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Evaluation of RIC Designed Pumped TBRG Tester (Rex)

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Aim

The aim of this report is to describe the Tipping Bucket Rain Gauge tester based on a peristaltic pump and digital scales designed by the RIC. This document will enable the reader to understand the overall system and design philosophy, trouble shoot and maintain the system, and competently extend the hardware or software if that becomes necessary.

Overview

The Bureau routinely tests Tipping Bucket Rain Gauges (TBRGs) at various rainfall rates to determine the accuracy, reproducibility and repeatability of gauges with respect to the Bureau specification [1] for tipping bucket rain gauges. This is accomplished by running known amounts of water through the gauges at various rates and recording the number of tips. Assuming that:

1. the temperature correction (volume versus mass) for the water employed in these experiments was negligible;

2. the Bureau's working references for mass provided a true mass within the bounds of uncertainty supplied with their calibration certificate after the relevant correction has been applied; and

3. filtered tap water would not significantly affect the results when substituted for distilled water as per earlier RIC results [2];

a new TBRG tester was designed.

Background

Using a Boyle bottle arrangement the existing rain gauge system known as Squiddly (Figure 1) runs a fixed volume of water through the rain gauge under test through a series of selectable nozzles under the force of gravity. The various nozzle sizes produce varying rainfall rates. The volume of water delivered is approximately 650 ml, equating to 100 tips for a TBRG having a 0.2 mm of rainfall per tip. A small and variable amount of water will remain within the piping of the system after flow has ceased. Although the volume of the bottle is fixed the actual delivered volume will vary and be unknown. Tests have shown this variation is of the order of approximately 1.5ml of water or ¼ of a tip. The other limitations of this system are, the lack of selectability of flow rate due to the limited number of nozzles and their fixed size, the variability of flow rate due to nozzles becoming blocked with time, and the variability of nozzle flow from run to run. In Squiddly the rainfall rate is determined by examining the TBRG tips versus time, hence there is no measurement of flow rate independent of the TBRG under test.

Peristaltic pumped systems have been used by others to test rain gauges [3]. A pumped TBRG tester was designed to provide greater flexibility in testing TBRGs and increase repeatability; the new system is called Rex.

Figure 1. Existing Rain Gauge testing unit (Squiddly) showing the Boyle bottle at the top and 6 selectable nozzles above the rain gauge.

Overview of Rex

The new system was nicknamed after "Rex Hunt" as it is a "catch and release" system (see Figure 2). The TBRG under test is placed in a weighing tray atop computer-controlled scales. Water is delivered to the gauge from a peristaltic pump controlled by the same computer. Water flows through the gauge and is collected in the tray below. In this system all water flowing through the gauge is collected and weighed reducing the uncertainty of the delivered volume to the uncertainty of the scales. In the case of the scales chosen, at the masses of interest, the 95% uncertainty was found to be approximately 0.3 gm or 4.6% of a tip (i.e. ≈ $1/20^{th}$ of a tip). The mean flow rate is measured by comparing the delivered mass with the start and end times for the pump, that is, the change in mass on the scales over change in time. Since the delivered volume is known (to approximately +/- 0.02% for 300 tips) the number of expected tips can be determined and compared to the number of recorded tips producing an estimate of the gauge correction at the experimental flow rate (hence implied rainfall rate).

Figure 2. Pumped Rain Gauge Tester (Rex) showing PC and software interface.

Overview of Operation

Water for the peristaltic pump is sourced from a header tank with float valve since the flow rate for these pumps is sensitive to the pressure head, that is, the difference in height level between the input and output streams. Large variations in head level (of the order of centimetres) will influence the delivered mean flow rate to the order of approximately 5-10% of the mean flow rate and therefore the water level within the header tank should be examined from time to time to ensure the float valve is operating correctly.

The system has been designed to work with the input and output ends of the pumping tube at approximately the same level. This is easy to establish by releasing the pump tube clamps and watching the direction water flows within the tube.

The pump is controlled via an RS232 interface, which sends commands to set the pumping, speed, pump start and stop times. The pumping speed has been measured to be stable to approximately 1% and reproducible for periods of approximately 2 days of continuous operation. After this time the tubing begins to degrade and the measured pumping speed can be seen to vary from the expected value. This can be monitored by calculating the pumping speeds from the TBRG test summary files.

Figure 3. Image of water delivery tubes (left), peristaltic pump (centre) and header tank (right).

The water from the pump is dribbled onto the side of the funnel of the TBRG and when sufficient water has been collected will cause the TBRG buckets to tip. An analog/digital interfacing card within the controlling PC detects this tipping action. Specifically, the Labview control program is interrupt driven by tips. On detecting a tip it records the time

of the start of the tip to a log file and increments the software tip counter. The program then looks for the end of the tip before returning to its detect tip function. If no tip has occurred for 120 seconds the program moves out of detection mode and into summary mode. In this mode the program reads the mass of water delivered from the scales, the total tips accumulated at the current pumping speed, and writes them to the summary file. The program then waits 3 minutes and reads the scales again, storing this value in the summary file. The second measure of mass is to enable the operator to determine if the drain valve was leaking during the experimental run. A discrepancy of 1 gm or more in the two masses recorded indicates a leak and the data should be discarded.

The program then opens the catching tray drain valve (Figure 4) to release the water collected during the run (there is a time delay of 5 mins to ensure the water is completely drained before closing the drain valve). The scales are then "tared", i.e. reset to zero, and the next pumping speed selected.

By taring the scales at the start of each run any water remaining within the TBRG or tray is negated – the mass recorded at the end of pumping will accurately reflect the mass delivered during that run. The time used for rate calculations is the time from "pump on" to "pump off", but the mass is measured 120 seconds after the last tip to ensure that the water has ceased moving within the system.

Figure 4. Top view showing water delivery slide and TBRG on the scales. Drain is on the bottom right of the weighing pan.

The cycle of operations in a Rex trial is summarized below:

1. close the weighing tray drain valve (fig.4 bottom right of tray);
2. set peristaltic pump speed (fig. 3 center);
3. tare the scales to read zero (fig. 4 center);

4. start pump and log *start* time to summary file;

5. record each tip event to event file (tip event time);

6. count to *n* tips as required for the trial (usually 300) then turn pump off;

7. log pump *off* time to summary file;

8. wait 120 seconds to ensure all tips have occurred;

9. log *total* tips to summary file;

10. interrogate scales for delivered water *mass* and log to summary file;

11. wait 3 minutes and interrogate scales again and log mass to summary file (for leak detection);

12. open drain valve for 5 minutes to clear water; and then

13. back to 1.

