Goulburn-Murray Water

In-situ REVS Testing of Large Dethridge Meter outlets in the GMID

Final

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Hydro Environmental

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Acknowledgements

This report has been prepared by Hydro Environmental and is based on data provided by Goulburn-Murray Water and Thiess Services.

The authors thank Geoff Mann, Ross Plunkett, Bill Heslop and Bruce Albrecht of Goulburn-Murray Water and Leon Tepper and Nurullah Ozbey of Thiess Services for their assistance in providing data and explanations as required.

Executive Summary

Project Objectives
The objectives of this project were to:

i) review and assess the latest in-situ field flow measurement error verification data for a sample of Large Dethridge Meter outlets provided by Thiess Services.

ii) provide a report outlining the tested flow measurement accuracy of Large Dethridge Meter outlets tested.

Background
Goulburn-Murray Water (G-MW) has made a decision not to install any new Dethridge meters due to their non-compliance with the new National Metering Standards and the sensitivity of the meter to its local operating environment.

Original estimates of the Dethridge meter accuracy were based on a literature review, testing undertaken at the Werribee Hydraulic Laboratory in the late 1980's, The Goulburn weir test facility in 2007 and in-situ tests of meters early in 2006/7. Due to the small sample of in-situ field tests during the 2006/7 tests, G-MW engaged Thiess Services in late 2007 to use its Remote Electronic Verification System (REVS) to test a larger sample of large irrigation meters. Testing was undertaken proportional to the meters in use, as a result an emphasis was placed on the testing of Large Dethridge Meter outlets.

Methodology
To achieve the two key project objectives Hydro Environmental:

i) checked the Thiess Services data collection process for rigor and integrity

ii) checked the Thiess Services analysis process for accuracy and integrity

iii) analysed in-situ field flow measurement error verification data for 53 LMOs (43 from 2008 and 10 from 2007) provided by Thiess Services

iv) prepared conclusions and recommendations based on the findings from the in-situ field flow measurement error verification data.

The REVS water meters were electronically verified by Siemens during the tests in Dec 2007. In January 2008 the REVS Unit was tested at the Manly Hydraulics Laboratory. Both of these tests verified that the REVS was measuring within the error bands identified in the October 2006 tests at Manly Hydraulics Laboratory.

Results
Based on the analysis undertaken by Hydro Environmental, and included in this report, the following general conclusions have been drawn:

Field Testing Results

i) The Thiess Services test and analysis methodology associated with their Remote Electronic Verification System (REVS) is sound for testing water meters in-situ

ii) Analysis of the Thiess Services in-situ field testing shows that;

a. the REVS unit measures accurately and the level of uncertainty is between 0.5 % and 0.9 % with an average of ± 0.53 % for this series of tests
b. the data collection, verification and calculation processes used by Thiess Services are appropriate
c. the LMO errors for the 43 Large Dethridge Meter outlets tested in 2008 are significant and highly dependant on the local environment with test results showing errors of between +3 % to -18 %. The average measurement error was -6.9 % (under measured). Of the 43 test results analysed, 40 test results measured in favour of G-MW customers
d. the average measurement error for the combined REVS test results for 2007 and 2008 from 53 meter outlets was -7.5 % (under measured).

Mathematical Model

iii) G-MW has used the set of field tests conducted at the test site at Goulburn weir to develop a mathematical model which provides a relationship between meter error and bottom clearance, flow rate and effective supply depth. The confidence in the result from this model assuming the sample tested is representative of the other Dethridge meters is ± 1.7 %. This model can be improved by undertaking more REVS tests and recalibrating the model. As an example 100 REVS tests will reduce the error to ± 1.1 %. This will be reported separately by G-MW.

Key Findings and Recommendations

A. The following key findings should be noted

A1. The accuracy with which the Large Dethridge meter measures the volume of water delivered is heavily dependent on its manufacturing tolerances, precision of installation and quality and consistency of maintenance, as well as the environment in which it operates. The results of this analysis can only be extrapolated to other Large Dethridge meters if, on average, the characteristics of the other meters are the same as the sample of 53 analysed for this report.

A2. The results in the Thiess Services report on 53 in-situ field tests of LMOs across the GMID meters show that the sample of LMOs significantly under recorded water measurement by an average of between -7.0 % and -8.0 % (mean of -7.5 %).

A3. The mean of the 2008 tests is about 3 % less than the -10 % (under measured) shown in the Hydro Environmental 2007 report entitled "*Future of the Dethridge Meter*".

