INSTRUMENT TEST REPORT NUMBER 655

Acceptance Tests of 20 Hydrological Services TB3B Tipping Bucket Rain Gauges

Tasia Livaditis
Physics Laboratory, OEB
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Authorisation

Bruce Forgan
A/Superintendent Atmosphere Watch

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11 Pages

Aim

To report the results of calibration and consistency checks performed on 20 Hydrological Services (HS) Tipping Bucket Rain Gauges (TBRG) Model Number TB3B.

Instruments Tested

The serial numbers of the 20 HS TB3B TBRGs tested are listed here:

- 96-107
- 96-300
- 96-861
- 96-876
- 96-886
- 96-892
- 96-901
- 96-998
- 96-1002
- 96-1003
- 96-1006
- 96-1014
- 96-1016
- 96-1019
- 96-1047
- 98-199
- 98-201
- 98-207
- 98-214
- 98-231

Experimental Method

A batch of twenty Hydrological Services Tipping Bucket Rain Gauges was tested to check their calibration and performance, using the calibration check[1] that delivers a known volume of water into the rain gauge at a nominal flow rate.

This procedure is carried out at six nominal flow rates ranging from 25mm/hr to 500mm/hr. The schedule of calibration is shown in Table 1.

Table 1: Calibration check test sequence

Sequence Number	Nominal Flow rate	Number of Runs	Run No.
1	25mm/hr	5	1-5
2	50mm/hr	5	6-10
3	127mm/hr	10	11-20
4	254mm/hr	10	21-30
5	381mm/hr	10	31-40
6	504mm/hr	10	41-50
7	25mm/hr	5	51-55
8	50mm/hr	5	56-60
Total Number of Runs:		60	

[1] A1980 Specification for Tipping Bucket Rain Gauge, 1999, Bureau of Meteorology.

Two automated test rigs were used to carry out this testing. The volume delivered by each is given in Table 2 below. Which automated test rig was used for each gauge is given in Table 3 below.

The volume delivered and the measured diameter of collection area was used to determine the theoretically expected number of tips. The variation in the delivered volume does not contribute a significant component to the overall uncertainty of the measurement. Corrections and uncertainties[2] are expressed in terms of a percentage to the theoretically expected number of tips unless otherwise specified.

Table 2 Calibrator Volumes

Automatic Calibrator (S/N)	Volume Delivered	Confidence Interval U95
Auto#1	652.8ml	0.2ml
Auto#2	653.4ml	0.2ml

Table 3 Auto calibrators used to test gauges

Serial Number	Auto Calibrator		Auto Calibrator
• 96-107	1	• 96-1006	1
• 96-300	1	• 96-1014	1
• 96-861	2	• 96-1016	1
• 96-876	1	• 96-1019	2
• 96-886	1	• 96-1047	2
• 96-892	2	• 98-199	1
• 96-901	2	• 98-201	2
• 96-998	2	• 98-207	2
• 96-1002	1	• 98-214	2
• 96-1003	2	• 98-231	2

[2] Statistical expressions in this report are in accordance with the ISO Guide to Expression of Uncertainty in Measurement. (ISO GEUM)

Table 4 lists the population tests on the corrections for these twenty gauges tested on each automated calibrator and shows there was no significant difference between the automatic calibrators. *Note: A population test excluding the four rejected gauges also concluded there was no significant difference between the automatic calibrators. This test was not included here.*

Table 4 Population tests between automated calibrators

Auto Calibrator	Sequence No:	1	7	2	8	3	4	5	6[3]
1	Mean correction[4]	0.3	0.4	1.3	1.3	2.1	2.9	3.3	4.9
	ESDM [5] (σ) (n=9)	0.3	0.6	0.7	0.4	0.6	0.6	0.6	0.6
2	Mean Correction	-0.5	-1.2	0.5	-0.2	0.6	1.1	2.6	4.9
	ESDM (σ) (n=11)	0.8	0.6	0.6	0.7	0.6	0.6	0.5	0.5
Hypothesis Test (Difference between means =0)	t-test value (k-factor[6] 2.6)	0.9	1.9	0.9	1.9	1.8	2.2	0.9	0.1
	Pass/Fail	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass

The gauges were tested as received from the manufacturer. The cases were removed only to enable the input of leads for the counting. The cases were replaced with the vents in the casing oriented towards the back of the gauge.

The testing was carried out from the 5 August to the 19 August 1999 at the WMO Region V, Australian Regional Instrument Centre, in the Bureau of Meteorology Head Office.