Rex produces two files (summary and event) as output; the first file allows the calculation of gauge corrections at the applied rainfall rates and allows some diagnostics, and a second data file which records the time of every tip event.

The serial interfaces to the peristaltic pump and the scales allow considerable flexibility in operation. For example, the software can be used to ramp the rainfall rate up, hold it, then ramp down in a simulation of a rainfall event. The pump can deliver very high or very low rainfall rates by selecting various tube sizes and in the prototype developed in the RIC by adding more tubes in parallel thereby increasing the available delivery rate. This has allowed reproducible rainfall rates from 4 to 1000 mm/hr to be produced.

The output of the TBRG reed switch is also monitored by a Trumeter digital counter. This device can be reset at the commencement of testing and compared to the total tips recorded by the Labview program to establish if any tips have been missed.

Experimental

Squiddly and Rex are fully automated in terms of water delivery and tip counting and data logging. The results of both testing systems were put into the same form, *corrections required per 100 tips* for each gauge at various rainfall rates to evaluate the gauges against the specification. The two systems employ differing techniques to arrive at the same experimental value – *the number of tips for a given volume of water at a particular rainfall rate*. Briefly Squiddly uses a Boyle bottle to deliver a fixed volume of water through fixed diameter nozzles under gravity. Hence the bottle volume determines the volume delivered and the 'rainfall rate' is determined by the nozzle diameter. Rex employs a peristaltic pump to deliver water into the gauge, which is positioned on a weighing tray (see Figure 2). Then the scales tared before water is delivered. The tray is

then weighed allowing an accurate determination of the mass delivered and the delivery rate. Here are implicit assumptions that:

1. the temperature of the water is constant;

2. the density of the water is known;

3. the volume is proportional to density;

Squiddly employs a fixed volume with the assumption that the temperature of the water at the start of a trial equals the temperature of the water at the end of the trial and that any variation in water density due to temperature is insignificant.

The nominal 'rainfall rate' is determined by setting the RPM of the peristaltic pump, the actual rate is determined experimentally by recording the turn on time of the pump, the turn off time of the pump, and the mass delivered to the scales.

The water used in these tests was Melbourne tap water filtered through an Aquapure AP124 in-line water purification filter. Earlier work within the RIC has shown that filtered water did not affect significantly the experimental outcome when compared with distilled water.

Performance

Weighing Uncertainty

The uncertainty of the scales was assessed by clearing the of all other mass (Table 1) and repeated with the scales tared to zero with the weighing tray and a TBRG in place to simulate an actual test (approximately 3500 gm total), Table 2. The scales read to 0.1 gm.

Table 1. Scale Test Data – Scales Only

Trial	Mass (gm)	Reading (gm)	Difference (gm)
1	10	10.1	0.1
2	20	20.0	0.0
3	30	30.0	0.0
4	50	50.0	0.0
5	70	69.9	-0.1
6	120	119.9	-0.1
7	220	219.9	-0.1
8	320	319.9	-0.1
9	420	420.1	0.1
10	620	620.1	0.1
11	820	820.2	0.2
12	1320	1320.3	0.3
13	1820	1820.1	0.1

Table 2. Scale Test Data – Scales Plus TBRG and Catching Tray

Trial	Mass (gm)	Reading (gm)	Difference (gm)
1	1000	999.8	-0.2
2	1400	1400.1	0.1
3	1700	1700.2	0.2
4	1790	1790.1	0.1

The differences found in these tests are not considered significant with respect to the testing of TBRGs since the greatest difference recorded was approximately 0.3 gm or 1/20th of a tip. These tests also confirmed that the scale was within the manufacturer's specification.

Mass asymmetry

The effect of asymmetric loading on the uncertainty of the scales was investigated and the results appear in Table 3.

Table 3. Scale Accuracy Test Data Due to Load Asymmetry

Trail	Position On Scale	Mass (gm)	Reading (gm)
1	Centre	1820.0	1820.1
2	Top right corner	1820.0	1820.1
3	Top left corner	1820.0	1820.0
4	Bottom right corner	1820.0	1820.1
5	Bottom left corner	1820.0	1820.1

From the mass data it can be seen that the U_{95} confidence level for the scales is no worse than 0.3 gm or about 1/20th of a tip and implies that asymmetric loading of the scale does not significantly affect scale accuracy.

Tip counting

The software/hardware of the pumped TBRG tester was evaluated against a solid state counter ("Trumeter" 7110DIN) and by manually monitoring the tips. An operator monitored the TBRG counts whilst the gauge was exposed to various flow rates over the range 25 – 500mm/hr for extended periods. The Trumeter was reset at the start of each

run and compared at the end of the run with the software total. After 3000 counts the manual observation, the TBRG tester and the solid-state counter agreed exactly. Continued testing found no discrepancy between the Trumeter counter and the Rex software over 20,000 tips and several days of operation. To date no discrepancies have been found.

Figure 5 below contains useful information on the differences between the time stamping of tips employed by Rex and Squiddly. The Squiddly tip detect is essentially a 'polled' system, software routinely checks for tips. Rex however is an interrupt driven system. The difference in approaches can be seen in the data in Figure 5. The Squiddly data are quantised, with the period of polling approximately 150 ms.

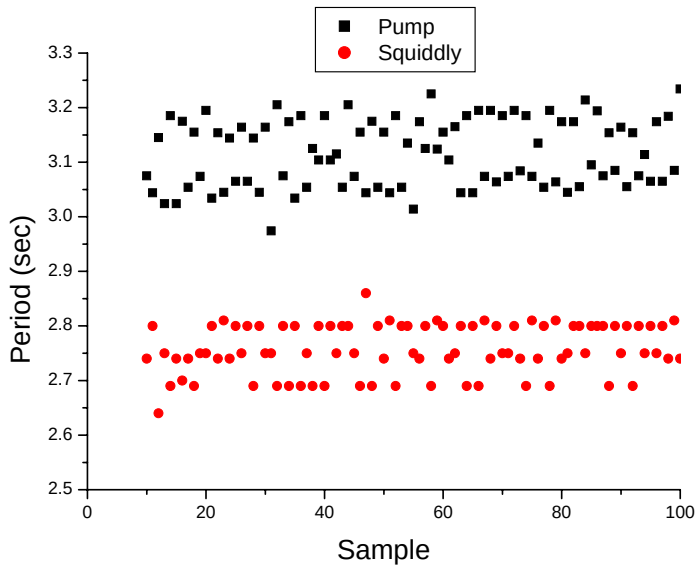

Figure 5. Timing plot, time between tips, for a high rainfall rate (approx. 300mm/hr) for both Squiddly and Rex.