This difference in accuracy is primarily due to the difference in the characteristics of the test samples with the;

i) mean flow rate being higher by an average of 1.1 ML/d
ii) tail water depth being lower by an average of 66 mm; and
iii) greater difference in level between channel water level and land being watered (i.e. greater command).

For the 2007 report tests, 70 % of the sites had tailwater depths of more than 180 mm whilst only 28 % the 2008 tests had tailwater depths above 180 mm. Drowning of the meter is said to occur when tailwater depths exceed 180 mm, resulting in a significant increase in the under recording of errors.

A4. Each REVS test costs about $5,000, whereas, by using a mathematical model developed from a sample of say 100 Large Dethridge Meter REVS tests, the cost of determining the relative accuracy of each Large Dethridge Meter would be reduced to about $240.

B. It is recommended that:

B1. G-MW continues to use the REVS unit as an audit tool to determine field accuracy on a range of large meter outlets.

B2. G-MW compares the results of the key characteristics governing the LMO error for a total of more than 100 REVS tests to ensure that the characteristics of the sample reported in this report is representative of LMOs across the GMID. This will determine whether the mean error of -7.5 % (under measured) is translatable to other Large Dethridge meters.

B3. If the accuracy of individual meters is required, G-MW's development of a mathematical model to extend the results of the in-situ tests by taking measurements of the key characteristics governing the error at each site (e.g. flow, clearance and supply depth) be continued. The mathematical model would then be used as a simple low cost method to determine the relative accuracy of each meter as required.

B4. The sample size of REVS tests should be increased to atleast 100 to improve the 95 % confidence from ± 1.7 % for 43 REVS tests to ± 1.1 % if the results are extended across the 13,205 Large Dethridge Meter outlets in the GMID.

B5. Further in-situ testing be undertaken to determine whether the error characteristics of the Small Dethridge meter and the Dethridge-Long meter are the same as the LMO.

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1. Project Objectives

Hydro Environmental was engaged by Goulburn-Murray Water (G-MW) to:

i) review and assess the latest in-situ field flow measurement error verification data for a sample of Large Dethridge Meter outlets provided by Thiess Services.

ii) provide a report outlining the tested flow measurement accuracy of Large Dethridge Meter outlets tested.

2. Background

Modernisation of the Goulburn Murray Irrigation District (GMID) irrigation water supply system, and the requirements of the National Water Initiatives framework for non urban water meter standards will require G-MW to develop an implementation plan that will address the upgrade to all non compliant meters across the GMID.

Modernisation of the GMID water supply system (including meter replacement) will be funded on the basis that any water saved will be distributed between the environment, G-MW customers and Melbourne Water. It is therefore important that water saved by upgrading meters be determined on a sound technical foundation.

Although meter error can be accurately determined in the controlled and relatively precise laboratory environment, it is the more difficult to obtain accurate data on the field performance of these meters.

G-MW used the Utility Services 'Remote Electronic Verification System' (REVS), which is a large portable meter certification rig, to collect data on the accuracy of a number of irrigation water meters in the GMID. This process is very expensive with the total cost being about $5,000 per meter tested.

The REVS could be used to test a statistically valid set of meters and determine the average reduction in water loss resulting from the installation of accurate meters.

The REVS tests undertaken by Thiess Services on ten sites, in the Central Goulburn Irrigation Area close to Tatura, in January – February 2007 indicated that the Large Dethridge Meter outlets (LMO) on average under measured by 10 %. However, the sample of meters was very small compared to the 13,205 meters owned by G-MW and may have not been representative of the average for GMID meters.

A large proportion of the water savings expected to result from investment in supply system infrastructure will result from replacing LMOs. As a significant proportion of these water savings may be transferred for use of non G-MW customers, it is important that the average savings are accurately known if the current G-MW customer water security is not to be eroded.

It was therefore decided to undertake REVS testing on a larger sample of LMOs to gain a better indication of LMO accuracy across the GMID.

2.1. Error Convention

To be consistent with the National Standard, throughout this report a positive error (+) means the meter over records (i.e. delivers less water than is shown on its display and a negative error (-) means the meter under records (i.e. the customer receives more water than is recorded).

2.2. Error Reporting

2.2.1. Meter Error

The National Standard indicates that meter error should be expressed as a percentage, and is equal to:

$$\textbf{Meter Error} = (V_i - V_a)/V_a \times 100 \qquad \textbf{- 1}$$

Where:

V_a = Actual volume, i.e. the total volume of water passing through the water meter in any given time interval. This is the volume measured by the electromagnetic meters on the REVS.

V_i = Indicated volume, i.e. the volume of water indicated by the meter on the tested device (LMO) in an in-situ test.

