SINCLAIR KNIGHT MERZ

SKM

Review of Flumegate^{TM} and Dethridge Meter Studies

REVIEW

- Final 2
- 17 May 2010

Review of Flumegate and Dethridge Meter Studies

REVIEW

- Final 2
- 17 May 2010

Sinclair Knight Merz
ABN 37 001 024 095
590 Orrong Road, Armadale 3143
PO Box 2500
Malvern VIC 3144 Australia
Tel: +61 3 9248 3100
Fax: +61 3 9500 1180
Web: www.skmconsulting.com

Contents

Document history and status

Revision	Date issued	Reviewed by	Approved by	Date approved	Revision type
Draft A	26/02/2010	S.Harding T. Ladson	S.Harding	26/02/2010	Initial draft sent to G-MW
Final	30/04/2010	S.Harding T. Ladson	S.Harding	30/04/2010	Final report sent to G-MW
Final 2	17/05/2010	S.Harding	S.Harding	17/05/2010	Minor edits made to final report.

Distribution of copies

Revision	Copy no	Quantity	Issued to
Draft A	1	1	Bill Heslop (G-MW)
Final	1	1	Garry Fyfe (G-MW)
Final 2	1	1	Garry Fyfe (G-MW)

Printed:	17 May 2010
Last saved:	17 May 2010 09:51 AM
File name:	I:\VWES\Projects\VW04891\Deliverables\Reports\R01ldl_meter_reviewc.docx
Author:	Lisa Lowe, Rory Nathan, Simon Lang and Rob Hyndman (Monash University)
Project manager:	Lisa Lowe
Name of organisation:	Goulburn-Murray Water
Name of project:	Review of Flumegate and Dethridge Meter Studies
Name of document:	Review
Document version:	Final (Version 2)
Project number:	VW04891

Executive Summary

Over the past several years Goulburn-Murray Water (G-MW) has undertaken a meter testing program to understand the accuracy of the meters used to measure the volume of water delivered to their customers. The testing program has focused on two types of meters, the Dethridge meter and FlumeGateM™. The purpose of this report is to provide a review of the reported meter accuracies resulting from the testing program with a view to better understand the average meter error across the entire GMID that is applicable to the 'use' term in a water balance of the whole GMID.

Dethridge Meter

A description of the meter testing program and the results for the Dethridge meter is presented in the following report prepared by HydroEnvironmental in 2009:

- In-situ Testing of Dethridge Meter Accuracy in the Goulburn-Murray Irrigation District. September 2009. Draft.

The conclusions drawn from this review of the HydroEnvironmental report and our analysis of the testing results presented by HydroEnviornmental are as follows:

- Since 2007, over 300 tests have been undertaken. The accuracies observed during these tests range from -32.6% to 5.77%.
- Factors such as the flow rate, bottom clearance, supply depth, tail water depth, the region and maintenance have an influence on the meter error.
- The meter accuracy presented by HydroEnvironmental (2009a) is calculated by averaging the results obtained for each test that represents a normal flow rate. This approach does not take into account the influence of factors such as the flow rate on the meter accuracy. Furthermore, the method may allow site specific factors that influence the meter accuracy of an individual Dethridge meter to have undue influence on the average meter error.
- The average meter error estimated using a mixed effects model, that takes into account the influence of various factors, is -8.42% and the range of the 95% confidence interval is -10.65% to -6.20%.
- The estimate of the average meter error is reduced if the design values for supply depth and clearance are adopted.
- The uncertainty surrounding the average meter error can be reduced by undertaking additional tests. In order to reduce the uncertainty in the estimates of the error to ±1% an additional 341 tests are required.
- Ideally the meters selected for testing and the conditions during the testing should be representative of the broader GMID. Due to drought there was a bias towards selecting meters

associated with high water users located on well operated channels. This bias may have resulted in a lower estimate of average meter error.

FlumeGateM™

A description of the testing undertaken and the accuracy estimates for the FlumeGate™ are presented in the following report prepared by HydroEnvironmental in 2009:

- In-situ Verification of FlumeGate™ Measurement Accuracy. August 2009b. Final.

The conclusions drawn from this review of the HydroEnvironmental report and our analysis of the testing results presented by HydroEnviornmental are as follows:

- Factors such as the flow rate, head loss and uncertainty associated with the testing method do not seem to influence the meter error.
- The meter accuracy presented by HydroEnvironmental (2009b) is calculated by averaging the results obtained for each test that represented normal flow rates. This approach does not account for site specific factors that influence the meter accuracy of an individual FlumeGate™ and which may have undue influence on the overall estimate of meter accuracy.
- The average meter error estimated from the results undertaken for each phase of the testing differed. If the results from all three phases of testing are combined the average meter error is estimated to be 1.5%. These estimates are based on individual meter errors that were generated by averaging the many estimates by Thiess for each flow rate at each meter and include the influence of any latency, that is any delay in sending data from the FlumeGate™ to the host where the data is time stamped.
- The range of the 95% confidence interval of the average meter error is ±2% when the results are combined from all three phases of testing.
- The uncertainty surrounding the average meter error can be reduced by undertaking additional tests. In order to reduce the uncertainty to ±1% an additional 62 tests are required.
- The simulation of the effect of latency at three sites suggests that the effect of latency is in the order of 1.8%. If these sites are representative of other sites, errors due to latency are likely to be small and may be in the order of -0.3%.
- Latency is not an issue for billing purposes. While this has an influence on the volume of water metered over an hour long period, the impact over the longer periods used to meter irrigation water use is negligible.

1. Introduction

Over the past several years Goulburn-Murray Water (G-MW) has undertaken a meter testing program to understand the accuracy of the meters used to measure the volume of water delivered to their customers. These measurements are used as the basis for billing customers, and also to provide G-MW with a better understanding of the total volume of water use within the delivery system and the delivery system efficiency.

The meter testing program has focused on two types of meters, the Dethridge Wheel and FlumeGateM^{TM}. A description of the testing undertaken and the results for each of these meters is presented in the following two reports prepared by HydroEnvironmental in 2009:

- In-situ Testing of Dethridge Meter Accuracy in the Goulburn-Murray Irrigation District. September 2009a. Draft; and,
- In-situ Verification of FlumeGate^{TM} Measurement Accuracy. August 2009b. Final.

The purpose of this report is to provide a review of the reported meter accuracies. In particular, this report addresses the following three points:

1) The ability to utilise the results to predict the average meter accuracy across the entire Goulburn Murray Irrigation District (GMID);
2) The number of additional tests required to improve the ability to predict the average meter error; and
3) The inherent accuracy of the methods used to complete the testing and possible improvements to the methods of data collection.

Meter error can vary considerably between meters. However, this review does not consider variation between individual meters or the compliance of individual meters with metering standards. This review focuses on the average meter error across the entire GMID that is applicable to the 'use' term in a water balance of the whole GMID.

The report is divided into two main sections. Chapter 2 covers the Dethridge meter, and the FlumeGateM^{TM} is considered in Chapter 3. Each chapter provides an introduction, background information and a section to address each of the three points above.

This review was undertaken by Sinclair Knight Merz and Professor Rob Hyndman, a Professor of Statistics at Monash University. Details of the involvement of Professor Rob Hyndman in the review are outlined in Appendix A.

2. Dethridge Meters

2.1. Introduction

A testing program to assess the accuracy of Dethridge Meters has been underway since 2007. The purpose of this chapter is to provide a review of the meter accuracies reported for the Dethridge Meter. In particular, this report addresses the following three points:

1) The ability to utilise the results to predict the average meter accuracy across the entire GMID (Section 2.3);
2) The number of additional tests required to improve the ability to predict the average meter error (Section 2.4); and,
3) The inherent accuracy of the methods used to complete the testing and possible improvements to the methods of data collection (Section 2.5).

The basis for this review is the following report prepared by HydroEnvironmental which provides a description of the testing undertaken and the results:

- In-situ Testing of Dethridge Meter Accuracy in the Goulburn-Murray Irrigation District. September 2009a. Draft.

The results from the Dethridge meter tests undertaken between 2007 and 2009 were presented in HydroEnvironmental (2009a) and are used as the base data for this review.

2.2. Background

Since 2007, close to 100 Dethridge meters across the six Irrigation Areas within the GMID have been tested to assess their accuracy. To undertake the testing, a portable in-situ measurement verification rig (IMVR) is installed near the Dethridge meter. The same volume of water is passed through the Dethridge meter and the IMVR over a 60 minute period. The meter error is calculated as the difference between the volume measured by the IMVR (actual volume, V_a) and the Dethridge meter (indicated volume, V_i) using the following equation.

$$Meter\ Error = \frac{(V_i - V_a)}{V_a} \times 100$$

- **Equation 1**

Using the equation above a positive meter error indicates that the Dethridge meter records more than the actual volume (as measured by the IMVR), and a negative meter error indicates that the Dethridge meter records less than the actual volume.

Within the GMID there are three different types of Dethridge meter in use:

- Small Dethridge Meter (SMO)
- Large (Standard) Dethridge Meter (LMO)
- Dethridge-Long Meter (DLMO)

Each type of Dethridge meter is designed to operate over a different range of flows. The Large Dethridge Meter (LMO) is the most common meter used in the GMID and to date the accuracy testing has predominantly been focused on these meters (HydroEnvironmental, 2009a). The minimum recommended flow rate of the LMO is 3 ML/day (HydroEnvironmental, 2009a). A total of 92 LMOs have been tested, along with 11 SMOs and 6 DLMOs.

There have been three periods of testing. In January 2007 ten meters were tested (HydroEnvironmental, 2007). Between September 2007 and February 2008 another 43 meters were tested (HydroEnvironmental, 2008). In 2009 the testing program included 42 meters (HydroEnvironmental, 2009a). Three meters were included in more than one of the testing periods. Approximately 300 tests were performed during these testing periods. There was a large scatter in the accuracy observed between tests and the accuracies ranged from -32.6% to 5.77%.

Two contractors were involved in the testing. All of the tests performed in 2007 and 2008 were undertaken by Thiess Services. In 2009, Thiess Services undertook testing in three of the GMID areas and AWMA Water Control Solutions undertook testing in the other three GMID areas. Both contractors used essentially the same procedures with a different IMVR. The IMVR used by each contractor was verified before the testing commenced. Details of the IMVR used and the verification processes are described in HydroEnvironmental (2009a).

Each meter was tested at three different flow rates. The first test undertaken for each meter was at a flow rate equivalent to that normally ordered by the customer. In practice the Dethridge meter is used to record deliveries over a range of flow rates for each customer. Additional tests were undertaken to check the accuracy over a range of possible flow rates.