Rainfall rate linearity

Figure 6 shows a plot of the rainfall rate versus RPM for the peristaltic pump. The rainfall rate was defined as the mass delivered divided by the time the water was being pumped, i.e., $\Delta m/\Delta t$. The rate is linear with a slope of approximately 6.2 mm/hr per RPM for the tube diameter chosen (Vinyl tubing ID 3/16", OD 5/16").

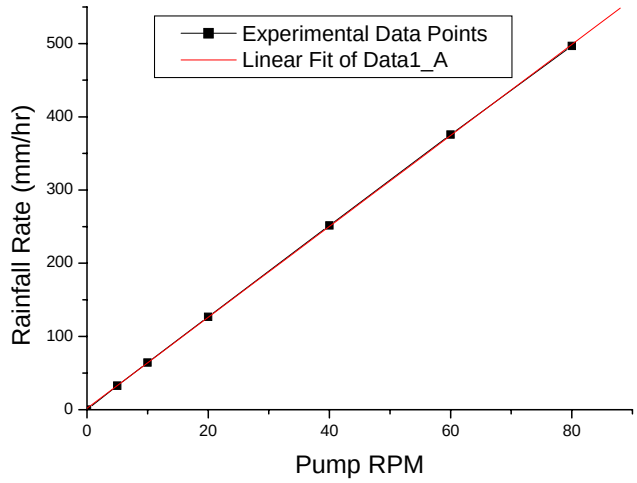

Figure 6. Plot of rainfall rate, (mass/time), versus pump RPM.

The repeatability of the pumped system is shown in Figure 7 below.

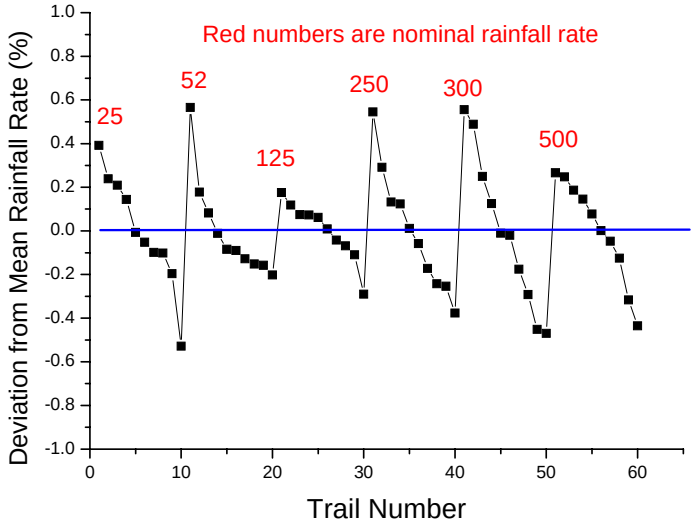

Figure 7. Repeated trials (10 of) at six rainfall rates showing the repeatability of set rainfall rate. Red numbers on plot indicate first trial at each rainfall rate.

Figure 7 has been plotted such that each rainfall rate is grouped together. During the experiment rainfall rates were in a loop from 25 – 500 mm/hr, which was repeated 10 times. The total trial lasted 50 hours and included approximately 20,000 tips in total. The drift down in rainfall rate of approximately 1% was therefore the total drift seen in 50

hours of continuous operation and results from the degradation in pumping tube. The tube becomes less elastic with use and the passage of time.

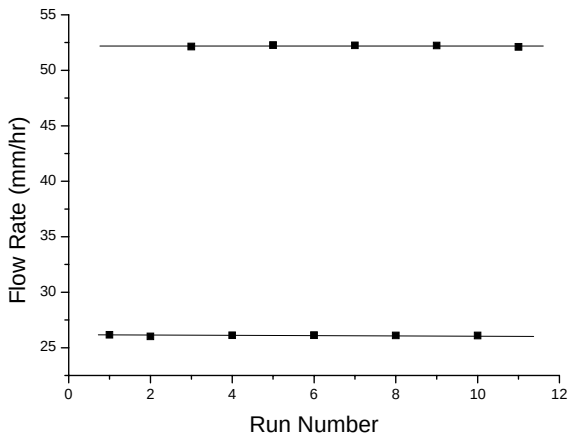

Figure 8. Expanded plot of the measured flow rate of Rex versus run number showing repeatability of flow rate.

Figure 8 shows an expanded plot of the measured flow rate of Rex versus run number showing repeatability of rainfall rate. In this plot trials of 25 mm/hr and 52 mm/hr were interleaved. Each data trial was approximately 300 tips. It also demonstrates the accuracy of the pumped system in producing rainfall rates. Rainfall rates are calculated from RPMs leading to small uncertainty in the actual rate produced. If desired a software feedback could have been incorporated to fine tune the experimental rainfall rate to achieve higher accuracies however this was not deemed necessary.

Comparison with Squiddly Results

Results of time between successive tips versus time (tip number) are shown in Figure 9. It can be seen that due to the Boyle bottle used in Squiddly the flow rate decreases at the end of the run leading to lengthening intervals between tips. This problem is not seen in the Rex data (Figure 10).

