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THE SENSITIVITY OF FLOW MEASUREMENT TO STAGE ERRORS FOR NEW ZEALAND CATCHMENTS (NOTE)

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ABSTRACT

Records from fifty automatic water-level recording stations representative of stations presently in operation within New Zealand were studied to determine the effect of water-level reading precision on the accuracy of flow records. The influence of stage-reading precisions of ± 1 mm, ± 3 mm and ± 10 mm on mean flow, median flow and the flow exceeded 95% of the time were tested.

Basins with small flows are shown to be the most sensitive to stage measuring error. Gains from the installation of weirs and flumes do not usually result in increased accuracy sufficient to offset the decreased sensitivity due to the smaller range of stage that occurs with very small flows.

A precision of ± 1 mm in water level is required for very small catchments and ± 3 mm for most other catchments up to 500 km^2, for a precision of ± 5% flow measurement at median flow.

The study shows that the percentage error from measurement precision generally increases as flow decreases.

INTRODUCTION

Flow data recording at a river gauging station involves the separate measurement of river stage and river flow. A continuous record of flow is subsequently computed from the stage record using a rating curve relationship between the measured flows and their corresponding river stages.

This study is concerned with the effects of errors in stage measurement on the accuracy of the time continuous flow record at gauging stations. The magnitude of a flow error depends on the gradient of the rating curve, which in turn is determined by hydraulic controls at the gauging station. The significance of this error depends on the flow magnitude (Fig. 1).

Fifty gauging stations are used to sample the effect of stage measurement errors on the accuracy of flow data.

Only errors in water-level reading by manual observation and in water level recording by automatic recorders are considered. Errors attributable to uncertainties in gauging, rating curves, data processing and hydraulic

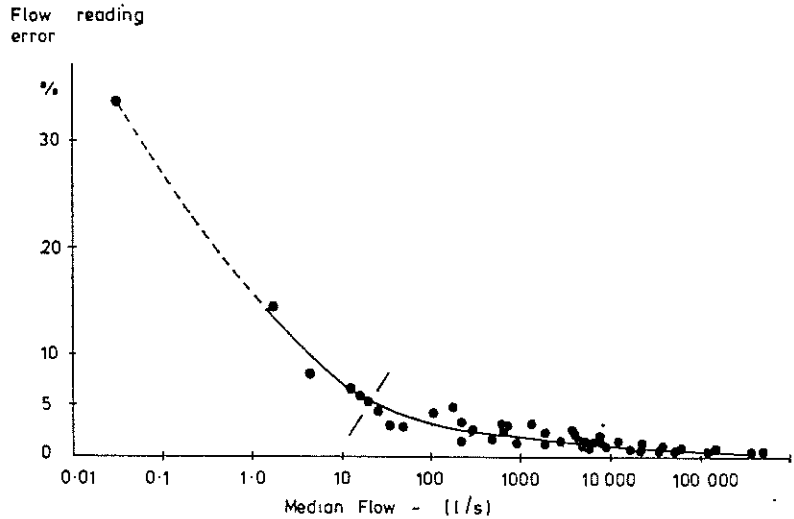

FIG. 1—Sensitivity in percent for a stage reading variation of ± 3 mm for all fifty stations in the study.

TABLE 1—Area of catchments used in this study compared to the 1981 area distribution of the National network (Freestone and Christian, 1982).

Catchment Area (km^2)	This Study No. of Stations	%	1981 National Network %
<5	8	16	17
5-50	11	22	21
50-500	18	36	35
500-5000	11	22	23
>5000	2	4	4
	50	100	100

stability are not considered. An analysis of the sources of uncertainties is given by Herschy (1978).

GAUGING STATIONS STUDIED

Fifty gauging stations were selected to conform with the distribution of catchment areas within the national network of gauging stations (Table 1).

Within each range, catchment area distribution was arranged as evenly as possible. The twelve smallest stations have weirs or flumes as

TABLE 2—Sensitivity for mean, median and 95% exceeded flows. (Deep Stream at Totara Rock, Station 74351).