A number of factors, other than the flow rate, may affect the accuracy of a Dethridge meter. During the testing the contractors recorded the following data:

- Tail water depth - a LMO Dethridge meter is considered to be drowned when the tailwater depth exceeds 180 mm.
- Supply depth – the LMO Dethridge meter is designed for a supply depth of 380 mm.
- Bottom clearance - the standard bottom clearance is 6 mm for the LMO.

HydroEnvironmental (2009a) also list a range of factors, in addition to the above, that may influence the accuracy. These factors relate to the installation of the Dethridge meter, damage to the meter, obstructions, upstream and downstream conditions and the effect of wind.

During testing the contractors recorded the number of rotations of the Dethridge Wheel and converted this to a flow rate by multiplying by a set volume for the particular meter type. In practice the number of rotations is measured and recorded by a pendant counter. The overall accuracy of a Dethridge meter is the combination of the meter error (as calculated by Equation 1) and the pendant counter error. In 2009 G-MW tested the accuracy of pendant counters (G-MW, 2009). Disused pendant counters were attached to a test rig and used to record a known number of rotations. The average error of the 288 pendant counters tested was -0.046% with a standard deviation of 0.4% (G-MW, 2009). An additional 13 tests were performed on new pendant counters. The new pendant counters were more accurate with an average error of -0.02% and a standard deviation of 0.08% (G-MW, 2009).

2.3. Assessment of Meter Accuracy

The results from the Dethridge meter tests undertaken between 2007 and 2009 were presented in HydroEnvironmental (2009a). The results are used in this review to address the first question listed in Section 2.1, that is, to estimate the overall accuracy of the measurements made by Dethridge meters. This should not be confused with the accuracy of an individual Dethridge meter. Rather, it is the average accuracy of the measurements made by the Dethridge meters that were tested. Some individual Dethridge meters will be more accurate that the average, while others will be less accurate. However, the average meter error is required to provide a better understanding of the overall water balance of the G-MW delivery system.

It should be noted that the analysis of the meter accuracy is limited to the LMO within this report. While there has been some testing of the SMO and the DLMO there is not enough information available to support a meaningful analysis.

In the GMID there are approximately 13,000 LMOs (HydroEnvironmental, 2009a). It is impractical to test each of these meters in order to calculate the average meter error. Rather, a sample of the meters is tested and the results used to infer the average error across the entire region. HydroEnvironmental (2009a) estimates accuracy of the Dethridge Meter by averaging the accuracy calculated for each of the individual tests. However, it is not sufficient to simply average the meter errors calculated for each of the individual tests. This is because the meter error observed for an individual meter is influenced not only by the underlying error associated with Dethridge meters, but also by other factors that may include:

- Flow rate.

- Tail water depth.
- Supply depth.
- Bottom clearance.
- Contractor engaged to undertake the testing.
- Other site specific factors.

During the testing each of these factors were recorded. One test per site was also based on the normal flow rate at the site and another factor is included to represent the tests that reflect the normal flow rate versus a higher or a lower flow rate.

The influence of these factors should be considered when estimating the average meter error. For example, the flow rate will influence the accuracy of the meter. If the average flow rate of the meters tested is greater (or less) than the average flow rate across the entire GMID then the test results will not be representative of the entire GMID. However, it is possible to take these factors into account in estimating the average meter error.

HydroEnvironmental (2009a) undertook some preliminary analysis of the effect of each factor on meter error. There was a lot of scatter in the plots of each factor against meter error. For example, Figure 8 from HydroEnvironmental (2009a) plots flow rate against meter error. In this figure there is a lot of scatter and HydroEnvironmental (2009a) conclude that the flow rate has very little influence on the meter error. However, much of the scatter is due to the differences between individual meters. When compared to other meters, an inaccurate meter will have a large meter error for all flow ranges, however at the individual gauge it may vary with the flow rate. Examination of the relationship between the flow rate and meter error at individual meters tells a different story. Of the 42 meters tested in 2009, 32 had the largest meter error for the lowest flow rate and 24 had the smallest meter error for the highest flow rate. These results demonstrate that there is likely to be a relationship between the meter error and the flow rate when other factors (such as individual meter effects) are taken into consideration. As such, it is important that the combined influence of these factors be considered in the analysis.

There are some factors that cannot be easily quantified that will influence the meter error at a particular test site. For example, a Dethridge Wheel may be damaged in some way and therefore have a large meter error. If this meter is tested several times it is likely to have a consistently high meter error. It is important that the affect of factors specific to a particular Dethridge meter do not have an undue influence on average meter error estimated for the GMID. This may occur if some meters are tested more often than others. Three tests were conducted at most of the 92 LMOs, however, up to ten tests were undertaken for some LMOs. If a poorly performing meter has been tested more often than an accurate meter this may bias the estimate of the average meter accuracy unless these random effects at individual test sites are accounted for in the analysis.

The meter accuracy presented by HydroEnvironmental (2009a) is calculated by averaging the results obtained for each test that best represents the normal flow at the meter. This approach does not take into account the influence of factors such as the flow rate on the meter accuracy. Furthermore, the method may allow site specific factors that influence the meter accuracy of an individual Dethridge meter to have undue influence on the results. An alternative approach that takes these factors into account is required and adopted for this review.

A mixed effects model is used here to estimate meter accuracy. This model predicts the meter error for an individual meter (m) and test (t) as a constant error adjusted to reflect the influence of a range of factors. There are three types of factors in the model and these are treated differently:

- *Categorical factors.* These include the influence of different testing contractors and a factor which indicates if the test represents the normal flow rate at the meter. The meter error is adjusted in the mixed effects model to represent each category. For example, a different adjustment may be required to represent tests undertaken within different regions by different contractors.
- *Numerical factors.* These include bottom clearance, supply depth, tail water depth and flow rate. The influences of numerical factors are accounted for by multiplying the value of the factor by a coefficient.
- *Random effects.* These represent factors that may influence the error at a particular meter (e.g. damage to the meter) or observed in a testing period and cannot easily be extrapolated to the rest of the GMID.

The model is represented by the equation below.

$$Error_{m,t} = \beta_0 + R_j + NFR_k + \beta_1 BC + \beta_2 SD + \beta_3 TWD + \beta_4 FR + e_m + e_y + \varepsilon_{m,t,y}$$

Equation 2

where:

$Error_{m,t}$ = Meter error (as a %) (m = meter, t = test)

β_0 = a constant value

R_j = Regions covered by different contractors (R_{Thiess} and R_{AWMA})

NFR_k = Indicates if the flow rate is the normal flow rate of the LMO (NFR_{yes} and NFR_{no})

BC = Bottom Clearance (in mm)

SD = Supply Depth (in mm)

TWD = Tailwater Depth (in mm)

FR = Flow Rate (in ML/day)

$\beta_{1,}\ \beta_{2,}\ \beta_{3,}\ \beta_4$ = Coefficients applied to the numerical factors

e_m = Represents the error associated with an individual meter

e_y = Represents the error associated with an individual year

$\varepsilon_{m,t,y}$ = Unexplained error

The values of the constant value assigned to each category of the categorical variables and the coefficients applied to the numerical variables in Equation 2 are selected to minimise the squared difference between the meter errors observed during the 299 tests reported by HydroEnvironmental (2009a),[1] and those estimated using the mixed effects model (Equation 2).

HydroEnvironmental (2009a) removed two test results from the analysis as they represented exceptional circumstances. These tests are also excluded in the current analysis. A large number of the tests represent conditions that differ from the design specifications. However, these tests were not removed from the analysis because these conditions may occur at other meters across the GMID. Therefore it is appropriate that these test results remain in the analysis.

Some of the factors included in Equation 2 may not influence the meter error. The influence of each factor included in Equation 2 on the overall meter error is tested using a statistical F-test. Essentially this test looks at how much the model is improved by including each individual factor. The inclusion of all factors in the model improved the predictions. It should be noted that the factor representing the contractor may be a surrogate for the GMID area tested given that the contractors tested in different areas.

The coefficient values selected for the terms in Equation 2 are presented in Table 1. These values were found to provide the best fit to the observed meter errors.

---

[1] In parts of their analysis, HydroEnvironmental (2009a) only consider the meter errors estimated when a meter is operating at its normal flow rate. In this current analysis the results from tests undertaken on all flow rates are considered.

- **Table 1 Results of the Linear Effects Model**

Factor		Adopted Value
Intercept	β_0	7.2090
Flow representative of normal flow rate (yes or no)	NFR_k - NFR_{yes}	-1.5240
	- NFR_{no}	0
Region - Thiess-Services	R_T	-1.4117
- AWMA	R_A	0
Bottom Clearance	β_1	-0.5806
Supply Depth	$\beta_{2,}$	-0.0139
Tail Water Depth	β_3	-0.0341
Flow Rate	β_4	0.5796

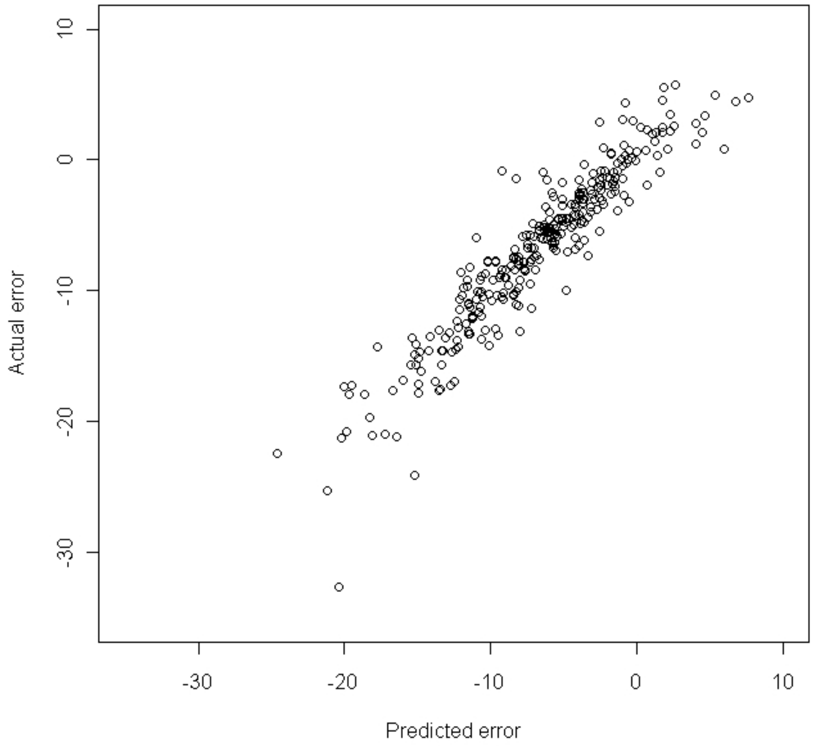
The meter error of an individual Dethridge meter included in the testing can be estimated using Equation 2 and the values given in Table 1. For example, consider the Dethridge meter MV 2037 that was tested in 2009 by Thiess Services. The clearance was 12 mm, the supply depth was 332.5 mm, the tailwater depth was 132.5 mm and the normal flow rate was 11.7 ML/day. The meter error is estimated as follows:

$$Error_{MV2032,1} = \beta_0 + R_T + NFR_{yes} + \beta_1 BC + \beta_2 SD + \beta_3 TWD + \beta_4 FR + (e_{MV02032} + e_{2009})$$

- **Equation 3**

$$= 7.2090 - 1.4117 - 1.5240 + (-0.5806 \times 12) + (-0.0139 \times 332.5) + (-0.03405 \times 132.5) + (0.5796 \times 11.7) + 1.8520$$

In the above calculations the background meter error bias associated with MV2037 in 2009 is equal to 1.8520. When the influence of the other factors is considered, the estimated error is -3.19%, compared to the observed error of -3.63%. The meter error predicted using Equation 2 is plotted against the observed meter error for each test in Figure 1.