2.2.2. Correct Volume

In determining the corrected delivery volume the indicated volume (Vi) must be adjusted by a correction factor. For example Vi may be taken over any given time period – such as an irrigation season. Equation 2 shows this relationship.

$$\text{Corrected Delivery} = \text{Correction Factor (CF)} \times \text{Vi} \qquad \textbf{- 2}$$

Meter error, in the form required by the National Standard (equation 1), should not be multiplied by the indicated delivery volume (V_i) to estimate the corrected delivery. The correction factor can be derived from the meter error (equation 3).

$$\text{Correction Factor} = \text{Va} / \text{Vi} = 1/\{(\text{Meter Error}/100) + 1\} \qquad \textbf{- 3}$$

Alternatively the correction factor can be determined directly from measurements of Vi and Va established in the test. For example, the LMO has a standard rating of 822 Litres per rotation of the wheel, if a REVS test shows the actual volume delivered per revolution of the wheel is 894 the variation from the standard meter rating 894/822 or 8.76 %. The associated meter error as defined by equation 1 is -8.05 %. The correction factor is 1.0876.

2.2.3. Water Savings

As the error varies between meters and the volume of water delivered by each meter will be different, to determine the combined corrected delivery volume for more than one LMO and determine water savings, it is important to weight the corrected delivery for each outlet according to the water supplied through each individual outlet and take the difference between the recorded and corrected volume to determine the water savings. The corrected delivery is expressed mathematically for a sample of *x* meters as follows:

$$\text{Corrected Delivery} = \sum_{x}^{1} \text{CF} \cdot \text{U}$$

Where:

CF = Correction Factor specific to each meter in the sample

U = Annual Usage specific to the corresponding meter in the sample.

3. Dethridge Meter Sizes

The Dethridge meter is a positive displacement meter and has been used by most major irrigation water providers in Australia, was invented in Australia in 1910 by John Dethridge, the commissioner of the Victorian State Rivers and Water Supply Commission at the time[1].

Up until recently the Dethridge meter has been in widespread use with over 40,000 meters installed throughout Australia when they were being used by all major providers of irrigation water[2].

Although the design of the Dethridge meter varies slightly from State to State, the general design and dimensions of the wheel have remained unchanged for more than 90 years. The Dethridge meter is both a meter and a flow control device with the Victorian version of the design having an upstream gate with which to control flow and flared downstream sidewalls to minimise downstream impedances to flow and minimise tailwater depths[3].

There are three models of the Dethridge meter used by G-MW with each having a different range of flows, recording accuracy and head loss to ensure the command component of level of service is not compromised. These meters and their associated flow rates are:

i) Small Dethridge Meter (SMO) — 1.6 ML/d to 5 ML/d

ii) Large (Standard) Dethridge Meter (LMO) — 3 ML/d to 12 ML/d

iii) Dethridge-Long Meter (DLMO) — 3 ML/d to 20 ML/d.

It should be noted that each LMO is designed to operate with 75 mm of head loss at 10 ML/d. Flows of 12 ML/d would require more available head.

3.1. In-situ Meter Verification

The REVS unit was used to undertake the in-situ analysis of a sample of LMOs within the GMID. The REVS unit was calibrated and verified for accuracy at the Manly Hydraulics Laboratory in Sydney. The testing report (MHL Oct 2006, No 1631) indicated that the REVS unit could measure accuracy within the uncertainty of the MHL Flow test rig (better than ± 1 %)[4].

In order to undertake in-situ field verification of LMOs, the following steps are undertaken.

i) the irrigation channel is temporarily blocked downstream of the irrigation meter

ii) the REVS unit pumps water to a header tank where it is gravity fed through one of the electromagnetic flow meters before being discharged either back into the supply channel or downstream to the customer

iii) software is used to alter the discharge rate through the variable speed pumps to maintain water level at a near constant level downstream of the meters being tested

iv) gate opening, supply depth, flow rate and tailwater conditions are monitored and recorded throughout the procedure

v) seepage rates and evaporation are also measured/estimated for the test period

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1 Future of the Dethridge Wheel, Hydro Environmental (2007)

2 Future of the Dethridge Wheel, Hydro Environmental (2007)

3 Future of the Dethridge Wheel, Hydro Environmental (2007)

4 Factsheet: G-MW's 2007/08 Irrigation Meter Testing Program

vi) the in-situ flow verification range is between 1 and 15 ML/day with flows ranging from 0-5.5 ML/day passing through the 150 mm diameter electromagnetic flow meter and flows ranging from 5-15 ML/day passing through the 300 mm diameter electromagnetic flow meter in the REVS[5]

vii) the time period for each test is approximately one hour which is adequate to reduce the uncertainty to a reasonable level of about ± 0.5 %.