[3] Run No. 6 is not covered by the acceptance criteria and throughout this report is not subject to any requirements of acceptance. All information for Run No. 6 is given for information purposes only.
[4] Correction defined as: Theoretical Number of Tips – Measured Number of Tips
[5] ESDM (Estimated Standard Deviation of the Mean), given as

$$\sigma = s/\sqrt{n}$$

Where s is standard deviation and n is the number of sample. This is in accordance with ISO GEUM.
[6] k-factor is the coverage factor selected according to Confidence Level of 95% and Number of Degrees of Freedom, in accordance with ISO GEUM.

Results and Discussion

Time Signature Analysis

Two gauges failed the calibration check. The cause of these failures was an anomalous run which recorded a large number of tips. The gauges that exhibited this anomalous behaviour were 96-998 and 96-876.

The recorded flow rate or time taken to deliver the same volume of water to the bucket did not change significantly over the entire run, particularly not during the anomalous runs of 123 tips for 96-998 and 118 tips for 96-876.

The time taken to deliver the volume of water to each gauge as recorded by the tips of the gauge indicates that it is not likely that the volume of the water delivered had changed significantly.

There was some variability in the time from the first to the last tip. As can be seen in Table 5 the seconds recorded for Run No. 3 is not significantly different from the population. The run immediately prior to this did show a significantly different time lapse between the first and the last tip of the run. Run No. 2 recorded 103 tips, which is close to expected. This indicates that there is little if any correlation between the volume delivered and the time taken to deliver it. However this does not conclusively show that additional water was not added to the bucket. The second gauge however supports the conclusion that the volume delivered is independent of the time taken to deliver it much more clearly as shown below in Table 6.

Table 5 Anomalous Run analysis, S/N 96-998

HS TB3B S/N 96-998			
Run No.	Number of Tips Recorded	Seconds recorded between last and first tip.	Equivalent Flow rate mm/hr
1	102	1462.5	51.3
2	103	1674.3	44.8
3	**123**	1560.3	48.1
4	104	1463.4	51.3
5	105	1485.8	50.5
Average		1529.3	49.2
U95% (k factor 3.5)		141.3	4.3

Table 6 Anomalous Run analysis S/N 98-876

HS TB3B S/N 98-876			
Run Number	Number of Tips Recorded	Seconds to deliver Volume	Equivalent Flow rate mm/hr
6	105	893.2	83.9
7	104	896.9	83.6
8	104	893.0	83.9
9	**118**	906.5	82.7
10	104	880.2	85.2
Average		894.0	83.9
U95% (k factor 3.5)		14.7	1.4

These data indicate that there was no significant difference between the times taken to deliver the water between runs of significantly different tips, but the number of tips recorded for Run No. 9 with 96-876 was too high by about 15 tips.

Hence there is strong evidence here to suggest that volume is not the determining factor of the anomalous number of tips.

The time signature of the tips for these gauges during the anomalous run was remarkably different to the time signature of the other satisfactory runs in the set. One possible cause of these anomalies may have been that the siphon either ceased to siphon or changed its characteristics. This seems to be the case indicated by the time signature of the gauges and the particular runs affected.

In Run No.9 for HS 96-876 with the higher number of tips, the time signature shown in Figure 1 was different to the time signature of the runs on either side. The time signature feature of runs 8 and 10 and the first part of Run No.9 show a ‘double tipping feature which is attributable to expected siphon operating. The Run No.9 single tips at consistent time spacing indicate a failure of the siphon. In the case of Run No. 9 the siphon may be functioning as either a flow through or may be dispensing less volume at more regular intervals due to some restriction in the mechanism.

The same feature is identified in the performance of HS 96-998 for Run Numbers 2 through 4, and is shown in Figure 2. For TBRG S/N 96-998 the anomalous Run No.3 clearly had a different time signature to Run Numbers 2 and 4. There was a significant absence of the ‘double tip’ in Run No. 3 that is characterized in runs 2 and 4.

