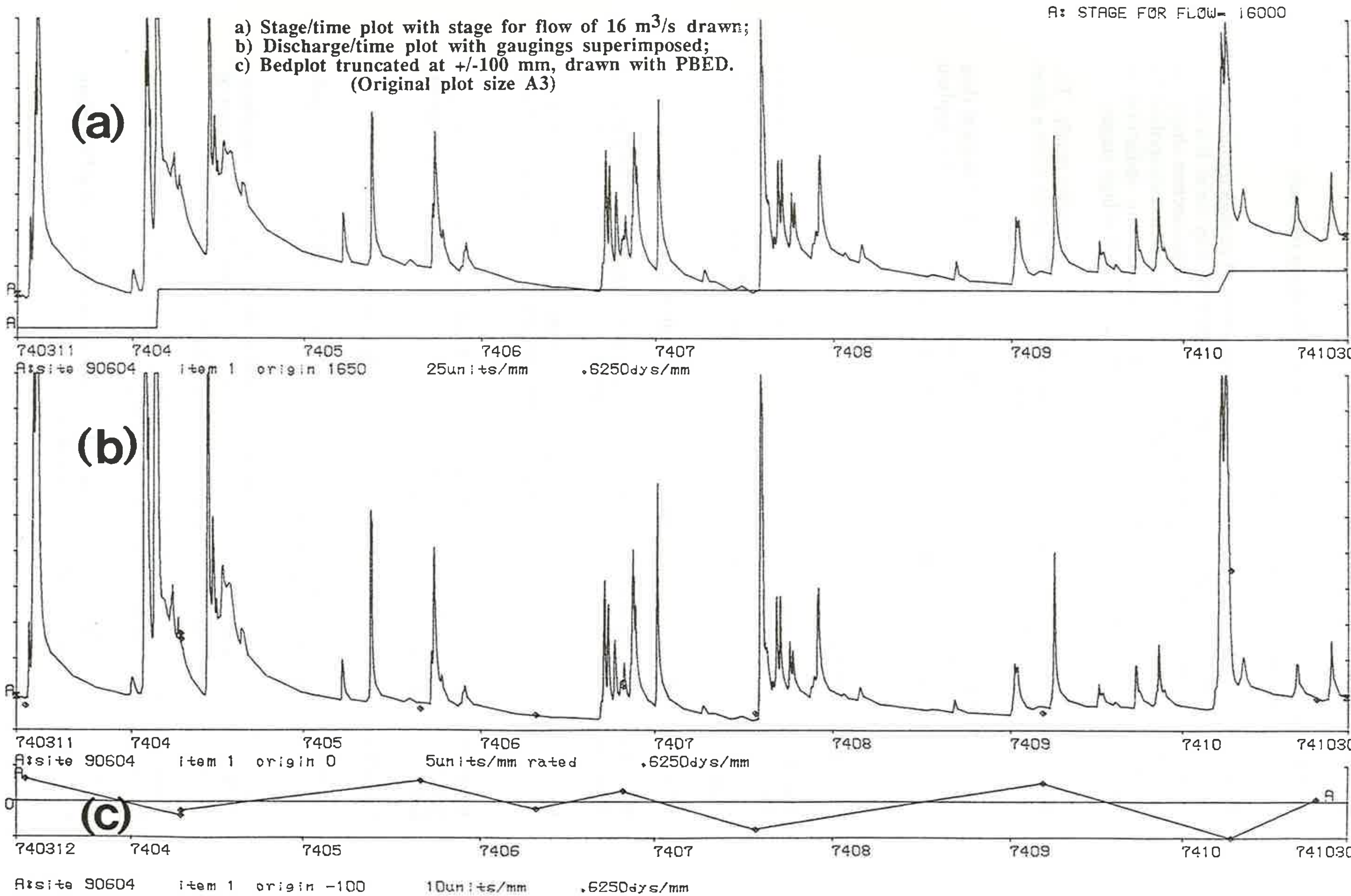


Fig 11: Plot of ratings for the Hokitika River using PLRATE.
(Original sheet size A3)

Fig 12: For the Hokitika River for the period 740311-741030:

a) Stage/time plot with stage for flow of 16 m^3/s drawn;
b) Discharge/time plot with gaugings superimposed;
c) Bedplot truncated at +/-100 mm, drawn with PBED.
(Original plot size A3)



6 SUMMARY

Reliable discharge data require carefully constructed ratings that make judicious use of all gauging information to hand.

In the absence of gaugings of high stages, extrapolation of ratings by taking the product of a stage/area curve ,and an extrapolated stage/velocity curve is a simple logical procedure. It uses available information about the cross-section shape and employs experience in the behaviour of the Froude number to extrapolate the stage/velocity curve. The method clearly demonstrates the reduction of uncertainty in discharge to be achieved by measuring velocites at high stages.

In some cases, type curves as demonstrated provide an acceptable result. The development of a type curve requires an intensive gauging effort over a short period while the channel is in a stable condition.

Checking of ratings is an on-going task. Quality assurance of hydrological data requires that the plots used to construct ratings, and the checks applied subsequently to the filed data should be available for reference.

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