- **Figure 1 Predicted versus Estimated Meter Error (%) for the Dethridge Wheel**

Equation 2 can be used to estimate the average meter error across the GMID. If it is assumed that the conditions observed during the tests are representative of the GMID than the average of each factor can be used in Equation 2. For example, the average bottom clearance observed in the tests is 8.66 mm. It is also assumed that all meters are operating at their normal flow rate and the contractor is Thiess-Services. Based on these values the average meter error is estimated to be -8.34%[2].

There is some uncertainty associated with the meter errors estimated using Equation 2. In Figure 1 the observed meter error for each test is compared to the meter error estimated using Equation 2. A confidence interval provides an indication of the range in which we expect the true average meter error to fall within. The width of the confidence interval is determined by the number of samples (or tests) and the magnitude of the variation not explained by the model. If we adopt the average factor values observed in the testing the 95% confidence interval associated with the meter error ranges from -10.54% to -6.05%[1].

---

[2] Note that this does not include the pendant counter error

The analysis presented so far in this section has been restricted to meter error which does not include the pendant counter meter uncertainty which is estimated to be -0.08%[3] for an LMO (G-MW, 2009). The overall average meter error is equal to -8.42% (= (-8.34%) + (-0.08%)). The uncertainty associated with the average error also increases to account for the uncertainty in the pendant counter error. This is estimated by combining the standard deviation associated with the average meter uncertainty (s_M) and the pendant counter uncertainty (s_{PC}) using the equation below:

$$s_T = \sqrt{(s_M)^2 + (s_{PC})^2}$$

- **Equation 4**

The 95% confidence interval associated with the combined meter error and pendant counter error ranges from -10.65% to -6.20%.

In the previous paragraphs it is assumed that the:

- Dethridge meters are operating at their normal flow rates and;
- Conditions at the tests sites are representative of the GMID (e.g. the average bottom clearance across the GMID is 8.66 mm).

The estimated average meter error and the associated uncertainty for three additional scenarios are presented in Table 2 below.

In Scenario 2 the design values for supply depth (380 mm) and clearance (6 mm) are adopted. The average meter error is estimated to be -6.24%. This is considerably lower than the meter error estimated for the average conditions observed at the test sites.

In Scenario 3 and 4 it is assumed that the meters are not operating at their normal flow rate. The estimated average meter error is lower than those estimated for the normal flow rate. For example, with the average operating conditions the meter error is -6.93% (compared to -8.42% for scenario 1) and under design conditions it is -4.83% (compared to -6.24% for scenario 2). In the first phase of testing the bottom clearance was adjusted and maintenance of the Dethridge meters tested was undertaken after the first test representing the normal flow rate (HydroEnvironmental, 2007). In subsequent testing phases some maintenance may have been undertaken after the third test at a site. The results of any tests undertaken after this maintenance have not been excluded from the analysis and this may account for the difference in the results observed for the normal flow rates and the other flow rates.

---

[3] The average pendant counter error for all types of Dethridge meters was equal to -0.046% (G-MW 2009).

- **Table 2 Average Total Error of Dethridge Wheels in the GMID**

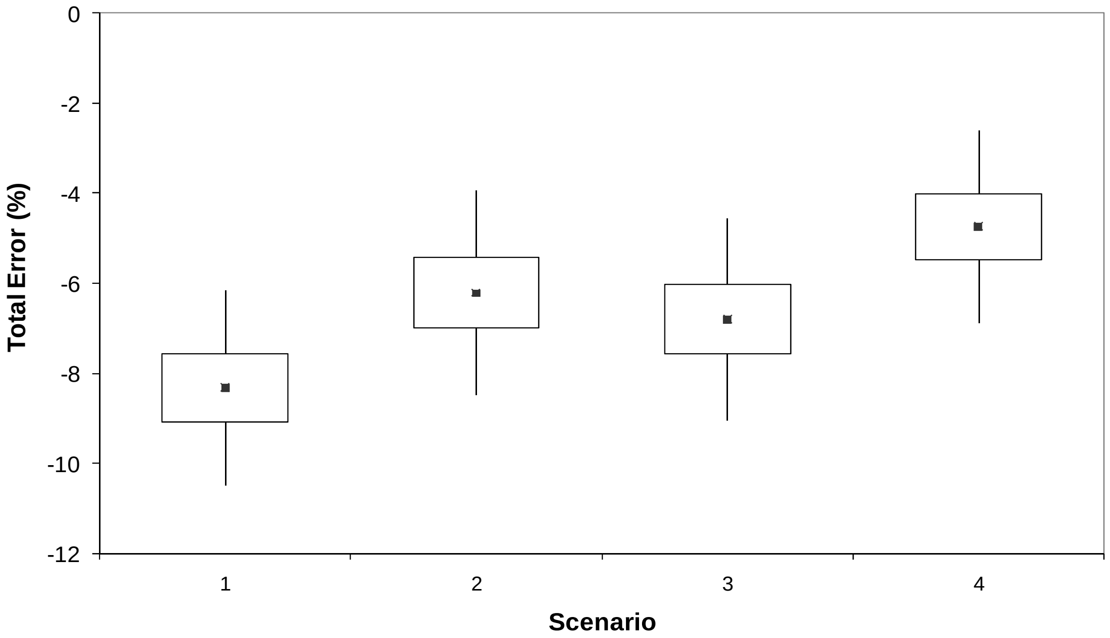
Scenario	Flow Rate*	Conditions	Average Total Error (%)	Lower 95% Confidence Interval	Higher 95% Confidence Interval
1	Normal flow rate	Average	-8.42	-10.65	-6.20
2	Normal flow rate	Design	-6.24	-8.51	-3.97
3	Other flow rates	Average	-6.93	-9.08	-4.78
4	Other flow rates	Design	-4.83	-6.94	-2.72

* The first test at each meter was undertaken at the normal flow rate at the site. Subsequent tests were undertaken to investigate the influence of varying flow rates. Some of the tests included in the other flow rates category reflect tests undertaken after the bottom clearance was adjusted and other maintenance performed at the meter.

The uncertainty associated with the estimated meter error for the four scenarios considered (as listed in Table 2) is illustrated using a box plot in Figure 2. This figure shows:

- The best estimate of average meter error as a square dot;
- The 50% confidence limit of the average meter error as an unfilled rectangle; and
- The 95% confidence limit of the average meter error as vertical lines.

For example, for the scenario based on the normal flow rate and the average conditions the best estimate of the average meter error is -8.42%. There is a 50% chance the average meter error is in the range from -9.09% to -7.58% and a 95% chance the average meter error is in the range from -10.65% to -6.20%.



- Figure 2 Box plots showing the expected range of the average error associated with a Dethridge Meter.

2.4. Additional Insitu Tests

In Section 2.3 the average meter error associated with the Dethridge meter was estimated to be -8.42% with an associated 95% confidence interval ranges from -10.65% to -6.20%. The accuracy of the average meter error is related to the number of meter tests undertaken and the variation observed in the meter errors.

As noted earlier, it is impractical to test each Dethridge meter to calculate the average meter error and so the results from a sample of meters are used to estimate the average meter error across the entire region. There are approximately 13,000 LMO in the GMID. If only a handful of meters were tested the observed average meter error would be less representative of the entire GMID than if, say, 95% of meters were tested. The selection of the number of meters to be tested is a trade-off between the accuracy of the estimate and the practicality and cost associated with the testing.

The number of samples (or tests) required to achieve a desired level of accuracy depends on the variation observed in the sample taken. If the observed meter error was highly consistent for each meter tested, then a smaller sample is required than if there is a lot of variation in the observed meter error.

The results are used in this review to address the second question listed in Section 2.1, that is, how many additional tests are required to improve the accuracy of the predicted average meter error. A trade-off between the accuracy that is acceptable and the practicality of undertaking additional tests is required. The number of tests required to achieve a desired accuracy is presented in this section.

The accuracy is represented as half the width of the 95% confidence interval. For example, the half width of the 95% confidence interval in Section 2.3 is ±2.22% for Scenario 1. As the accuracy is inversely proportional to the square root of the number of samples, the first estimate of the number of tests required to reach a desired accuracy can be calculated using the following equation:

$$\sqrt{\frac{n'_r}{n_e}} = \frac{\omega_e}{\omega_r}$$

- **Equation 5**

where:

n'_r = an initial estimate of the number of required tests

n_e = the number of tests already taken

ω_r = the required level of accuracy (the half width of the 95% confidence interval)

ω_e = the existing level of accuracy (the half width of the 95% confidence interval)

Equation 5 can be rearranged to give the equation below:

$$n'_r = n_e \left(\frac{\omega_e}{\omega_r}\right)^2$$

- **Equation 6**

The number of required tests estimated from Equation 6 does not consider the total number of Dethridge meters across the GMID (N). The total number of tests required (n_r) is estimated using the following equation:

$$n_r = \frac{n'_r}{1 + \left(\frac{n'_r}{N}\right)}$$

- **Equation 7**

To date there have been 90 tests undertaken that represent normal flows ($n_e = 90$), the level of accuracy is ±2.22% ($\omega_r = 2.22$) and there are approximately 13,000 Dethridge meters in the GMID ($N = 13{,}000$). Using Equation 6 and Equation 7 the number of additional tests required to achieve an accuracy of ±1% is 341 (Table 3). The number of additional tests required to obtain various required accuracies are presented in Table 3.