Flow	Flow	Flow difference in *l*/s and % from rating table for specified stage accuracy ranges					
	l/s	1 mm	(%)	3 mm	(%)	10 mm	(%)
Q mean	2680	11	(0.4)	33	(1.2)	110	(4.1)
Q median	1670	9	(0.5)	27	(1.6)	90	(5.4)
Q 95%	680	3	(0.4)	9	(1.3)	30	(4.4)

measuring structures, and a variety of types of these structures was included in the stations chosen.

The median catchment area from the 1981 index (Freestone and Christian, 1982) is 117 km^2 and compares with 130 km^2 for this study.

METHOD

For each of the fifty stations, sensitivity was calculated for stage measuring accuracies of ± 1 mm, ± 3 mm and ± 10 mm. These accuracy values have a practical basis. The Ministry of Works and Development staff read water-levels to the nearest millimetre. Some digital recorders read to the nearest 1 mm and others, with 300 mm pulleys, read to the nearest 3 mm, which is also the premetrication reading precision value. The value ± 10 mm is representative of the accuracy attainable with a disturbed water surface. It is also a conservative estimate of the reading precision of some of the less accurate water-level recorders in use.

The three reading accuracies were then applied to three phases of flow at each station: mean flow (Q mean), median flow (Q median), and the flow exceeded 95% of the time (Q 95%). An example of sensitivities of flows as absolute values and as percentages of the flow is given in Table 2.

An example of the calculation method follows:

Example

From Table 2 select the *median* flow and for a stage reading accuracy of ± *3 mm* calculate station sensitivity by:

Median flow: = 1670 *l*/s

From the rating table, 3 mm resolution at median flow results in a flow variation of: ± 27 *l*/s

Therefore sensitivity at median flow for a stage reading accuracy of ± 3 mm is $\frac{27}{1670} \times 100$ = ± 1.6%

Rating curves often do not correspond to theoretical relationships due to unsteady flow regimes. Difficulties in accurately establishing the gauge height where zero flow occurs at natural sites also affects the rating equation. For these reasons only the relationship between increasing error and decreasing flow is used to explain the data (Fig. 1).

TABLE 3—Stations used in this study, with percent errors in flow resulting from stated errors in stage measurement.

Gauging Station Structure Notation: (1) Compound V notch weir; (2) H flume; (3) 120° V notch weir; (4) 90° V notch weir; (5) Cippoletti weir; (6) Broadcrested weir; (7) Crump weir. Other stations operate on natural channel controls.