For these tests, LMOs are tested as found and are not adjusted in any way. The supply level, tailwater level and flow rates will be nominated by the G-MW Operations Manager to best represent the operation of each individual meter. At each site three flow rates were tested. These represented the normal ordered flow rate as well as a low and high flow rate used to assess linearity across the flow range.

The bottom and side clearances of each Large Dethridge meter was measured using a calibrated depth gauge. The target value for these clearances are 10 mm side clearance and 6 mm bottom clearance.

3.2. Verification of Data Integrity

As part of the test result verification process Hydro Environmental reviewed the data recording and checking process used by Thiess Services to ensure they were accurate and robust. This review was undertaken before the tests were analysed with comments being made on:

i) the checking process for ensuring each of the 12 pulses corresponding to a single rotation of the Large Dethridge meter were recorded

ii) the Hydro Environmental preference to use volume rather than flow for interpolating the test results

iii) clarifying changes to the reporting sheets.

Thiess Services have since acted upon the Hydro Environmental comments, which has improved the integrity and robustness of the results obtained from the 2008 tests.

3.3. Manly Hydraulics Report

Laboratory testing of the flow verification unit developed by Thiess Services was conducted by the NSW Department of Commerce Manly Hydraulics to verify the accuracy of irrigation meters installed in open channels. These tests were conducted in October 2006.

The tests conducted comparing the REVS 150 mm and 300 mm diameter electromagnetic flow meters with Manly Hydraulics MagMaster concluded that correction factors had to be applied to the 300 mm MagFlow measurements to ensure the reported results are accurate. All reported results from the REVS used those correction factors.

In January 2008 the REVS was retested by Manly Hydraulics. These tests confirmed that both meters used by the REVS recorded results which are within the upper and lower limits of the expected volume ranges at 95 % confidence levels.

[5] Factsheet: G-MW's 2007/08 Irrigation Meter Testing Program

3.4. Siemens Verification Test Report

Laboratory testing of the 150 mm and 300 mm diameter electromagnetic flow meters was conducted in October 2006 before the REVS was built to ensure that they are electronically within the design specifications .

In November 2007 Siemens electronically retested both the 150 mm and the 300 mm MagFlow meters used by the REVS and found that both meters were within calibration.

Test certificates were provided for both tests and these certificated a satisfactory result with the test parameters being within 2 % of their original value.

3.5. Site Selection

Construction accuracy, maintenance and component replacement diligence varies between Irrigation Areas across the GMID. The number of Large Dethridge meters tested across the GMID was proportional to the type and total number of meters in each Irrigation Area. Other factors which affected site selection included:-

- Asset condition rating of outlet (one meter was found to be in an extremely poor condition and was subsequently omitted from the analysis)
- Maintenance history
- Operating parameters
- Annual usage and high use Vs low use outlets
- Accessibility for the REVS
- Water availability and stability of supply depth
- Permission and cooperation granted by property manager.

Table 1 lists the proportion of Large Dethridge meters tested in each Irrigation Area in comparison to the total number of Dethridge meters.

Table 1: Distribution of Dethridge Meter types across G-MW

Irrigation Area	Reported No. of LMOs Tested	Total Number of Meters in the GMID			
		LMOs	DLMOs	SMOs	Total Meters
Central Goulburn	15	3,728	71	1,245	5,044
Pyramid-Boort	6	2,009	79	114	2,202
Murray Valley	5	1,685	17	1,008	2,710
Shepparton	4	1,372	19	735	2,126
Rochester	5	1,590	46	355	1,991
Torrumbarry	8	2,821	91	635	3,547
TOTAL	**43**	**13,205**	**323**	**4,092**	**17,620**

Poulton, D 2008, pers.comm., 21 April

3.6. Test Results

The primary purpose of the REVS testing was to determine the accuracy of meters under their normal operating conditions. That is for the channel water levels, flow rate and tailwater depth normally experienced at that site. This was the same as was done in the 2007 tests. However in 2008 the REVS was set up on each site, it was also decided to test each meter at a higher and lower flow rate. These latter tests are provided in **Section 4.2** of this report.

For each site tested, REVS tests were generally conducted under the following conditions:

i) normal site operating conditions (e.g. 7 ML/d)

ii) a flow above that usually taken by the landowner (e.g. 10 ML/d)

iii) a flow below that normally taken by the landowner (e.g. 5 ML/d).