Figure 1 Time Signature of SN 96-876

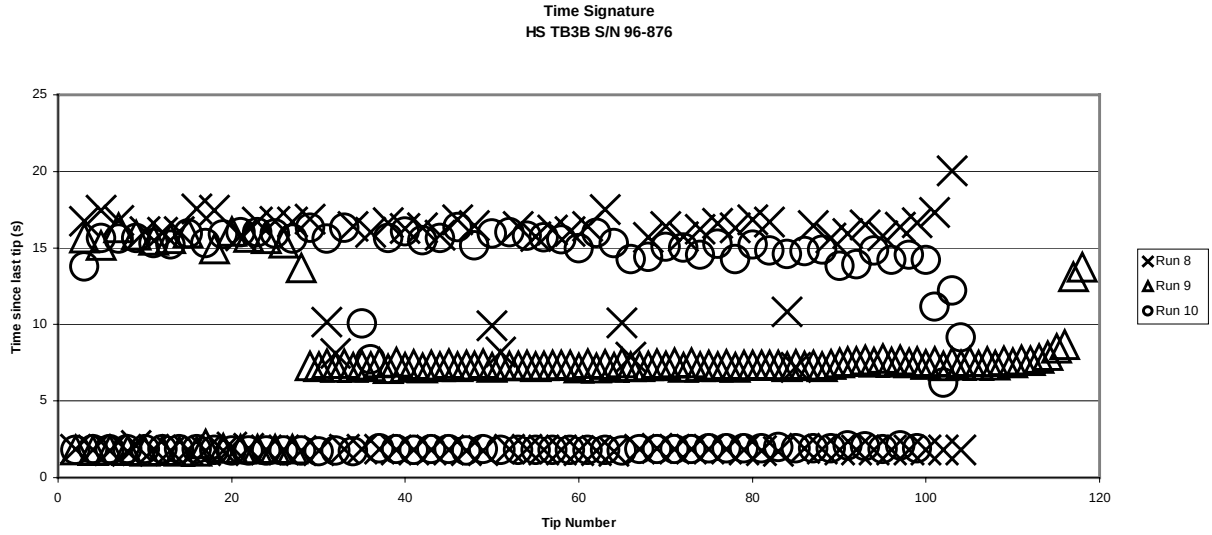
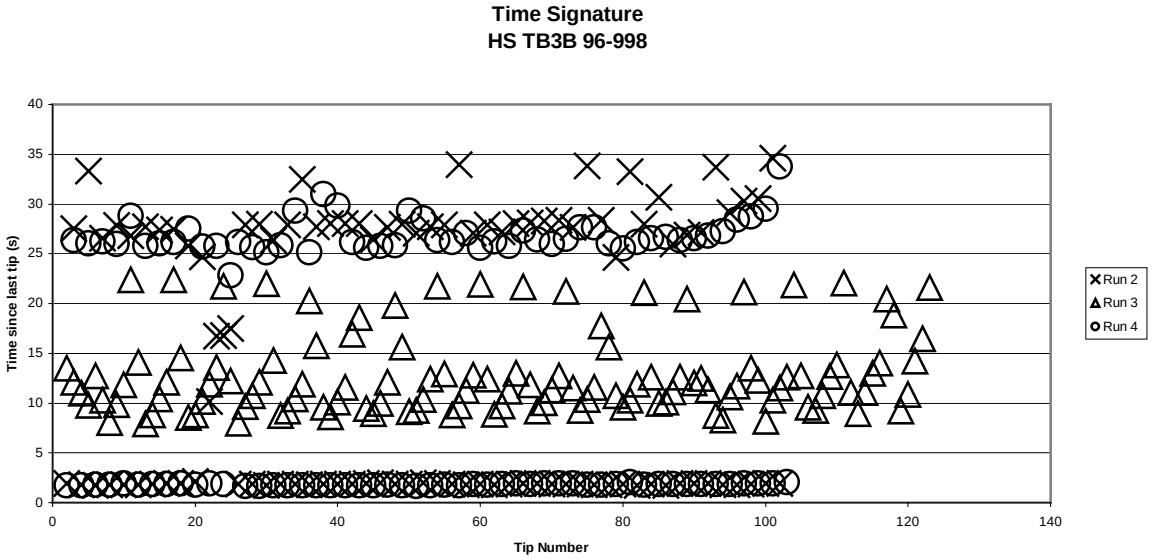


Figure 2 Time Signature of SN 96-998



The conclusion is that anomalous runs of 123 and 118 tips for gauges 96-998 and 96-876 respectively were not a product of either a different volume being delivered to the bucket by the automated calibrators, or of the system delivering the water at a significantly different flow rate. The time signatures indicate that the mechanism causing the anomalous runs is within the gauge.

Consistency Within the Batch

Normally the mean correction for any flow rate must be within ±3% of the expected value. As HS were not required to correct any HS calibration offset to the Bureau reference, the mean correction to the expected number of tips at each flow rate was not assessed, as an acceptance criterion.

The HS gauges were required to be consistent within the batch, that is,

(a) the range (defined as the largest difference between any two gauges) of the mean correction for the batch should not exceed 6% for flow rates less than 250mm/hr and 8% for flow rates greater than 250mm/hr and less than 350mm/hr, and

(b) the mean correction for a gauge at each flow rate falls within the population of the batch according to a t-test analysis of the gauge and the batch.