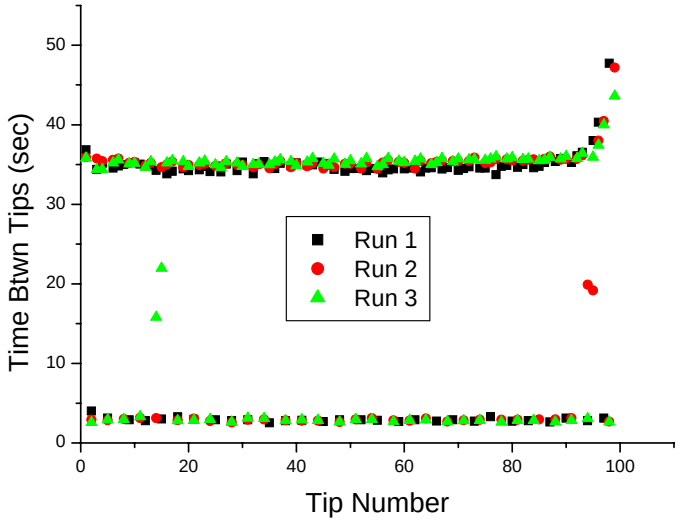

Figure 9. Typical Squiddly data at low flow rate – note rising tail due to loss of head pressure.

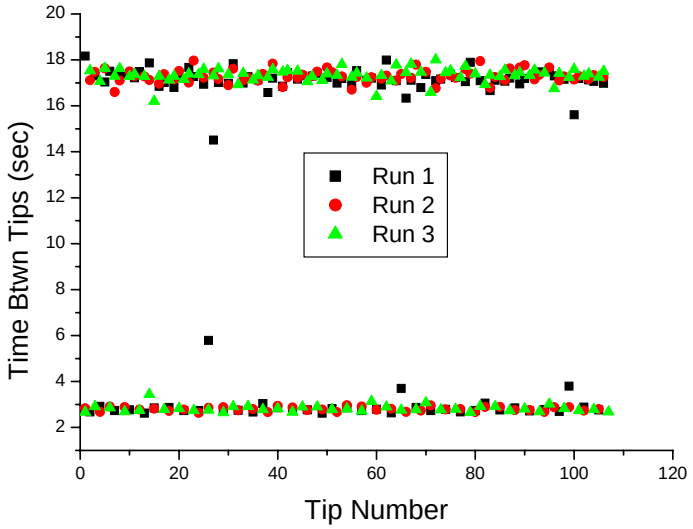

Figure 10. Typical Rex results at low rainfall rate. Note the lack of "tail".

The earlier results from Squiddly were compared to Rex for the RIMCO 8020 TBRG s/n 81223 after bedding-in. The results appear in Figure 11 below.

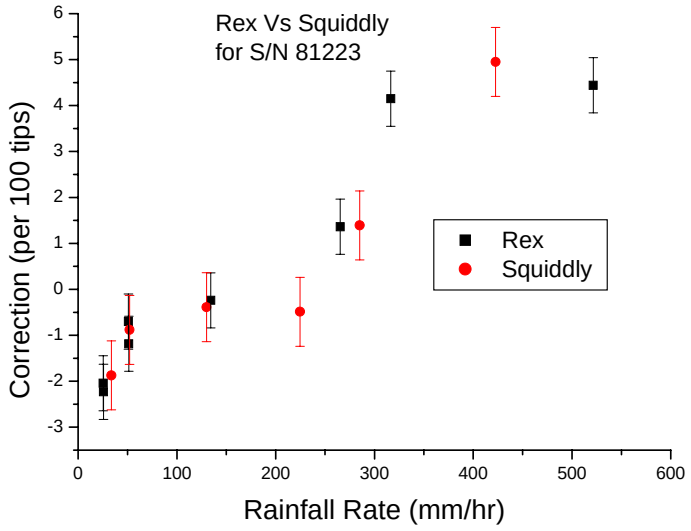

Figure 11. Comparison of Rex results with Squiddly results for the same gauge, (Squiddly bars are 0.75 tips). Rex error bars reflect the 2-tip ambiguity at the start of a run. Lack of repeatability in Squiddly flow rates is evident.

From Figure 11 it can be seen that the two systems are in good agreement although the actual flow rate for Squiddly varies considerably from that nominated; the Rex values (black data points) are within 4 % of the nominated average rainfall rate.

Rex TBRG characterization tests

The pumped system can also be employed to characterise a TBRG over a wider range and at better rainfall rate resolution than Squiddly due to the level of control given by the peristaltic pump. This is illustrated in Figure 12. The fixed number of set flow rates utilised in Squiddly has been replaced by an almost infinite number of selectable rainfall rates allowing gauges to be more fully characterised and suspected problem areas examined in detail. For example, figure 12 suggests that this TBRG may have a problem at, or around, a rainfall rate of 100mm/hr.

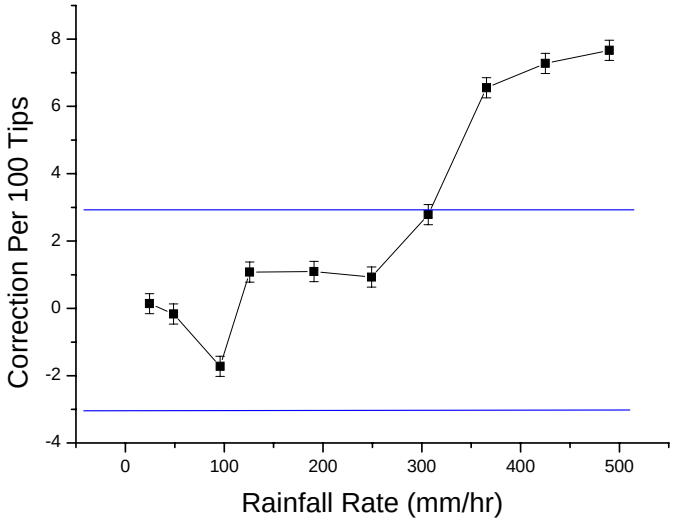

Figure 12. Plot of correction versus rainfall rate for a TBRG. Blue horizontal lines show current Bureau specification.

Uncertainty Analysis

The calculation of uncertainty for a TBRG testing rig is a non-trivial matter is handled in a separate document [4].

Discussion

Considerable work by the RIC has consistently demonstrated that *the behaviour of new TBRGs alters as a result of water throughput [2]*. This is best illustrated in Figure 13. In this figure the corrections for a TBRG are plotted against run number, each run comprising of approximately 1800 to 2100 ml of water (300 tips). It can be seen that the behaviour of this gauge changes significantly during the early tests, only stabilising after approximately 7000 tips (≈ 45.5 L of water!).