G-MW conducted a total of 140 field tests on 45 LMOs in the GMID between the 24 January 2007 and the 21 February 2008. At least three individual field tests were conducted at each site with the maximum being five individual field tests.

These multiple tests at each site were conducted to improve understanding of meter error and any factors that may be influencing it. As G-MW is mainly interested in the expected meter error under actual operating conditions of the 140 tests undertaken only those tests (one per site) were analysed for the purpose of this report.

The results from two LMO tests were omitted from the analysis due to abnormally windy conditions or excessive damage to LMO fins and vanes, influencing the flow rate being recorded and hence, impacting on error readings. The details concerning the two omitted outlier tests are presented in **Appendix A**.

As a result only 43 tests were analysed from 13,205 LMOs (0.3 % of the population) in the GMID.

3.7. Certainty of Results

Thiess Services has indicated that the average uncertainty in the results is ± 0.53 %. That is the average measurement error for this sample of LMOs is between 6.4 % and 7.4 %.

3.8. Sources of LMO Measurement Error

As indicted in **Figure 1** there is a wide variation in the accuracy of the LMOs tested indicating that there are a number of different physical and environmental factors which may affect measurement accuracy.

If the Dethridge meter, and in particular the eight finned drum, is incorrectly installed or damaged, or the bearings wear such that design clearances are not maintained, serious inaccuracies can result.

A more comprehensive list of factors which affect the measurement accuracy of the Dethridge meter include:

i) tolerances on the drum manufacture (fin length differences, drum roundness etc.)

ii) damage to the drum or fins

iii) tolerances on the concrete emplacement manufacture

iv) whether the drum is in the centre of the emplacement

v) whether the sump in the emplacement and the tip of the drum fins do not have the same pivot point

vi) damage to the downstream sill of the emplacement

vii) variations in clearances between the fins and the emplacement

viii) obstructions to the rotation of the drum

ix) amount of wear on the bearings

x) flow rate of the water passing through the meter

xi) elevation and flatness of the floor of the emplacement construction tolerances or uneven wear of emplacement

xii) upstream water level

xiii) downstream water level

xiv) fluctuations in channel water levels

xv) the degree to which the door is sealed under no flow

xvi) unstable channel water velocities

xvii) obstructions in approach waterways

xviii) the amount the door is opened

xix) wind direction and velocity.

More detail on the LMO can be obtained from http://www.ancid.org.au/ktf/, cited May, 2007.

4. In-situ Field Verification Results

A total of 43 LMOs were analysed. Based on the available tests, data conclusions have been drawn from the REVS results.

Flow rates for the LMOs varied from 2.2 ML/d to 14.6 ML/d, with seven (two below and five above) of the 43 tests being outside the range of flows recommended for the Large Dethridge meter (3 ML/d - 12 ML/d). The results of the REVS Large Dethridge meter tests are tabulated in **Appendix B** and presented graphically in **Figure 1**.

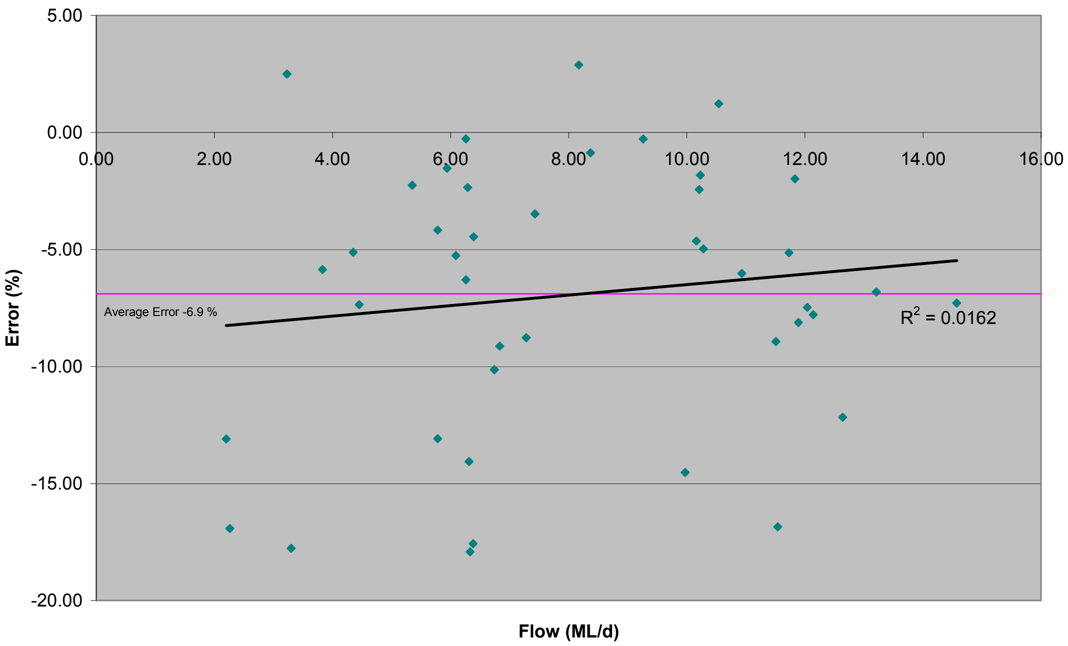

Figure 1: GMID Large Dethridge meter Error (%) v Flow (ML/d)