Gauges that were statistically different from the rest of the batch at any given flow rate and were identified as the gauges that contributed to a range of mean corrections larger than 6% were considered unacceptable.

Gauges HS 96-876 and 96-998 were included in the analysis but Sequence Numbers 1 and 2 were not examined for consistency. As a result the consistency testing for sequence numbers 3, 4, 5, 7 and 8 identified gauges 98-231 and 96-1014 as unacceptable.

As shown in Table 7 the calibration of S/N 98-231 was not consistent with the rest of the population of the batch at any of the flow rates and the range criterion failed with and without this gauge. A t-significance test indicates that none of the mean corrections at any flow rate coincide with the mean correction of the batch. This gauge exhibited a larger number of tips than the rest of the population of twenty gauges.

Excluding gauges HS 96-998, 96-876 and 98-231, the maximum range was 7.0% for Sequence Number 7, and the next largest was 6.4% for Sequence Number 3. This range of mean values is too large to expect that the batch tested would meet acceptance criteria of ±3% within the expected number of tips. Hence the remaining 19 gauges would still not pass the batch acceptance criteria.

Table 7 Statistical analysis of HS 98-231

HS TB3B S/N 98-231								
Seq. No:	1	7	2	8	3	4	5	6
Range including 98-231	10.6	8.0	9.1	7.4	7.8	7.8	6.2	5.5
Range Excluding 98-231	7.7	7.0	7.7	4.9	6.4	5.4	5.0	5.0
Batch Average	-0.1	-0.5	0.8	0.5	1.3	1.9	2.9	4.9
ESDM (σ)	1.2	1.1	1.6	1.6	1.0	1.0	1.0	0.7
ν[7] degrees of freedom	19	19	19	19	19	19	19	19
98-231 correction	-5.9	-4.6	-4.2	-4.4	-2.7	-2.5	-0.2	2.4
t-value	4.7	3.8	3.1	3.0	3.8	4.3	3.0	3.8
t-test criterion	< 2.1	< 2.1	< 2.1	< 2.1	< 2.1	< 2.1	< 2.1	< 2.1
Pass/Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail

The remaining 19 gauge data were examined to identify any additional outliers. Gauge 96-1014 was found to be the candidate for removal from the batch (that already excluded HS 98-231). As Table 8 shows, removing HS 96-1014 leaving 18 gauges ensures that all batch criteria are satisfied. *(Note that Sequences 1 and 2 were ignored.)*

If the batch was reduced to the 16 gauges remaining after excluding (HS 96-998, 96 – 876, 96-1014, 98-231) all batch and calibration criteria are satisfied. Table 9 shows the results of the batch consistency testing, indicating that these remaining gauges are within the required ranges.

[7] ν degrees of freedom, where ν=n-1, where n = number of samples, in accordance with ISO GEUM.

Table 8 Statistical analysis of HS 96-1014

HS TB3B S/N 96-1014								
Seq. No:	1	7	2	8	3	4	5	6
Range Excluding 98-231	7.7	7.0	7.7	4.9	6.4	5.4	5.0	5.0
Range (%) Excluding 98-231 and 96-1014	7.7	5.9	6.1	4.9	5.3	5.1	5.0	5.0
Batch Average	-0.1	-0.5	0.8	0.5	1.3	1.9	2.9	4.9
ESDM (σ)	1.2	1.1	1.6	1.6	1.0	1.0	1.0	0.7
ν degrees of freedom	19	19	19	19	19	19	19	19
96-1014 correction	0.7	3.4	4.9	1.8	5.1	5.3	5.3	7.8
t-value	0.6	3.6	2.5	0.8	3.7	3.3	2.3	4.3
t-test criterion	< 2.1	< 2.1	< 2.1	< 2.1	< 2.1	< 2.1	< 2.1	< 2.1
Pass/Fail	Pass	Fail	Fail	Pass	Fail	Fail	Fail	Fail

Table 9 Remaining Gauges – Range analysis

Range Excluding 96-998, 96-876, 96-1014, 98-231								
Seq. No:	1	7	2	8	3	4	5	6
Range (%)	5.76	5.86	4.41	4.90	5.28	5.09	5.00	4.99

Conclusion

Four gauges were deemed unacceptable. Two gauges, 96-998 and 96-876, were rejected for unacceptably high readings on a single run. Two gauges, 96-1014 and 98-231, were unacceptable, as they did not meet acceptable consistency requirements within the batch.

References

1. ISO Guide to Expression of Uncertainty in Measurement.
2. A1980 Specification for Tipping Bucket Rain Gauge, 1999, Bureau of Meteorology.