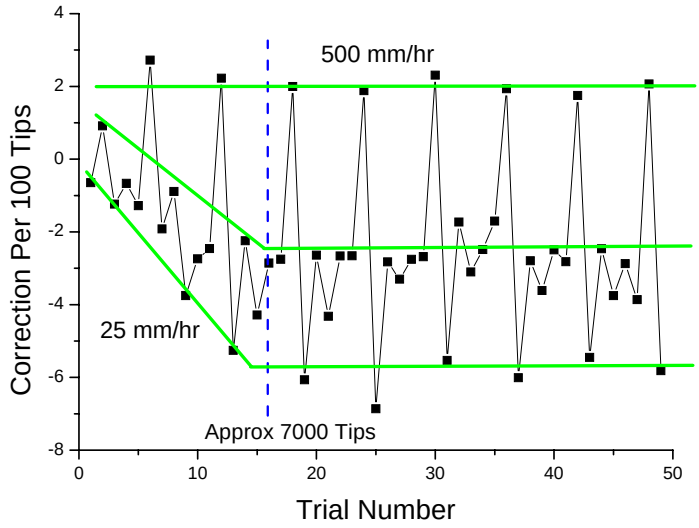

Figure 13. Correction versus trial number showing drift in correction versus total number of tips. 25 and 500 mm/hr data points marked. Centre green line is around the 52-mm/hr data points.

The extent of 'bedding-in' of the gauge under test is clearly shown in Figure 13. The bedding-in process is sufficient to move a gauge out of specification at lower rainfall rates. More problematically, the correction at 300-mm/hr rainfall rate drifts down by approximately 3 tips while the correction at 25 mm/hr drifts considerably (≈ 6 tips). This 'pulling apart' of the correction implies that a gauge initially adjusted to meet the specification will tend to fall outside the specification at lower rainfall rates after repeated testing, a result which has been demonstrated in later studies as shown in figure 14.

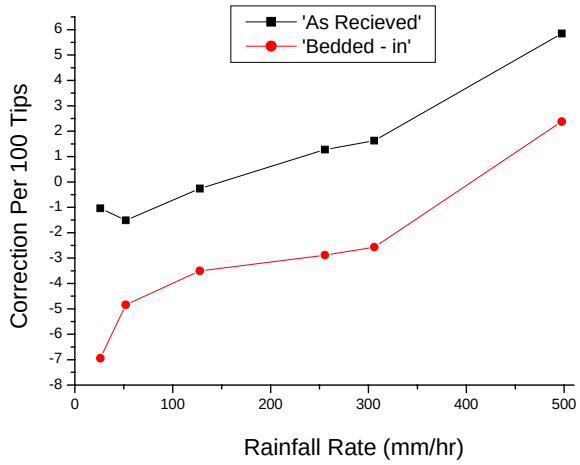

Figure 14. 'As-received' group average corrections of five Hydrological Services Model TB3 gauges 'as-received' (blk) compared with another batch of 'bedded-in' gauges (red).

These are significant results as Squiddly tests new gauges with approximately 6000 tips, while Rex only uses 1800 tips. A squiddly TBRG test uses symmetric 5 x 100 tip runs, that is, the slowest rate runs are done at both the start and end of the test. The Squiddly test therefore provides statistics on the stability of the gauge. Rex can be programmed to imitate squiddly or any other test sequence. Figure 15 the correction versus rainfall rates calculated from Squiddly data for 'as-received' TBRGs of a particular model are shown. In Figure 16 the Rex data for the same model gauge (as-received) is shown.

Due to the bedding-in process direct comparison of data from Rex and Squiddly is not possible for the same gauge since bedding in has altered the gauge response.

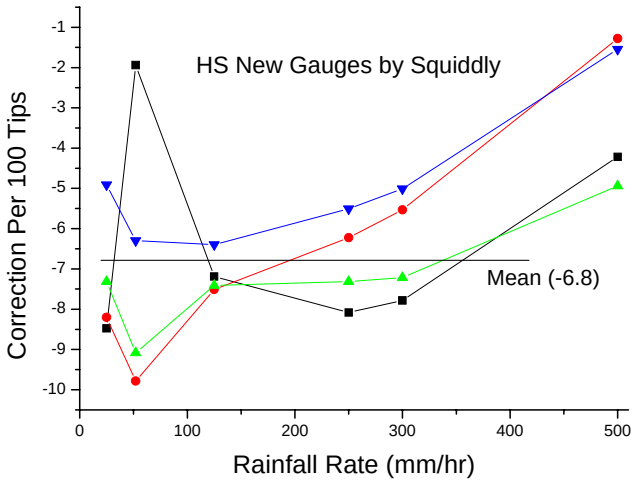

Figure 15. Corrections for 4 Hydrological Services Model TB3 TBRGs tested by Squiddly

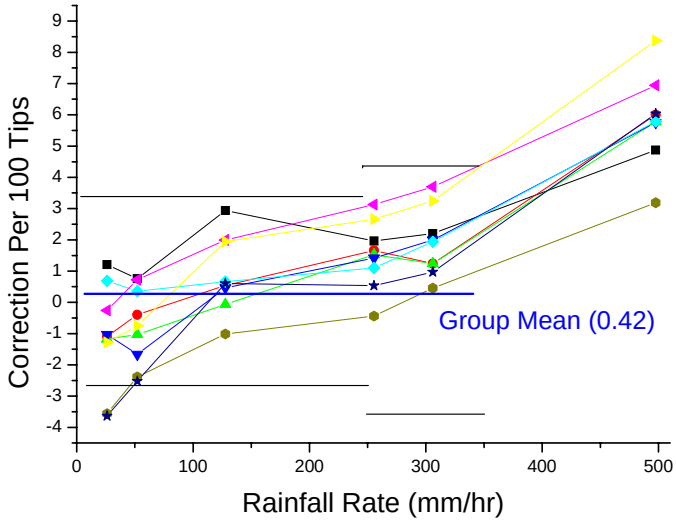

Figure 16. Corrections for 10 'as-received' Hydrological Services Model TB3 *gauges as tested by Rex.*

These figures clearly illustrate that the 'bedding-in' of the gauge significantly affects the results obtained during testing. The mean offsets obtained from each testing system is roughly in line with that predicted by Figure 13, that is, Squiddly will give a larger (more negative) offset than Rex. Repeated 300 tip trials by Rex produce graphs such as Figure 13, which contains considerably more information than the output from Squiddly. Figures such as 13 can be employed to assess whether a gauge does bed-in, whether it has stabilised during testing, and how the corrections versus rainfall rate alter with exposure to water flow.