The graph shows the LMO accuracy (%) (Dethridge meter volume / REVS volume) for various flow rates across the GMID. It is noted that there is a large scatter within the results, which highlights the highly variable nature of LMO accuracy that is influenced by all of the factors listed in **Section 3.8**.

The average measurement error for the tests analysed, excluding outliers, was -6.9 % (R^2=0.0162) with an average flow of approximately 8.1 ML/d. Error changed by 0.22 % for each Megalitre change in flow.

Variables such as bottom clearance, tailwater depth, upstream level and maintenance issues have been assessed for each test and are discussed in detail in the following sections and were used to explain the difference between the results reported by Hydro Environmental in 2007 and this report.

4.1. Variables

4.1.1. Bottom Clearance

The standard bottom clearance on the LMO is 6 mm. The range of bottom clearances for the test sites reported varied between 4.0 to ~30.0 mm. The REVS results are presented in **Figure 2**.

The average bottom clearance was 9.3 mm which is approximately 3 mm above the standard bottom clearance. The 11 tests with a bottom clearance less than 6 mm had an average measurement error of 4.1 %, in comparison, the remaining 32 tests had a bottom clearance of greater than 6 mm and had an average measurement error of 8.3 %.

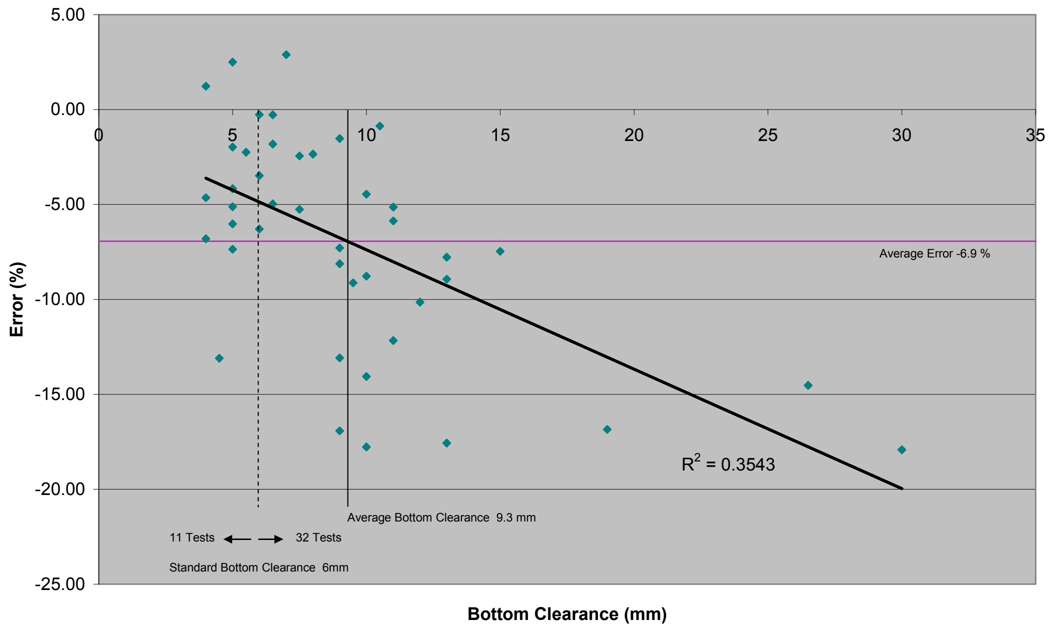

Figure 2: GMID Large Dethridge meter Error (%) v Bottom Clearance (mm)

These results indicate that errors increase by 0.6 % for each mm change in clearance, however, the R^2 value is low at 0.3543 which reflected the high variability in the results[6].

The variation in LMO bottom clearances could be caused by the deterioration of the emplacement, bearings etc. over time.