- **Table 3 Additional tests required to improve the accuracy estimates of the Dethridge Wheel error**

Required Accuracy (%)	Sample Size	Additional Samples
0.5	1,567	1,477
1.0	431	341
1.5	195	105
2.0	110	20

2.5. Data Collection Method

This section addresses the third question listed in Section 2.1, that is, to consider the inherent accuracy of the methods used to complete the testing and recommend possible improvements to the methods of data collection. Throughout the discussion below, the following aspects of this question are considered:

- Are the meters selected for testing representative of conditions across the GMID?
- Is the testing procedure adequate?
- Are the conditions during testing likely to be representative of conditions across the GMID?
- Have conditions changed between testing periods?

In discussing each of these questions the review also considers approaches to reduce the uncertainty surrounding the average meter error.

Selection of meters for testing

The Dethridge meters selected for testing should be representative of the conditions across the GMID. A range of factors may influence meter error (as demonstrated in Section 2.3) and ideally the meters tested should be representative of factors including the range of flow rates, bottom clearances and the supply and tailwater depths. However, there are a number of practical considerations that limit the selection of meters for testing and these may influence the results.

The selection of meters for testing is constrained during drought. Only meters in operation during the testing period can be considered. As such, a higher proportion of high water users (that have a higher flow rate) than is typical across the GMID were selected. The testing was also associated with meters located on the better maintained channels and that have good command. As a result of this bias the results presented may be more accurate than the average conditions across the GMID.

The Dethridge meters tested may not be representative of the other factors that influence the average meter error (such as supply depth). In Section 2.3 the average meter error was estimated for the average conditions observed during the tests and also for the design settings. The results indicated a change in the average meter error when these conditions were altered. Rather than select Dethridge meters that are representative of the GMID it may be more practical to adjust the average meter estimates using the mixed effects model. Some effort will be required to ascertain the average conditions across the GMID. Where information is not already collected by G-MW a survey may be required. However, the effort required to collect this information may be less than needed to undertake testing of a representative sample of Dethridge Wheels.

Maintenance also affects the model accuracy. G-MW has a maintenance program in place across most of the GMID and over the past five years has undertaken additional maintenance measures. During maintenance the side and bottom tolerances may be reset and this can improve the accuracy of the meter. In 2009 HydroEnvironmental noted the Dethridge meters that had undergone maintenance. The difference between the meter error at maintained and unmaintained meters was assessed (but did not consider the influence of any other factors) and HydroEnvironmental (2009a) suggest that maintenance may reduce the error by approximately 3%. The percentage of meters included in the testing that have undergone maintenance may not be representative of the wider GMID and this may bias the results. It is recommended that a rating of the degree of maintenance be recorded as part of any future testing. The rating could be included as an additional factor in the mixed effects model and may help reduce the unexplained scatter in model error results (and therefore reduce the uncertainty associated with meter error). The average meter error could also be estimated using the average condition of meters across the GMID. The average rating of conditions could be determined by examining a sample of Dethridge meters, by collecting this information as part of the maintenance program, or based on the experience of G-MW staff.

In Section 2.3 the meter error was combined with the pendant counter error. In the study of pendant counter error undertaken by G-MW, the pendant counters were obtained from disused Dethridge meters. A small sample of 13 new pendant counters were also tested and found to have a smaller error. Therefore it is possible that the pendant counter error adopted in this analysis is an overestimate of the pendant counter error in the field. However, the pendant counter error is small in comparison to the meter error and further testing should not be a high priority.

Testing Procedure

The CRC for Irrigation Futures undertook a review of the measured in-situ verification of meters for non-urban water supply (Cape et al., 2008). They conclude that the only viable method to test open channel methods is the pump-around system. This is the approach adopted by G-MW. A certification process was used to assess the accuracy of the in-situ measurement verification rigs (IMVRs) used in the analysis. No recommendations are made regarding the overall approach or accuracy of the IMVRs.

The meter accuracy of the IMVR is expected to decrease if the rig operates outside of the recommended range. The magnitude of the recommended range is provided in HydroEnvironmental (2009a). The flow rates applied in each test were inspected and found to fall within the recommended range.

Testing Conditions

Ideally the conditions during testing should be representative of the conditions across the GMID. A number of conditions during testing may not be representative of the general conditions, and these include the tail water conditions and maintenance of the meters.

The testing procedure requires a coffer dam to be constructed downstream of the outlet. This affects the downstream tail water conditions which may not be reflective of field conditions across the GMID. As the tail water depth affects the meter accuracy (as shown in Section 2.3) these conditions may bias the results.

Maintenance activities took place as part of the testing procedure. In Phase I of the testing the bottom clearance of the Dethridge Wheel was adjusted to 15 mm for the second test and to 6 mm for the third test (HydroEnvironmental 2007). Maintenance was also undertaken prior to the third test and may bias the results. In subsequent testing periods maintenance was performed at some sites only after the third test was complete. In any future testing phases it is recommended that a subjective rating of the conditions at the meter be made.

Furthermore, the testing does not represent all conditions that take place across the GMID. For example, the lowest flow rates that occur in practice are not represented in the testing.

Differences between Testing Periods

The average meter error reported by HydroEnvironmental (2009a) varied between years. In 2007 the average meter error is reported as -11.68%, in 2008 it is -7.15% and in 2009 it is -4.84%. Some of the variation observed may be explained by differences in conditions at the meters tested each year. For example, the average tested flow rate varies between the years and may influence the meter accuracy.

The annual meter errors reported in HydroEnvironmental (2009a) were based on all tests undertaken during the year, that is, it included both the first test undertaken at each site that represents the normal flow rate and also all subsequent tests undertaken at high and low flow rates. In Section 2.3 the average meter error was found to differ between the first and subsequent tests. If only the tests that are undertaken at the normal flow rate are considered, the average meter error is -11.6% in 2007, -5.7% in 2008 and -6.8% in 2009. This indicates that the variability observed between years may be influenced by a range of different factors.

Since 2007 significant modernisation works have been completed in the GMID, resulting in upstream water levels being controlled by automation works, thus reducing variability in the testing regime by providing a steadier upstream water level. In addition, in the 2009 testing a larger proportion of the meters tested was located on channels with good control and this may bias the results. This degree of variability in the upstream water levels was not reported by HydroEnvironmental (2009a) and was not considered in estimating the average meter error in Section 2.3. However, this bias may have resulted in a more accurate result.

Maintenance also affects the meter accuracy. If the percentage of well maintained meters varies between the testing periods the average meter accuracy may also vary. As HydroEnvironmental (2009a) does not indicate how well maintained each meter is prior to testing it is not possible to assess the extent to which this may influence changes in the average meter accuracy reported between years.

It is also possible that there may be some subtle differences in the methods applied between years, but there is no indication that this is the case. It is recommended that G-MW note any differences in the methods adopted in the testing and also differences in the characteristics of the samples selected for testing. This information may help explain differences in the meter error observed for different testing periods.

2.6. Conclusions

Since 2007, close to 100 meters have been tested to assess the accuracy of Dethridge meters across the six irrigation areas in the GMID. The conclusions drawn from this review are as follows:

- Factors such as the flow rate, bottom clearance, supply depth, tail water depth, the region and maintenance have an influence on the meter error.
- The meter accuracy presented by HydroEnvironmental (2009a) is calculated by averaging the results obtained for each test that represented normal flow rates. This approach does not take into account the influence of factors such as the flow rate on the meter accuracy. Furthermore, the method may allow site specific factors that influence the meter accuracy of an individual Dethridge meter to have undue influence on the results.
- A mixed effects model was used to calculate the average meter error that takes into account the influence of various factors.
- The average meter error is estimated to be -8.42% and the range of the 95% confidence interval is -10.65% to -6.20%.
- The estimate of the average meter error is reduced if the design values for supply depth and clearance are adopted.

- The uncertainty surrounding the average meter error can be reduced by undertaking additional tests. In order to reduce the uncertainty to ±1% an additional 341 tests are required.
- Ideally the meters selected for testing and the conditions during the testing should be representative of the broader GMID. Due to drought there was a bias towards selecting meters associated with high water users located on well operated channels. This bias may have resulted in a more accurate result.

3. Flumegate^{TM}

3.1. Introduction

The purpose of this chapter is to provide a review of the meter accuracies reported for the FlumeGateM^{TM}. In particular, this report addresses the following three points:

1) The ability to utilise the results to predict the average meter accuracy across the entire Goulburn Murray Irrigation District (GMID);
2) The number of additional tests required to improve the ability to predict the average meter error; and
3) The inherent accuracy of the methods used to complete the testing and possible improvements to the methods of data collection. This review also considers the influence of the method used to record the flow rate of the FlumeGateM^{TM} at a host site rather than at the FlumeGateM^{TM} on the accuracy of the FlumeGateM^{TM}.

The basis for this review is the following reports which provide a description of the testing undertaken and the results:

- HydroEnvironmental. In-situ Verification of FlumeGate^{TM} Measurement Accuracy. August 2009b. Final.
- Thiess Services. Insitu Flow Verification Report for FlumeGate^{TM}. June 2009.

The results from the tests were presented in HydroEnvironmental (2009b) and are used as the base data for this review.

3.2. Background

A number of Dethridge meters in the Central Goulburn Irrigation Area have been replaced with the FlumeGateM^{TM} manufactured by Rubicon Systems. The FlumeGateM^{TM} is both a control and measurement device, which is operated remotely. The device uses ultrasonic sensors to measure water levels either side of the FlumeGateM^{TM}, position sensors to measure the location of the gate tip and an algorithm to calculate flow rates from the sensor information (Hydro Environmental, 2009b).

Since 2007, G-MW has used Thiess Services' Remote Electronic Verification System (REVS) to test the accuracy of 17 FlumeGateM^{TM}. The testing has been done in three distinct phases:

- Phase I (February 2007);
- Phase II (September – December 2007); and

- Phase III (November – December 2008).

Of the 17 FlumeGateM™ tested, one was the 1485-620 FlumeGateM™, 14 were the 1050-674 FlumeGateM™ and two were the 626-620 FlumeGateM™. The recommended minimum flow for accurate measurement through these devices is 5 ML/d, 4 ML/d and 3 ML/d respectively. In addition, accurate measurement cannot be guaranteed if headloss across the FlumeGateM™ is less than 40 mm (Hydro Environmental, 2009b).