A second source of inconsistency is the chaotic nature of the TBRGs at low rainfall rates. The term chaotic is used here in the strict sense of the word. The bucket of the TBRG when almost at its capacity is at an unstable equilibrium. Any perturbation will move it away from equilibrium. For example, the slightest increase in mass or a vibration. This is illustrated in Figure 17 below. This is a plot of the time between tips (y axis) for a series of sequential tips from a TBRG at a 'set' rainfall rate of 25mm/hr (found to be 25mm/hr +/- 1% over the period of the run). At about sample 60 (roughly 25 minutes into the run) the TBRG flipped from an alternating pattern of a long tip (40 sec) followed by a short tip (3 sec) to an intermediate length tip (25 sec). Analysis shows that the average time between tips is approximately the same before and after the discontinuity in behaviour. However when the same flow rate was repeated (figure 18) the gauge remained in a stable regime.

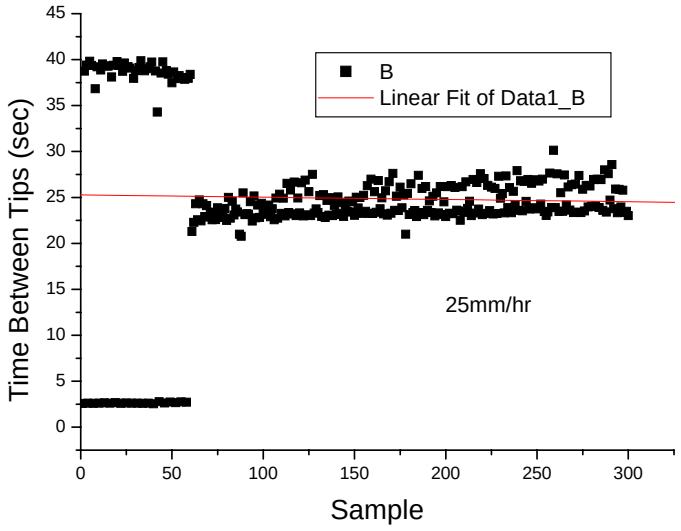

Figure 17. Example of TBRG changing the tipping frequency within a run.

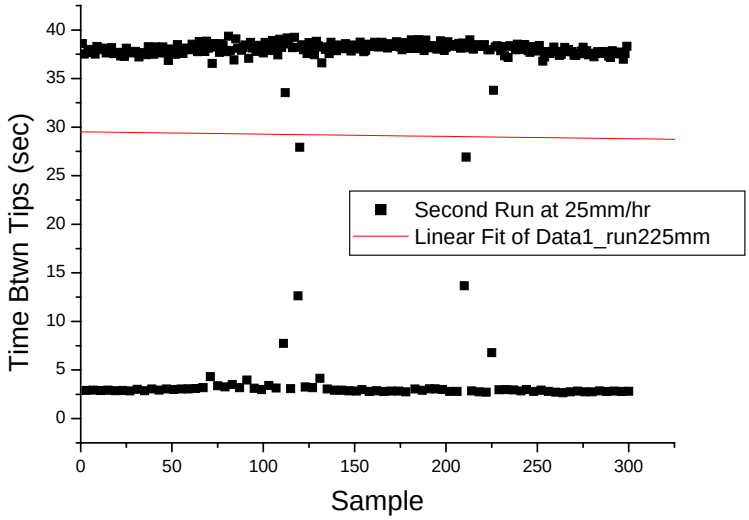

Figure 18. Example of a more constant tipping process for the same gauge shown in Figure 17.

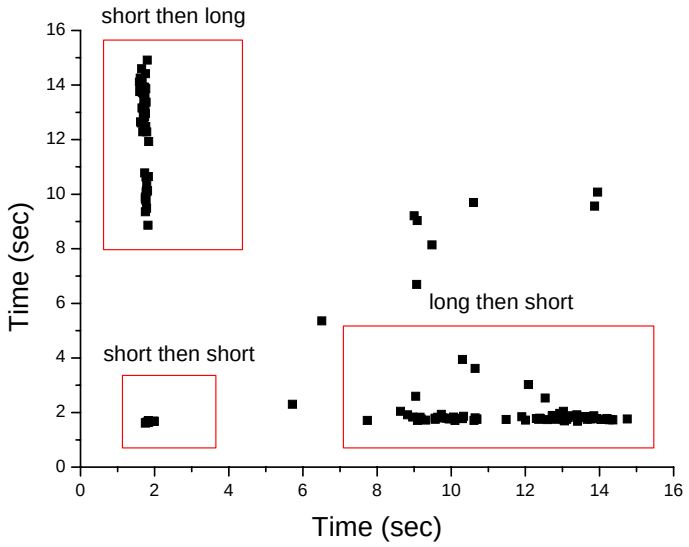

Figure 19. Lag plot of time between successive tips for a gauge at 25mm/hr rainfall rate.

Figure 19 is a lag plot of successive tips for a TBRG at a low rainfall rate. That is the x-axis is the time between tip *N* and *N-1*, while the y-axis is the time between tip *N+1* and *N*. There are 300 tips, hence 150 points on the graph which have been grouped as either 'short then short' for a short tip followed by a short tip, 'long then short' for a long tip followed by a short tip. It can be said that while the time between tips is not random it is impossible to predict whether the tip to the next tip will be long or short. The cluster of events around (2,2) is interesting since it implies that the siphon delivered 13 ml to the buckets. In this example it occurred 11 times out of 150 pairs.

This effect was confirmed in later testing of the siphon that was found to deliver over 10 ml a significant number of times. This is shown plotted in Figure 20 as mass of water contained within the siphon versus time. This was accomplished by separating the funnel and syphon of a TBRG from the base and placing them on an electronic scale such that their mass could be monitored whilst water from a peristaltic pump was flowing through them. It can be seen that there is wide variation in the mass released by the siphon into the buckets. This is also an important result since the gauge type shown is currently in Bureau use.