4.1.2. Tailwater Depth

The range of tailwater depths for LMOs analysed is presented in **Figure 3**. The average tailwater depth is 153 mm compared with the 180 mm allowed before drowning is said to occur. Once again these results are highly variable with an $R^2=0.2439$. Those tests with tailwater depths greater than 180 mm recorded an average measurement error of 10 %, whilst those tests with tailwater depths less than 180 mm had an average measurement error of 5 %.

Overall these results indicate that the under recording of errors increases by 0.06 % for each mm increase in tailwater depth.

6 Methodology for determining corrected delivery volume through Large Dethridge Meters, R J Keller & Associates (2008)

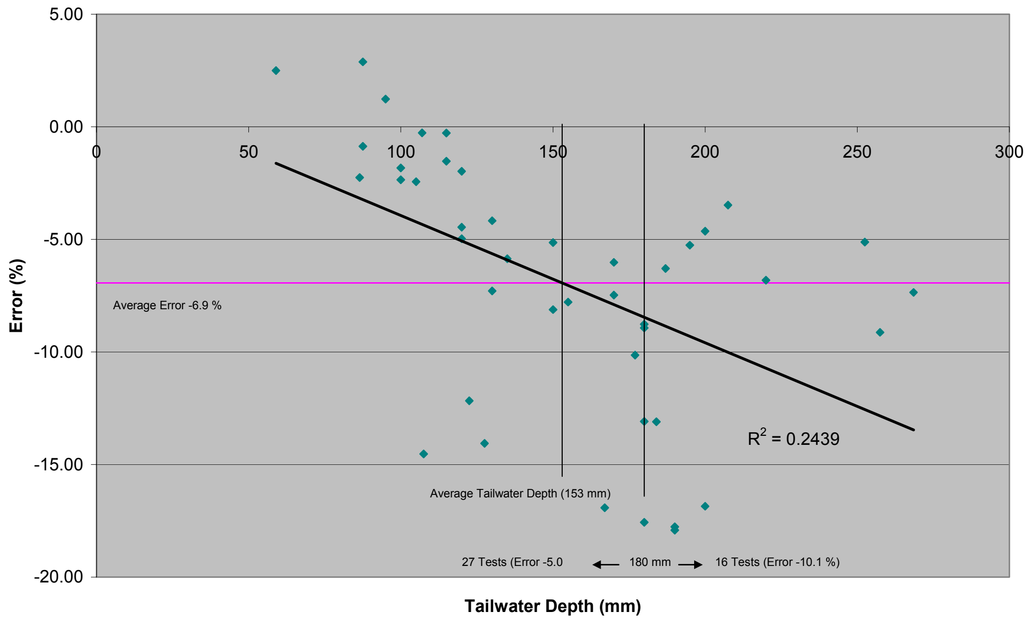

Figure 3: GMID Large Dethridge meter Error (%) v Tailwater Depth (mm)

4.1.3. Upstream Water Level

The average upstream water level for LMOs analysed was 425 mm. A supply level greater than the recommended standard supply depth of 380 mm can have negative implications on results, with the under recording of errors increasing by 0.01 % per mm rise in level. Once again the results are highly variable with an R^2=0.0158.

Results presented in **Figure 4** indicate that tests with an upstream level greater than 380 mm had an average measurement error of 8.3 %, compared to tests with an upstream level less than 380 mm which had an average measurement error of 4.1 %.