Station Number	River and Station Name (Structure)	Catchment area km²	Reading accuracy of flow in % for 3 levels of precision of stage reading and for 3 flow phases								
			Mean Flow			Median Flow			Flow exceeded 95% of time		
			± 1mm %	± 3mm %	± 10mm %	± 1mm %	± 3mm %	± 10mm %	± 1mm %	± 3mm %	± 10mm %
1457401	Moutere Catchment 5 (1)	0.0696	3.1	9.2	28	11	34	>100	80	>100	>100
1143409	Purukohukohu at Puruki (2)	0.344	2.0	6.1	20	2.6	7.9	26	13	42	>100
46662	Pukewaenga at Conservation (2)	0.389	2.3	7.0	23	4.8	14	48	58	>100	>100
91411	Pattinson at Weir 1 (3)	0.75	1.4	4.3	14	2.2	6.5	22	7.5	21	71
74363	Tussockburn at Old Mine (3)	0.83	1.6	5.0	16	2.0	5.9	20	2.3	6.5	23
15534	Wairere at Wainui Rd. (4)	2.59	1.1	3.4	11	1.5	4.4	15	2.7	7.9	26
46645	Kokopu at McBeths (3)	3.08	1.3	3.8	13	1.7	5.2	17	9.8	30	98
1014601	Hatchery at Weir (5)	Spr	1.4	4.1	14	1.4	4.1	14	1.6	4.7	16
29503	Orongorongo at Up. Dam (6)	9.0	0.7	1.9	6.7	0.8	2.4	7.6	1.2	3.6	12
74701	Nobles at Bull Ck (4)	9.8	0.8	2.3	7.8	0.9	3.0	10	3.3	10	33
46609	Mangere at Kara. W. (7)	12.3	0.8	2.4	8.1	1.1	3.3	11	2.2	6.6	22
4901	Ngunguru at Dugmores (4)	12.5	0.5	1.4	4.4	0.5	1.5	5.2	0.9	2.6	8.6
93602	Waimangaroa at Smoke Stack	19.6	0.3	1.0	3.5	0.9	2.4	8.2	1.9	5.7	19
3503	Puketotara at Backblocks	23.1	0.7	2.0	6.7	1.0	2.9	9.5	1.6	4.3	15
74353	Gimmerburn at Rough R'ge (4)	23.7	0.7	2.2	7.3	1.0	2.9	9.6	2.3	6.8	24
33115	Mangaetoroa at Schl	33.2	0.5	1.5	4.9	0.5	1.6	5.3	1.1	3.1	11
29242	Atiwhakatu at Mt Holdsworth	38.8	0.5	1.5	4.9	0.6	2.1	6.8	1.0	2.8	9.6
64610	Stanton at Cheddar Vlly	41.6	0.7	2.1	7.1	1.5	4.6	15	4.8	14	48
21410	Waihi at Waihi	49.7	0.7	2.2	7.3	1.1	3.2	11	2.0	6.1	21
43803	Papakura at SH Br.	52.6	0.8	2.3	7.7	1.0	3.1	10	1.7	5.2	17
14610	Utuhina at SH Br.	59.6	0.3	1.0	3.4	0.4	1.2	3.8	0.7	2.0	6.6
33114	Waitangi at Tangiwai	63.5	0.4	1.1	3.7	0.4	1.3	4.5	0.8	2.1	7.1
64606	Waiau at Malings Pass	74.6	0.4	1.2	4.2	0.5	1.4	4.8	0.5	1.6	5.4
29808	Hutt at Kaitoke (6)	88.8	0.4	1.1	3.7	0.4	1.3	4.3	0.6	1.9	6.4
74351	Deep Stm at Totara Rock	105	0.4	1.2	4.1	0.5	1.6	5.4	0.4	1.3	4.4
19712	Mangatu at Omapere	155	0.5	1.5	4.9	0.8	2.5	8.5	0.5	1.5	5.0
14628	Mangorewa at Saunders	179	0.2	0.6	1.9	0.2	0.7	2.2	0.3	0.8	2.7
19709	Wharekopai at Killarny	181	0.3	1.0	3.4	0.5	1.5	4.9	0.8	2.4	8.0
91103	Taipo at SH Br.	181	0.3	0.8	2.7	0.3	1.0	3.2	0.7	2.0	6.9
93901	Ngakawau at Lineslip	186	0.2	0.6	2.0	0.3	0.9	3.1	0.5	1.5	5.2
1316	Awanui at School Cut	222	0.2	0.6	2.0	0.4	1.3	4.3	0.6	1.7	6.0
93207	Inangahua at Blacks Pt	234	0.4	1.2	3.8	0.4	1.3	4.2	0.9	2.8	9.4
16502	Motu at Waitangirua	295	0.3	0.8	2.8	0.4	1.3	4.4	0.9	2.8	9.4
32726	Hautapu at Taihape Rd	303	0.3	0.8	2.5	0.5	1.5	4.9	1.4	4.3	14
18902	Hikuwai at Willow Flat	307	0.2	0.7	2.2	0.7	2.0	6.7	1.4	4.3	14
57502	Wairoa at gorge	464	0.4	1.1	3.7	0.6	1.8	5.9	1.1	3.3	11
33107	Whangaehu at Karioi	492	0.2	0.7	2.4	0.2	0.6	1.9	0.2	0.6	1.8
33111	Mangawhero at Ore Ore	506	0.2	0.7	2.2	0.3	0.9	3.0	0.6	1.9	6.3
15410	Whirinaki at Galatea	534	0.5	1.4	4.6	0.5	1.4	4.6	0.6	1.8	6.0
14601	Kaituna at L. Rotoiti Out.	632	0.2	0.5	1.8	0.2	0.6	1.9	0.2	0.7	2.2
74315	Taieri at Macatamneys	666	0.4	1.1	3.7	0.5	1.4	4.8	1.6	4.7	16
15302	Tarawera at Awakaponga	906	0.1	0.4	1.2	0.1	0.4	1.3	0.2	0.5	1.7
86802	Haast at Roaring Billy	1020	0.2	0.5	1.6	0.2	0.6	1.9	0.2	0.7	2.4
16501	Motu at Houpoto	1393	0.2	0.5	1.5	0.2	0.6	1.8	0.5	1.5	4.9
93202	Buller at Longford	1410	0.2	0.5	1.7	0.2	0.6	2.0	0.2	0.7	2.5
15514	Whakatane at Whakatane	1557	0.2	0.5	1.6	0.2	0.7	2.3	0.4	1.1	3.6
21801	Mohaka at Raupunga	2370	0.2	0.5	1.8	0.2	0.6	2.1	0.3	1.0	3.5
68502	Rakaia at Gorge	2640	0.2	0.5	1.5	0.2	0.5	1.5	0.1	0.4	1.3
1043446	Waikato at Mercer	13701	0.1	0.2	0.5	0.1	0.2	0.6	0.1	0.2	0.8
75207	Clutha at Balclutha	20306	0.1	0.2	0.7	0.1	0.3	0.9	0.1	0.4	1.3