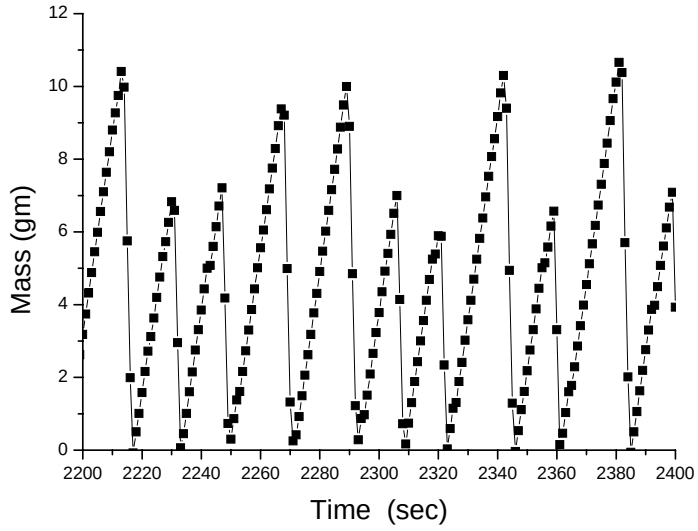

Figure 20. Plot of the variation in the amount of water held within a Rimco siphon with time at a nominal rainfall rate of 50 mm/hr.

One potential problem of a pumped TBRG tester is the pulsed nature of the output from peristaltic pumps. This arises due to the rollers of the pump pinching off the pumping tube and delivering small preset volumes of water as pulses. This was overcome in Rex by employing two 'out of phase' pumping tubes which are then mixed (thereby doubling the pulse frequency) and by allowing the pump outflow to run down a plastic slide which smoothed out the pulses due to the effects of friction/surface tension. These two modifications led to a steady stream of water entering the TBRG funnel as judged visually. The difference in gauge response before and after these modifications can be seen in Figure 21 where the tip interval for Rex and Squiddly are compared. It can be seen that the Rex data was inherently more variable than that produced by Squiddly before the inclusion of the slide. These results should be compared to those presented earlier in Figures 9 and 10. Clearly the pulsing of Rex has been removed to a level comparable to Squiddly.

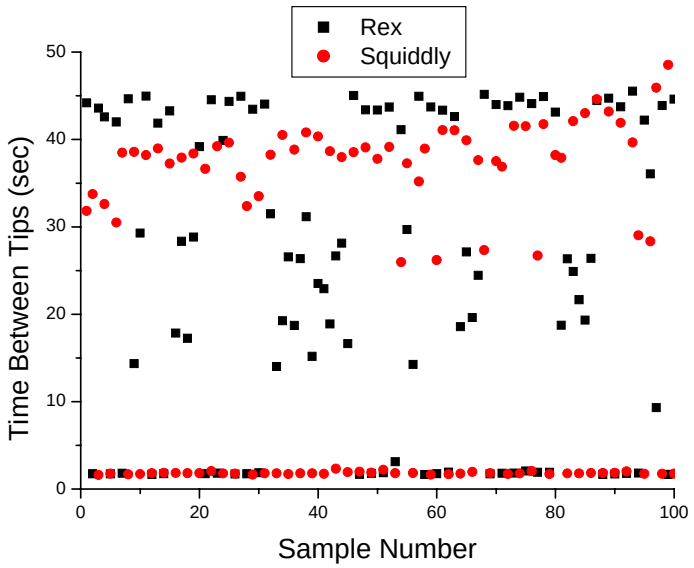

Figure 21. Comparison of the time between tips for Rex (blk) and Squiddly (red) at 25-mm/hr rainfall rate for the same Rimco gauge before flow smoothing.

Advantages of the Pumped TBRG Tester

1. The system is composed of commercial off-the-shelf components and is easier to repair, replace or duplicate.

2. The control systems have been simplified so that the number of moving components has been reduced (to 2), considerably increasing mean time between failures, and the mean time to fail.

3. The pumped system can produce virtually any rainfall rate over the range 4 to 1000 mm/hr with an accuracy of approximately 4%. (Approximately 1% if calibrated at start of run).

4. The rainfall rate is accurately calculated as mass delivered over time – not by relying on the gauge activation (as with Squiddly).

5. The delivered volume of water is a measured quantity not an assumed value (as for Squiddly.

6. The pumped system can "bed-in" gauges before beginning testing.

7. The techniques developed for Rex can be used to characterise other types of rain gauges such as pluviographs.

8. The pumped system can be programmed to initiate ‘rainfall’ start and stop times allowing it to be used in the determination of TBRG temporal characteristics, that is, how accurately TBRGs report rainfall rate.

9. The calculation of measurement uncertainty for Rex is tractable.

10. Rex can be employed to bed-in gauges by delivery large volumes of water over time before testing of the gauge begins.

Disadvantages

1. Tubing needs regular replacement (once a week during continuous operation).

2. Some drift in rainfall rate (approx. 0.5% per 24 hours of operation).

3. Equipment of the systems is approximately $11k each.

4. Minimum of 300 tips required to reduce biases in the ‘taring’method.

Proposed Testing Methods

The different methodology employed by Rex allows great flexibility in testing. It is clear from graphs like figure 14 that the type and duration of testing significantly affects the results obtained using the gauges currently used in the Bureau’s networks. This suggests a number of testing methods.

Program 1. Imitation of Squiddly

In this scheme Rex would deliver water as per the testing schedule utilised by Squiddly. That is 500 tips at 25 and 50 mm/hr, followed by 1000 tip runs at 125, 250, 300 and 500 mm/hr followed by repeats of the 500 tip runs at 25 and 52 mm/hr. The corrections would then be calculated for 100 tips. This method would allow the best comparison with historical TBRG data collected on Squiddly. This scheme would require approximately 24 hours to test one gauge.

Program 2. Interleaved 300 tip trails

In this scheme Rex would do 10 complete runs consisting of 300 tip trials at each of the rainfall rates leading to the generation of plots such as Figure 13. This scheme would require approximately 50 hours of testing per gauge but would produce useful data on gauge stability versus total tips and could be used to determine if a gauge was in fact bedded-in or whether its characteristics were still changing. This program is suited to characterizing a TBRG.

Program 3. Test – Bed in – Test

In this scheme Rex would perform a 300 tip test at each rainfall rate, bed the gauge in for 5000 tips (at 300 mm/hr for example) then repeat the 300 tip test at each rainfall rate.