Twenty five separate test events were conducted at the 17 FlumeGateM™ selected. Within each test event, the FlumeGateM™ accuracy was measured at a number of flow rates, resulting in 77 flow rate tests. Of these 77 tests, 20 were removed from the accuracy assessments performed by Hydro Environmental (2009b) and Thiess Services (2009) because the flow rate was below the minimum recommended for accurate measurement.

The methods used to test the accuracy of the FlumeGateM™ are summarised by HydroEnvironmental (2009b) and Thiess Services (2009). The methods are similar to those used to test the accuracy of Dethridge meters.

The major difference between the FlumeGateM™ and Dethridge meter tests is the influence of latency in the flow rate and volume recorded by FlumeGateM™ and REVS. To summarise:

- Information on flow rates collected at the FlumeGateM™ is sent to a host where it is time stamped.
- Data may be sent from the FlumeGateM™ to the host based on either a time increment or a volume increment. That is, the host may request data from the FlumeGateM™ on a regular time interval (such as 1 minute or 1 hour) or the FlumeGateM™ may send data to the host once it has measured a certain volume of water (e.g. 0.1 ML/d).
- When the telecommunications system is overloaded there may be some delay in sending information between the FlumeGateM™ and the host. As a result there may be a difference between the time of the flow measurement taken at the FlumeGateM™ and the time stamp given to the data at the host.
- The timing of this latency is random.
- During Phase I testing, Rubicon placed the FlumeGateM™ in system identification mode. Under this configuration information was sent to the host at a one minute time interval and once an additional 0.1 ML/d was metered.
- During Phase II and III of the testing G-MW configured the FlumeGateM™. It is possible to configure each FlumeGateM™ separately, and therefore the polling frequency may vary from site to site.

- Latency is not an issue for billing purposes because billing is based on metering over a long time period. However, latency is an issue for testing meter accuracy because it is important that the start and end time of testing is synchronised between the FlumeGateM^{TM} and Thiess' REVS unit.

In an attempt to overcome this issue of latency, Thiess compared the percentage difference in flow volume recorded by the FlumeGateM^{TM} and REVS assuming a number of different, but equally likely, start and end times. Consequently, from the 57 different flow rate tests, 178 estimates of measurement accuracy were made.

3.3. Assessment of Meter Accuracy

The meter test results are used in this review to address the first question listed in Section 3.1, that is, to estimate the overall accuracy of the measurements made by FlumeGateM^{TM}. The analysis undertaken below is based on the results presented in HydroEnvironmental (2009b). To give a single observation of meter accuracy at each flow rate for this analysis, the many estimates of meter error made by Thiess for each flow rate (to overcome latency issues) were averaged prior to fitting the model. The issue of latency is addressed in Section 3.5.

It is impractical to test every FlumeGateM^{TM} in order to calculate the average meter error. Rather, a sample of the meters is tested and the results used to infer the average error across the entire region. HydroEnvironmental (2009b) calculate the overall meter accuracy based on the average of all individual tests.

However, it is not sufficient to simply average the meter errors calculated for each of the individual tests. This is because the meter error observed for an individual meter is influenced not only by the underlying error associated with the FlumeGateM^{TM}, but also by other factors that may include:

- Flow rate
- Head loss over the FlumeGateM^{TM}
- Uncertainty in REVS measurement
- Site specific factors

During the testing each of these factors were recorded. The influence of these factors should be considered when estimating the average meter error.

A mixed effects model is used to describe the accuracy of the FlumeGateM^{TM}. This model predicts the meter error for an individual meter (m) and test (t) as a constant error adjusted to reflect the influence of a range of factors. There are three types of factors in the model and these are treated differently:

- *Categorical factors.* The only categorical factor is the testing phase. The meter error is adjusted in the mixed effects model to represent each phase of the testing. For example, a different adjustment may be required to represent tests in Phase I compared to Phase II or Phase III.
- *Numerical factors.* These include head loss, uncertainty in REVS measurement, and flow rate. The influences of numerical factors are accounted for by multiplying the value of the factor by a coefficient.
- *Random effects.* These represent factors that may influence the error at a particular meter or observed in a testing period, but that cannot easily be extrapolated to other FlumeGatesM™ in the GMID.

The model is represented by the equation below.

$$Error_{m,t} = \beta_0 + P_j + \beta_1 HL + \beta_2 REVS + \beta_3 FR + e_m + \varepsilon_{m,t,y}$$

Equation 8

where:

$Error_{m,t}$ = Meter error (%) (m = meter, t = test)

β_0 = a constant value

P_j = Phase (P1, P2 or P3)

HL = Head Loss over FlumeGateM™ (in mm)

$REVS$ = Uncertainty in REVS measurement (in %)

FR = Flow Rate (in ML/day)

$\beta_1, \beta_2, \beta_3$ = Coefficients applied to the numerical factors

e_m = Represents the error associated with an individual meter

$\varepsilon_{m,t,y}$ = Error associated with the individual measurement at the meter

The value of the constant, the value assigned to each category of the categorical variables and the coefficients applied to the numerical variables in Equation 8 are selected to minimise the squared difference between the meter errors observed during the 57 different flow rate tests reported by HydroEnvironmental (2009b) and those estimated using the model.

Some of the factors included in Equation 8 may not influence the meter error. The influence of each factor included in Equation 8 on the overall meter error is tested using a statistical F-test. The ability to predict meter error did not improve when the head loss, uncertainty in REVS measurements or flow rate was included in the model. The model was adjusted to exclude these factors:

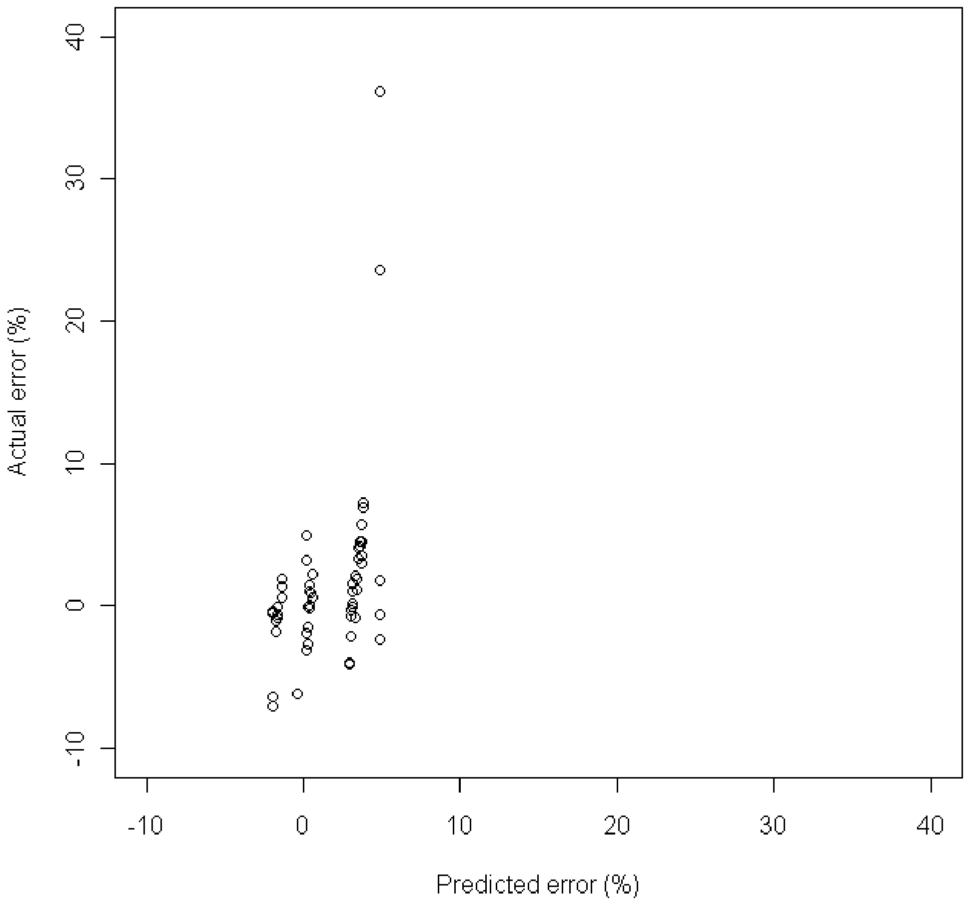
$$Error_{m,t} = \beta_0 + P_j + e_m + \varepsilon_{m,t,y}$$

- **Equation 9**

The coefficient values selected for the terms in Equation 9 are presented in Table 4. These values were found to provide the best fit to the observed meter errors. The meter error predicted using Equation 9 is plotted against the observed meter error for each test in Figure 3. There are two tests in Figure 3 where the actual error is much greater than the predicted error. These tests were undertaken at RN174 in Phase III of the testing. HydroEnvironmental (2009b) indicates that the metering error is due to upstream water level errors. The estimated average meter error for each phase of the testing is presented in Table 5 below.

- **Table 4 Results of the Linear Effects Model for the FlumeGateM™**

Factor		Adopted Value
Intercept	β_0	0.004315
Testing Phase	$P1$	0
	$P2$	-0.022195
	$P3$	0.031063



- **Figure 3 Predicted versus Estimated Meter Error (%) for the FlumeGateM^{TM}**

The model was further adjusted to allow an estimate of the meter error resulting from the combination of all phases of testing to be estimated:

$$Error_{m,t} = \beta_0 + e_m + \varepsilon_{m,t,y}$$

- **Equation 10**

The estimated average meter error for the combined results from all phases of testing is also presented in Table 5 below.

There is some uncertainty associated with the meter errors estimated using Equation 9 and 10. A confidence interval provides an indication of the range within which we expect the true average meter error to fall. The width of the confidence interval is determined by the number of samples (or tests) and the magnitude of the variation not explained by the model. The 95% confidence interval associated with the meter error ranges for each phase of testing is also reported in Table 5.