RESULTS

The fifty stations used are listed in Table 3, with nine values of sensitivity for each station. Sensitivity is expressed as a percentage of the particular flow considered. A typical result is plotted in Figure 1. In this

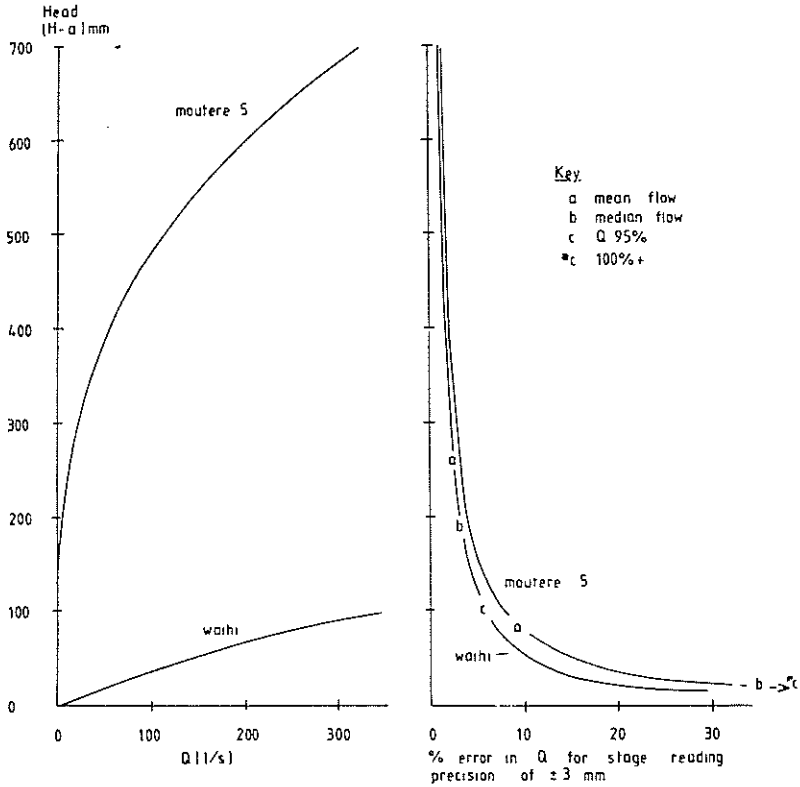

FIG. 2—Two extremes of rating sensitivity (for this study) on the left and the corresponding error curves on the right.

example, median flow is used in conjunction with a stage reading error of ± 3 mm. A well defined relationship exists between flow and percent error. Error increases with decreasing flow. The curve shown represents a visual fit.