This would allow calculation of drift. The time required for this testing regime would be approximately 12 hours per gauge. This program is suited to the batch testing of TBRGs.

Program 4. Combination

The best compromise to decrease experimental uncertainty and reduce the time of testing would appear to be a combination of programs 2 & 3. For example, from a batch of 20 gauges 2 should be subjected to *Program 2* in order to establish the number of tips required to bed the gauges in. The rest of the batch would then be tested using *Program 3*. This would allow approximately 20 gauges per week to be tested with two Rex systems.

Conclusions and Recommendations

1. The pumped TBRG tester should be adopted as the primary method for rain gauge testing and characterisation within the RIC.

2. The expanded capabilities of Rex should be employed to characterise TBRGs over a wider range and at higher resolution.

3. A second Rex system should be built to reduce turn around time on TBRG testing.

4. Rex testing via program 3 be implemented for batch testing.

5. Rex testing via program 4 be implemented for future tender evaluations.

[1] Commonwealth Bureau of Meteorology Equipment Specification A1980 Aug. 2003

[2] Michael Berechree, *Stability of five McVann Model 7499 TBRG,* RIC, ITR 660 Aug. 2001

[3] M. D. Humphrey and J. D. Istok, *A New Method for Automated Dynamic Calibration of Tipping-Bucket Rain Gauges,,* A T M O S A N D O C E A N I C T E C H, V14, p. 1513 –1519, Dec. 1997

[4] Bruce Forgan, *Uncertainty Analysis of TBRG Testing*, Technical note in press September 2003

Appendix A - Operating Instructions

1. Remove all weight from the scales and ensure that the scales are level. There is a small ring level on the right hand front of the instrument. If it is not level, use adjustment feet at each corner to level the scales.

2. Internally calibrate the scales by depressing the 'Tare' button until the display reads 'Cal' and then release pressure on the button. The scales will then calibrate against an internal mass. When finished the scales will tare to zero.

3. Replace the weighing tray on the scales such that the weight is evenly distributed.

4. Remove the funnel from the base of the TBRG by loosening the screws at the base of the outer cover. Remove and packing materials used in transporting the TBRG and ensure the buckets tip freely.

5. Loosen and move to one side the cable terminals connected to the TBRG reed switch if present. Connect the DAQ card inputs (blue wires) to the TBRG under test and place the TBRG within the weighing tray and as centrally as possible.

6. Level the TBRG by adjusting the foot screws at the bottom of the TBRG using the ring and bubble level on each TBRG as a guide.

7. Replace the TBRG funnel and outer cover. Ensure that neither the pumping tubes or the slide are in contact with the TBRG or weighing tray. Also ensure that the cabling to the TBRG and the solenoid drain are loose and not adding significant weight to the scales. Observe the scales for a minute or so and satisfy yourself that the mass on the scales is stable.

8. Position the TBRG end of the pump tube slide so that it almost touches the edge of the TBRG rim and drops water near the top of the sloping funnel.

9. Run the Labview Application 'TBRG TesterV4'

10. You will be prompted for operator name, TBRG serial number and TBRG type. The files names are automatically generated based on the date. The xxxxxx_Data.txt is a log file of all data plus every tip event; the xxxx_Summary.txt is a summary of the total tips, total mass etc.

11. The program will test all comms and the TBRG before beginning the testing of the gauge and will exit if a fault is found.

Appendix B - Maintenance

1. The only routine maintenance is the periodic replacement of the pump tubing. This should be done at least once a week during continuous testing. In order to prolong tube life the clamps holding the tube onto the pump rollers should be released when the system is not in use.

2. On a weekly basis examine the last TBRG test summary file to determine if the pumping speeds have drifted significantly (i.e. more than 5% from their nominal values). If this has occurred and the system has new tubing then the Labview pump controller speeds should be changed within the Labview program to bring the actual pumping speed within range.

3. The calibration of the scales should be checked every six months using the calibrated laboratory masses. A difference of more than 0.5gm over the range 0 – 1800gms should be considered a fail. if it fails the catching tray and a TBRG should then be placed back on the scales and the scales tared. The scales should then be re-checked with the same masses, again an error of 0.5gm should be considered a fail for the scales.

4. The solenoid operated drain valve should be examined daily to ensure it is not leaking when closed. If it is, this is usually caused by material lodging under the valve seat. The spring closure on these valves is weak and any material lodging within them will cause a leak. Disassemble the valve and remove any objects or build up.

Appendix C - Trouble Shooting

If there is variability in pump flow rate -

1. replace the pump tubing;
2. check that the tubing is fully submersed;
3. check that the header tank for constancy of level;
4. check drain is operating correctly – failure to drain completely will eventually lead to an overflow condition and an inaccurate determination of delivered mass. This will show up in the summary file as unrealistically small delivered volumes for the number of tips recorded.

Large differences in tips measured versus expected tips (i.e. greater than 50 out of 1000) -

1. check that the drain is operating correctly using Labview VI's "Open drain" and "Close drain";
2. check that the scale is correctly taring;
3. check that the drain valve is not leaking when 'closed' – the two masses recorded in the summary files are measured at the completion of the run and are taken 3 minutes apart. If the drain valve was leaking then the second mass value will be smaller than the first measured mass. Differences of greater that 1 gm probably indicate a significant leak and the data for that run should be discarded.

Program not responding -

1. most likely a failure to detect tips, so check the TBRG connections to the NI card
2. check the TBRG for reed switch operation using a multi-meter across terminals 25 and 33 of the DAQ card. When operating correctly the multimeter should show 5V when the reed switch is open and approximately,0V, briefly, when the reed switch closes.

Appendix D - Connections

With every gauge to be tested the outputs of the TBRG under test are connected to terminals 25 and 33 on the patch board of the 6025E DAQ card The order is not important since the signal is a switch closure.

The rest of the wiring should be permanently left in place. However for completeness, the PC RS232 comms ports are connected – com1 to the peristaltic pump, com 2 to the scales. The outputs of the 6025E DAQ card are: terminals 20 and 21 are connected together (drain relay voltage drive) and then to the relay positive controlling the weighing tray drain. Terminal 24 (ground) is connected to the relay ground.