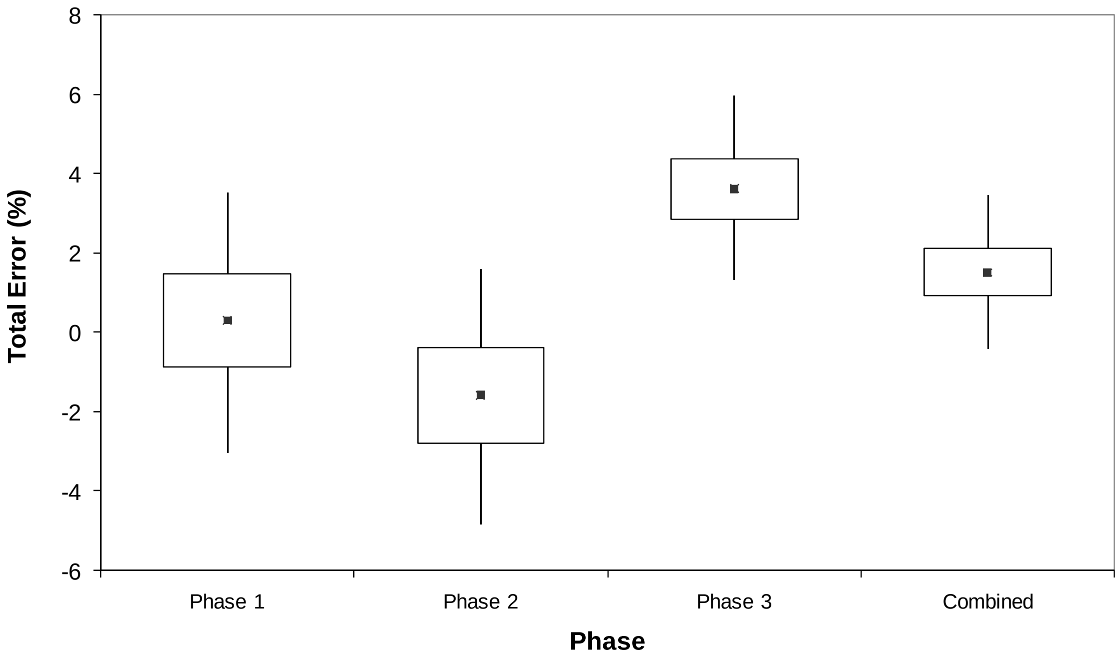
- **Table 5 Average Total Error of FlumeGateM^{TM}**

Phase	Average Total Error (%)	Lower 95% Confidence Interval	Higher 95% Confidence Interval
1	0.30	-3.03	3.53
2	-1.58	-4.83	1.59
3	3.63	1.33	5.96
Combined	1.51	-0.42	3.45

From Table 5, it is apparent that the predicted meter accuracy is dependent on the testing phase. This is demonstrated by Figure 4, which shows for each phase:

- The best estimate of average meter error as a square dot;
- The 50% confidence limit of the average meter error as an unfilled rectangle; and
- The 95% confidence limit of the average meter error as vertical lines.

For example, for Phase I the best estimate of the average meter error is 0.3%. There is a 50% chance the average meter error is in the range from -0.86% to 1.47% and a 95% chance the average meter error is in the range from -3.03% to 3.53%. In contrast, for Phase III the best estimate of the average meter error is 3.63%. There is a 50% chance the average meter error is in the range 2.85% to 4.37% and a 95% chance the average meter error is in the range from 1.33% to 5.96%. The range of the 95% confidence interval of the average meter error estimated for Phase I and Phase II of the testing is approximately ±3%, and ±2.3% for Phase III. When the three phases of testing are combined the range of the 95% confidence interval is ±2%.



- **Figure 4 Box plots showing the expected range of the average error associated with a FlumeGateM^{TM}.**

As stated above, the results presented are based on the average of the many estimates of meter error made by Thiess for each flow rate and include any uncertainty due to latency effects. The effect of latency is addressed in Section 3.5.

3.4. Additional Insitu Tests

To date, 17 of the 143 FlumeGatesM^{TM} in the GMID have been tested. The number of samples (or tests) required to achieve a desired level of accuracy depends on the variation observed in the sample taken. If the observed meter error was highly consistent for each meter tested then a smaller sample is required than if there is a lot of variation in the observed meter errors.

The results are used in this review to address the second question listed in Section 3.1, that is, how many additional tests are required to improve the accuracy of the predicted average meter error. A trade-off between the accuracy that is acceptable and the practicality of undertaking additional tests is required. The number of tests required to achieve a desired accuracy is presented in this section.

The accuracy is represented as half the width of the 95% confidence interval. As the accuracy is inversely proportional to the square root of the number of samples, the first estimate of the number of tests required to reach a desired accuracy can be calculated using the following equation:

$$\sqrt{\frac{n'_r}{n_e}} = \frac{\omega_e}{\omega_r}$$

- **Equation 11**

where:

n'_r = an initial estimate of the number of required tests

n_e = the number of tests already taken

ω_r = the required level of accuracy (the half width of the 95% confidence interval)

ω_e = the existing level of accuracy (the half width of the 95% confidence interval)

Equation 11 can be rearranged to give the equation below:

$$n'_r = n_e \left(\frac{\omega_e}{\omega_r}\right)^2$$

- **Equation 12**

The number of required tests estimated from Equation 12 does not consider the total number of Dethridge meters across the GMID (N). The total number of tests required (n_r) is estimated using the following equation:

$$n_r = \frac{n'_r}{1 + \left(\frac{n'_r}{N}\right)}$$

- **Equation 13**

Using Equation 12 and Equation 13 the number of additional tests required to obtain various required accuracies was estimated (Table 6). Each phase of the testing was considered separately and the analysis was based on the accuracy of the meter errors estimated in the previous section. The number of additional tests required to achieve a required accuracy of ±1% are similar when estimated using the results from Phase I and Phase II of the testing, that is, approximately 60 additional tests are required. Based on the results from Phase III or the combination of the three phases, fewer additional tests are required to meet a required accuracy.

- **Table 6 Additional tests required to improve the accuracy estimates of the FlumeGateM^{TM}**

Required Accuracy (%)	Phase 1		Phase 2		Phase 3		Combined	
	Sample Size	Additional Samples	Sample Size	Additional Samples	Sample Size	Additional Samples	Sample Size	Additional Samples
0.5	120	103	119	102	103	86	120	69
1.0	80	63	79	62	56	39	82	31
1.5	52	35	50	33	31	14	53	2
2.0	35	18	34	17	20	3	36	0

3.5. Data Collection Method

This section addresses the third question listed in Section 3.1, that is, to consider the inherent accuracy of the methods used to complete the testing and recommend possible improvements to the methods of data collection.

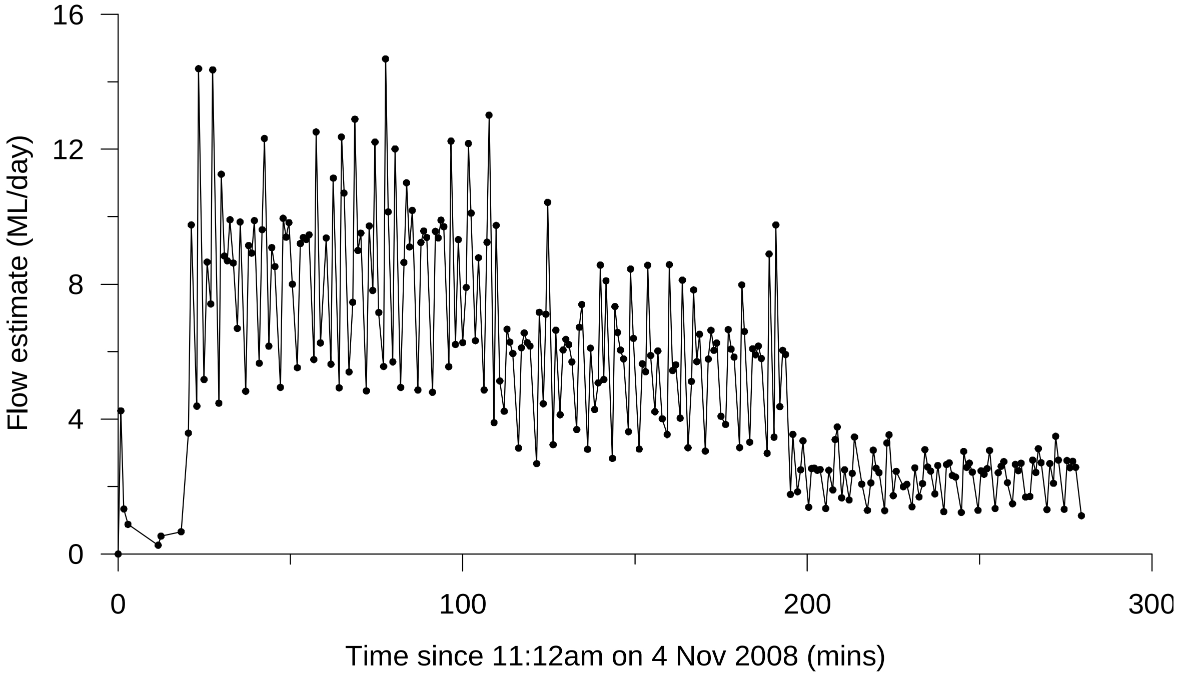
In an attempt to overcome this issue of latency, Thiess compared the percentage difference in flow volume recorded by the FlumeGateM^{TM} and REVS assuming a number of different, but equally likely, start and end times. The spreadsheets used to undertake these calculations were provided by Thiess Services for review. The process adopted by Thiess to assess the meter accuracy is acceptable and independent checks also demonstrated a variation in the accuracies as the assumed start and end time of the test are varied. The range in the accuracies estimated for each meter provides an indication of the influence of latency.

The remainder of this section assesses the effect of variability in latency on flow measurements in more detail.