Ratings for Moutere 5 and Waihi rivers serve to represent the extremes of rating sensitivity (Fig. 2). A few of the larger rivers have flatter ratings than Waihi, but extension of these to zero flow is not practical. The Moutere 5 rating is more sensitive than that for Waihi, but because the Waihi flows are much greater than those for Moutere 5, the % error of mean, median and Q 95% flows are less for Waihi (Fig. 2). The general relationship between error and decreasing flow is seen to be dominant over factors such as high rating sensivity.

The data plotted in Figure 1 suggest that small and large catchments can be distinguished. For small catchments (median flows less than about 20 *l*/s) the measurement sensitivity error increases by about 10% for each

TABLE 4—Mean percentage error and standard deviations for the 44 large catchments and for the 6 small catchments.

	Stage reading precision	Median Flow			
		>20 l/s n=44		<20 l/s n=6	
		Mean (%)	Standard Deviation (%)	Mean (%)	Standard Deviation (%)
Q mean	1 mm	0.42	0.28	1.95	0.68
	3 mm	1.22	0.82	5.90	2.00
	10 mm	4.07	2.77	19.00	5.79
Q median	1 mm	0.55	0.38	4.08	3.34
	3 mm	1.67	1.11	12.3	10.1
	10 mm	5.53	3.72	41.0	33.8
Q 95%	1 mm	1.04	0.94	28.4	29.6
	3 mm	3.10	2.80	85.6	88.6
	10 mm	10.4	9.31	289	293

tenfold decrease in median flow rate; for large catchments the error increases by about 1% for each tenfold decrease in median flow rate.

Over the whole range of flows and water-level reading accuracies, the difference between the small catchments and large catchments is even more marked (Table 4). The Moutere 5 station does reach zero flow so Q 95% values are very small and show a large error. (It should be remembered that at zero flow this high error reduces to zero). Without Moutere 5 the reading error for the small catchments at ± 3 mm and Q95% changes from 85.6 to 54.7%, which is still large in comparison to the value for the 44 catchments. Removing Moutere 5 from median flow calculations makes a similar difference, but at mean flow the difference is minimal.

Although there is a strong relationship between flow magnitude and percent error there are variations that should be noted. For example ranking the stations for median flow will produce a different order than a ranking of Q 95% flow due to wide variations in flow duration characteristics.

Even though structures such as weirs and flumes have been installed in the smaller catchments, sensitivity has usually not improved sufficiently to offset the decreased sensitivity that occurs with very low flows. Care should still be taken when selecting structures for new stations. Although differences in sensitivity between those for a given flow are smaller than those between the measurement of large and small flows the differences are significant.

A measurement of sensitivity can and should be made at a site by gauging at low flow before a station is established, to ensure that precision requirements can be met. Sensitivity is calculated by multiplying the measured channel width by 3 mm (or 1 mm or 10 mm) and the mean velocity. This produces an estimate of flow error, resulting from a water-

level reading error, which can be compared with gauged flow. Nearby stations can be used to estimate by correlation techniques the flow phase at the time of gauging. Flow range and duration should also be estimated so that a range of sensitivity calculations can be made.

CONCLUSIONS

Small catchments are more sensitive to stage measuring error and are therefore most difficult to monitor accurately.

Where median flow is less than about 20 *l*/s and stage is measured to ± 3 mm, the error at median flow may be of the order of 5% (Figure 1).

Stations with catchment area less than about 50 km^2 show errors greater than 5% at Q 95% for a water-level reading precision of ± 3 mm (Table 3). The few exceptions are sites with high base flows.

Water-level reading precision of ± 1 mm is required for very small catchments and ± 3 mm for most other catchments up to 500 km^2. if 5% accuracy of flow measurement is to be achieved at median flow.

Although the fifty stations used are only 6% of the total network their selection was designed so that the findings might be applied to the whole network. The findings from this study indicate which stations in the rest of the network are likely to be most affected by stage measurement errors. Application of the method would take the form of investigating individual sites to calculate sensitivity at given flows.

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