3.5.1. Nature of the Issue

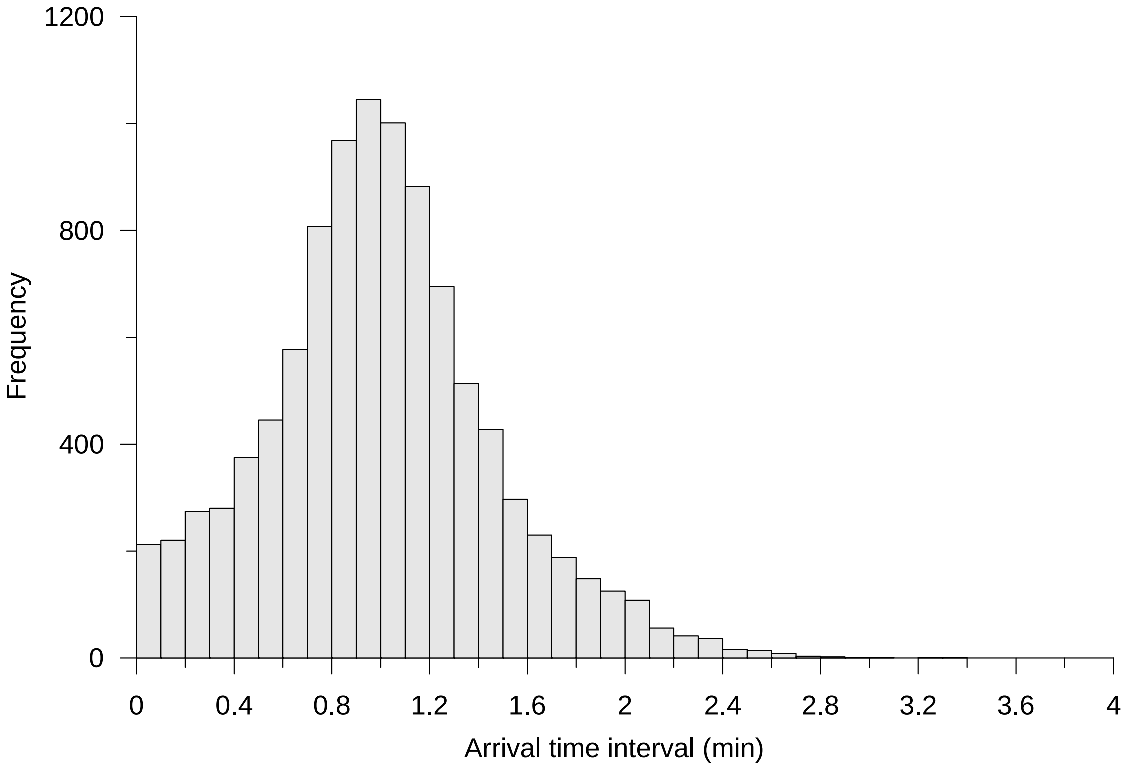
Flow rate through the FlumeGateM^{TM} is computed by calculating the differences in volume of water passing through the meter over a given time period. Data on flow volume is sent via telemetry to a base station, and the time that the volume data is received by the logger is recorded. The remote telemetry unit (RTU) used to transmit the volume data employs a store and forward messaging system which means messages can follow various paths through the network of RTUs that make up the channel control system. This means message propagation times are varied and message arrivals could well be out of order and delayed depending on what queues and buffers were doing en-route. The result is that it is not possible to rely on message arrival time to infer when a message was sent, or when a piece of data in its payload was collected. At best the information will be delayed by a few seconds, but depending on communications timeout parameters, it could be minutes, or even not arrive at all, if message packets get dropped because of communications errors.

The consequence of the variable time delay, or latency, in this configuration is that it confounds the estimation of flow rate. By way of illustration, if a given volume of water passes through the FlumeGateM™ over a one minute period, but due to time delays it is recorded as being observed over a two minute period, then the estimate of the flow rate is half the actual. The converse is obviously true: if because of previous delays the time interval between the arrival of volume data is less than one minute, then the estimated flow is greater than actual. The effect of this variable latency on flow estimates is illustrated in Figure 5, which shows the three flow rates tested at the site, but from which it is seen that the flows appear to fluctuate markedly from one time interval to the next. If the transmission is triggered by a change of state event (eg every n buckets) a high variability in apparent arrival times may be observed because transmission is variable. This will be apparent if the inter-sample volume changes are a constant, which were not observed for this example.



- **Figure 5 Example variation in flow estimates over time intervals recorded by data logger for flume gate at outlet RN 91.**

The distribution of arrival times is zero-bounded and skewed. Figure 6 below illustrates the distribution of arrival times based on the above data set. It is seen that while the average arrival time (1 minute) is the same as the intervals at which the data is assumed to be sent, there is a thick tail within which the flow estimates are higher than actual, and a thin (unbounded) tail where the flow estimates would be less than actual. The skewed nature of the distribution would suggest that any flow estimate will be biased in some manner, but clearly the longer the time interval over which the volumes are computed the smaller the confounding influence of latency. The manner in which latency impacts on flow estimates is explored in the following section.



- **Figure 6 Example distribution of arrival time intervals for messages sent from outlet RN 91 recorded in November 2008.**

3.5.2. Nature of Latency Bias

The manner in which variable system latency impacts on the flow estimate is dependent on the time interval over which the computations are made. The easiest way of exploring the nature of the associated bias is by numerical simulation. To this end, a simple Monte Carlo model was developed using data obtained from the flow tests.

The simulation model simply involved:

- Sending a data packet every one minute representing a fixed continuous flow of 7.2 ML/day
- Allowance for a stochastic propagation time based on a distribution of arrival times (as shown in Figure 6)
- Computation of flows based on arrival times over different accumulated periods.

The arrival times are not serially correlated and thus the times were generated independently using a normal distribution, where the skewness was handled by use of a Box Cox transformation. Just under 5% of messages arrived out of time sequence (eg a message arrived after a subsequent message had already arrived). A stochastic series of propagation times was generated for a seven day period (10,000 minutes), where flow estimates were computed for non-overlapping sequences of 10, 30, 60, 180, and 360 packets of data. Given that the average arrival time of this information is 1 minute, these sequences represent flow estimates computed for time periods of 10 minutes, 30 minutes, 1 hour, 3 hours, and 6 hours, over the seven day period.

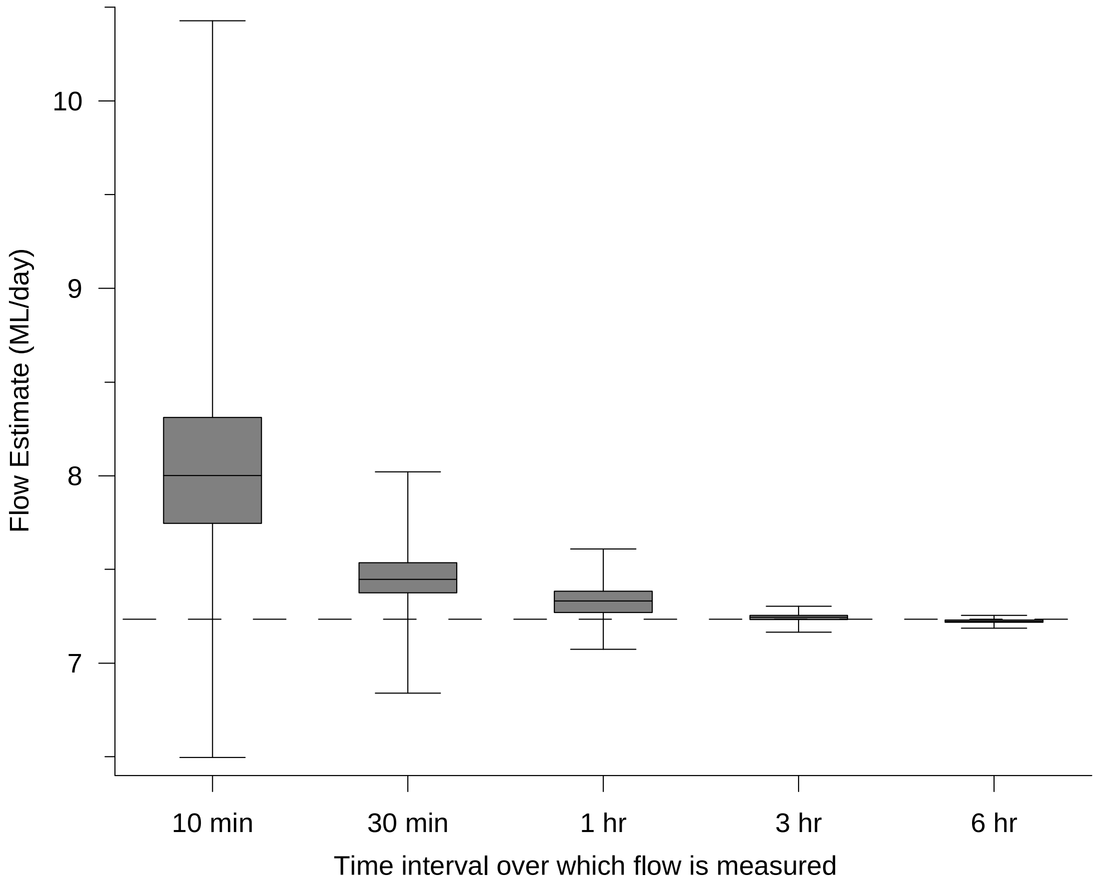
The results of this simulation are shown in Figure 7. It is clearly seen that the degree of bias decreases with the increasing period over which the flow estimates are computed. This is not surprising as errors in the arrival time of a few minutes become progressively less important as the period of interest lengthens. However, the skewed and zero-bounded nature of the propagation times yields a significant positive bias, and this is evident even when the flow estimates are computed for a one hour period. The degree of bias is summarised in Table 7.

The results shown in Table 7 show that variability in system latency causes the flow estimates to be over-estimated. The notional duration of the flow tests undertaken by Thiess was one hour, and thus the degree of over-estimation would be between 1% and 1.8%. The degree of bias may vary with the amount of traffic in the network, and may also vary somewhat with location and time of the test. This analysis was applied to additional sites (outlets RN174 and RN180) and a similar pattern to that summarised in Table 7 and Figure 7 were obtained.

- **Table 7 Degree of bias for different computation periods (based on data for outlet RN 91 recorded in November 2008).**

Computation period:	10 min	30 min	1 hour	3 hour	6 hour
Over-estimation error:	11.7%	3.6%	1.8%	0.6%	0.3%

The simulation of the effect of latency on three sites suggests that the effect of latency is in the order of 1.8%. If these sites are representative of other sites, errors due to latency are likely to be small and may be in the order of -0.3% (=1.5% - 1.8%).



- **Figure 7 Influence of latency on bias of flow estimates computed over increasing periods of time.**

3.5.3. Accounting for Variation in Latency

For the future, the obvious solution to this problem is to transmit the time of the event along with the data. This approach wholly obviates the influence of latency. Analysis of the data would also be assisted by ensuring that the clocks used in the independent flow testing are synchronised with the clocks used in the remote telemetry unit. It is our understanding that the RTUs are capable of recording the time of event and transmitting a timestamp along with the event data, and also that clock synchronisation is a standard function of the RTU network.

The analysis of historic test data is problematic, but there are two approaches that could be used:

- Estimate the assumed sent time from the data, and compute the flow estimates using these fixed intervals of time.
- Develop Monte-Carlo simulation models for each test, and estimate the degree of bias associated with the test conditions.

The first approach is simplest, but will only be easily accommodated if the data was sent on the basis of fixed time intervals rather than a volume trigger. The results for this approach (using the same data set as previously) are shown in Figure 8. It is seen that the assumption of data packets sent every minute yields a flow time series that is physically much more realistic than that based on arrival times. The difference between independent flow estimates undertaken by Thiess over a single one hour period are -1.6% when based on assumed sent times, but 11.7% using arrival times. While these results are based on the volume measured by the REVS prior to correction for changes in the volume of water stored in the pool and tank, it does give an indication of the influence of variable arrival times.

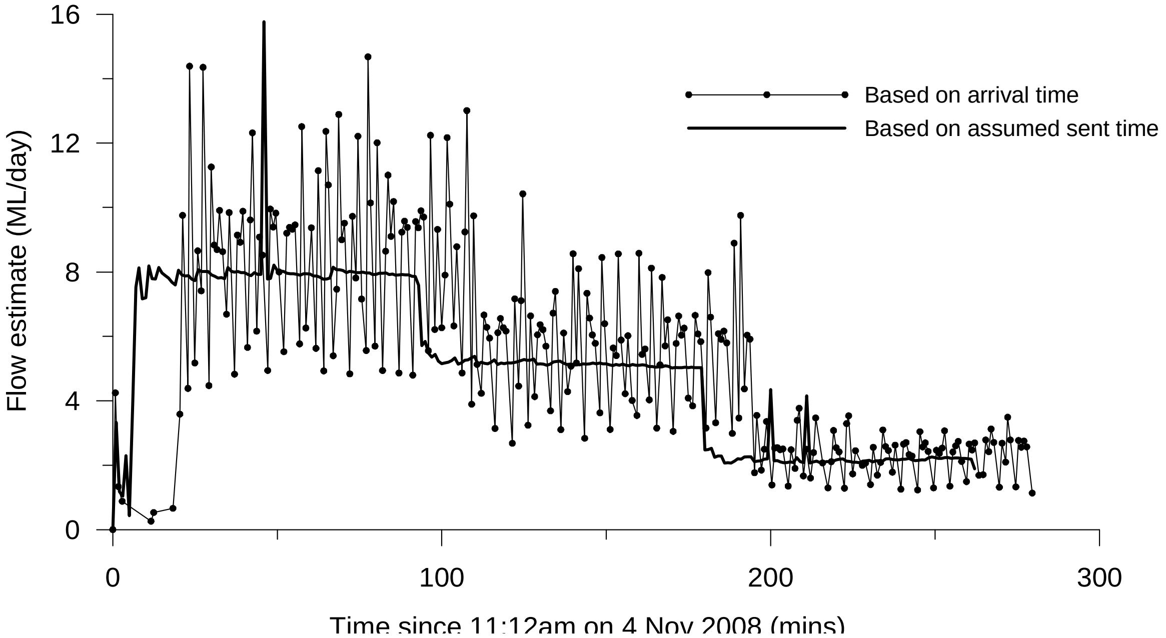
Whilst this would appear to provide a simple and straightforward means to removing the effects of latency, the approach does assume that:

1) the messages were triggered at fixed time intervals and not volume thresholds, and
2) the clocks between the independent test rig and the remote telemetry unit were synchronised.

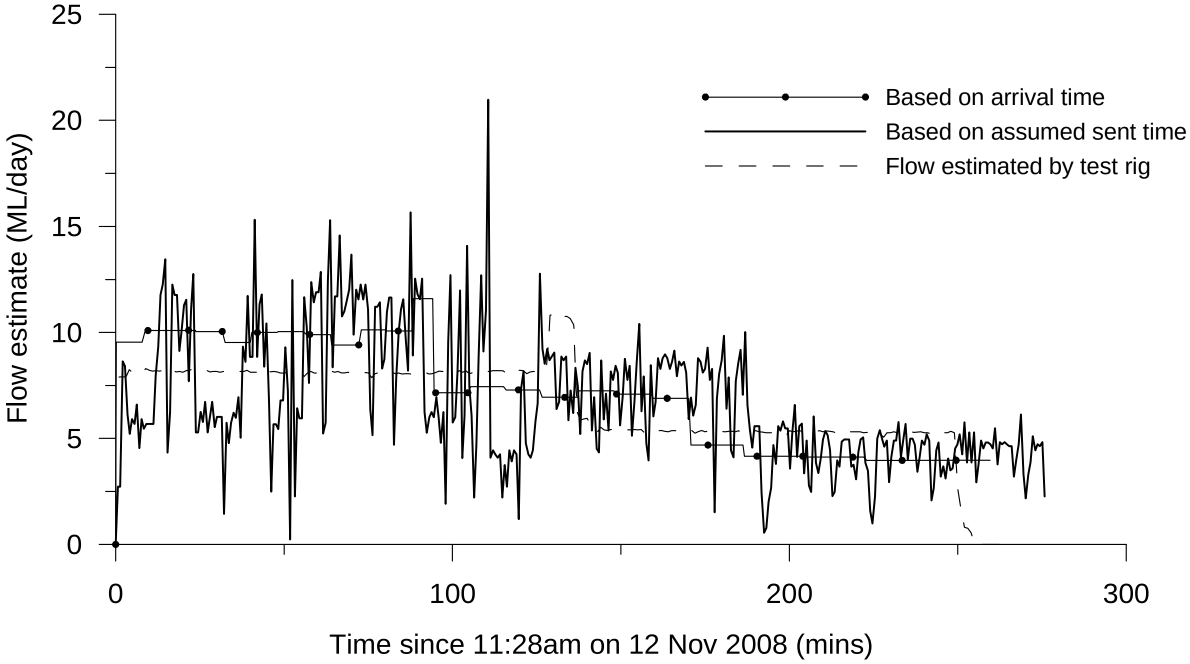
Examination of some data sets indicates that these two assumptions are not always met. For example, while similar results to that shown above were obtained for tests conducted at outlet RN100, some judgement and care is required to select a reasonably stationary but representative period over which to do the comparison. At site RN174 the messages appear to be triggered by changes in state rather than at fixed time intervals. Figure 9 shows that the estimate based on arrival time is more realistic and stable.

The second approach (once automated) probably requires little additional effort, and provides an indication of the expected level of bias as shown in Table 7.

In practice, it would be desirable to adopt both approaches as developing a data base of characteristic biases would be useful in interpreting the results based on assumed start time.



- **Figure 8 Comparison of flow estimates for flume gate at outlet RN 91 in November 2008, based on (a) assumed sent times at fixed 1 minute intervals and (b) arrival times that include the influence of latency.**



- **Figure 9 Comparison of flow estimates for flume gate at outlet RN 174 in November 2008, based on (a) assumed sent times at fixed 70 second intervals and (b) arrival times that include the influence of latency.**

3.6. Conclusions

The conclusions drawn from this review are as follows:

- Factors such as the flow rate, head loss and uncertainty in REVS measurements do not seem to influence the meter error.
- The meter accuracy presented by HydroEnvironmental (2009b) is calculated by averaging the results obtained for each test that represented normal flow rates. This approach does not account for site specific factors that influence the meter accuracy of an individual FlumeGate™ and which may have undue influence on the results.
- The average meter error estimated from the results undertaken for each phase of the testing differed. If the results from all three phases of testing are combined the average meter error is estimated to be 1.5%. These estimates are based on individual meter errors that were generated by averaging the many estimates by Thiess for each flow rate at each meter and include the influence of latency effects.
- The range of the 95% confidence interval of the average meter error estimated for Phase I and Phase II of the testing is approximately ±3%, and ±2% for Phase III. The range of the 95% confidence interval is ±2% when the results are combined from all three phases of testing.
- The uncertainty surrounding the average meter error can be reduced by undertaking additional tests. In order to reduce the uncertainty to ±1% an additional 62 tests are required.
- The simulation of the effect of latency at three sites suggests that the effect of latency is in the order of 1.8%. If these sites are representative of other sites, errors due to latency are likely to be small and may be in the order of -0.3%.
- Latency is not an issue for billing purposes. While this has an influence on the volume of water metered over an hour long period, the impact over the longer periods used to meter irrigation water use is negligible.

4. References

Cape, J. et al., 2008. Measured in-situ Verification of Meters for Non-Urban Water Supply, CRC for Irrigation Futures.

G-MW, 2009. Dethridge Meter Pendant Counter Accuracy Testing Report. #2658408, Goulburn-Murray Water.

HydroEnvironmental, 2007. Future of the Dethridge Meter, May 2007. Final.

HydroEnvironmental, 2008. In-situ REVS Testing of Large Dethridge Meter outlets in the GMID, August 2008. Final.

HydroEnvironmental, 2009a. In-situ Testing of Dethridge Meter Accuracy in the Goulburn-Murray Irrigation District, September 2009. Draft.

HydroEnvironmental, 2009b. In-situ Verification of FlumeGateM^{TM} Measurement Accuracy, August 2009. Draft.

Thiess Services, 2009. Insitu Flow Verification Report for FlumeGate^{TM}, June 2009.

Appendix A

MONASH University

Rob J Hyndman
Professor of Statistics

April 27, 2010

Garry Fyfe
Manager, Strategic Asset Planning
Goulburn-Murray Water

Dear Mr Fyfe

Re: Review of Flumegate and Dethridge Meter Studies

This letter is to provide details of my involvement in the report by SKM on the above subject, dated April 2010.

22 December 2009 A meeting was held with SKM. SKM discussed the background to the review and outlined their proposed analysis. SKM also provided copies of the following reports by HydroEnvironmental and spreadsheets that contained the data presented in the Appendix of each report.

- Hydroenvirnmental, 2009. In-situ Testing of Dethridge Meter Accuracy in the Goulburn-Murray Irrigation District. September 2009. DRAFT
- HydroEnvironmental, 2009. In-situ Verification of FlumeGateMTM Measurement Accuracy. August 2009. FINAL.
- G-MW, 2009. Dethridge Meter Pendant Counter Accuracy Testing Report. #2658408, Goulburn-Murray Water.

29 December 2009 After reading the HydroEnvironmental reports and looking at the data I provided SKM with a few initial comments on the analysis undertaken by HydroEnviornmental and recommended a method to be used to estimate meter accuracy and calculate confidence intervals.

22 January 2010 A meeting was held with SKM to discuss the method to be used to calculate meter accuracy, calculate confidence intervals and estimate the number of additional samples required. Based on this discussion, there were some revisions to the method I recommended on 29 December 2009. I recommended that SKM use the statistical package R to undertake the analysis and wrote some code to do this analysis.

25 February 2010 SKM provided me with modelling outputs used in the analysis, spreadsheets used to undertake calculations and the draft report for review. I provided comments which were incorporated into the draft report.

29 April 2010 SKM provided me with a copy of the final report to review prior to release.

I believe that the outcomes of the report are consistent with the statistical analysis described in the report.

Yours sincerely,

Rob J Hyndman

Department of Econometrics & Business Statistics
PO Box 11E, Monash University,
Victoria 3800, Australia.

Telephone: +61 3 9905 2358; Facsimile: +61 3 9905 5474
Email: Rob.Hyndman@buseco.monash.edu.au
WWW: robjhyndman.com