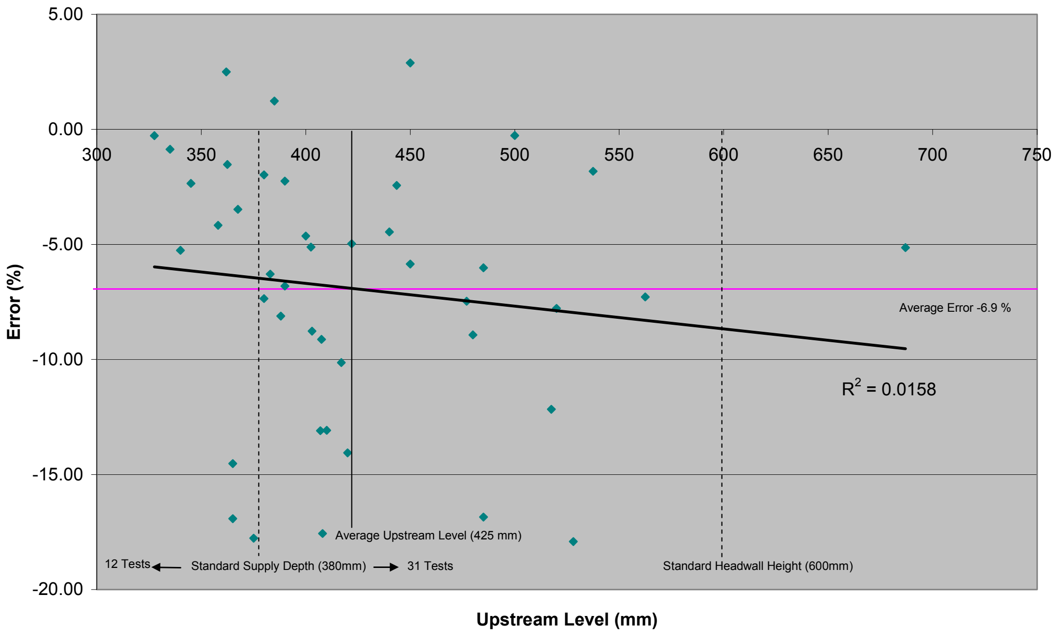

Figure 4: GMID Large Dethridge meter Error (%) v Upstream Level (mm)

4.1.4. Combined 2007 and 2008 Tests

The results from the 10 LMOs tested in the Central Goulburn Irrigation Area near Tatura in 2007 (average measurement error -10.0 %) and the 43 LMOs (average measurement error -6.9 %) analysed in this report have been combined to give an overall error for the combined population. When combined the average measurement error, excluding outliers, was -7.5 % (R^2=0.0462) with an average flow of approximately 7.8 ML/d. For the combined dataset measurement error changed by 0.40 % for each Megalitre change in flow.

The results for the combined REVS Large Dethridge meter tests are presented graphically in **Figure 5**. The 2007 results are tabulated in **Appendix C**.

Comparisons between the results from the REVS test results in early 2007 and the REVS test results in early 2008 are described in **Section 4.1.5**.

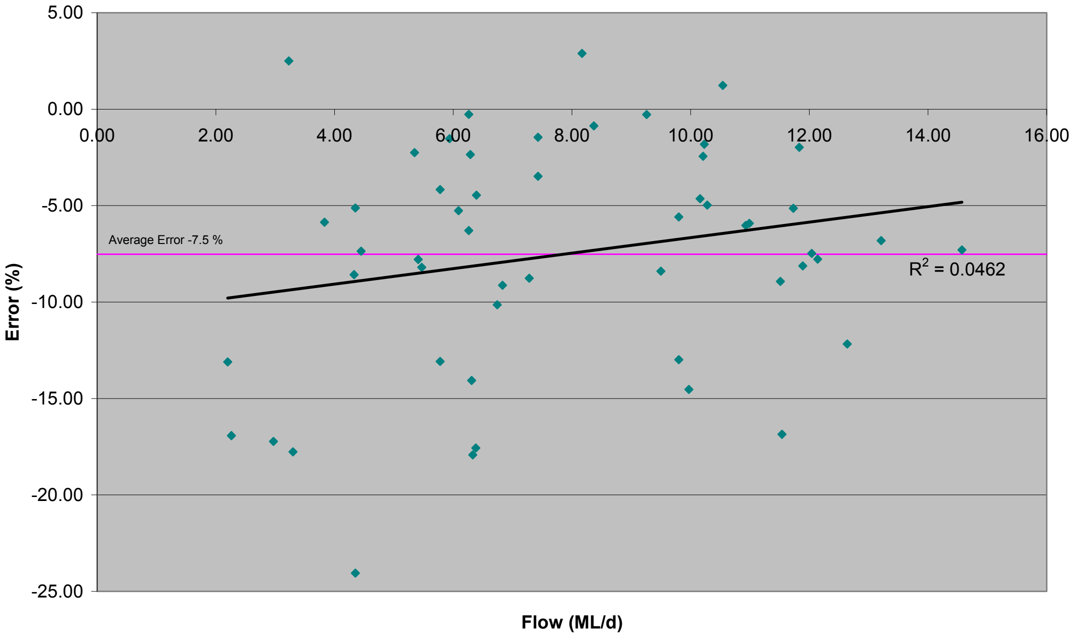

Figure 5: Combined GMID Large Dethridge meter tests for 2007 and 2008

4.1.5. Comparison with 2007 Tests

The errors observed from this analysis are on average about 3 % lower than those observed from the small sample tested in early 2007. The reason for this change can be explained by the difference in the average characteristics of the two LMO test samples as shown in **Table 2**.

Table 2: Difference in LMO Characteristics between the 2007 and 2008 Tests

		Readings & Settings at Test Commencement					Result
Report	No. of Tests	Av. Flow Rate	Av. Bottom Fin Clearance	Av. U/S Supply depth	Av. Depth D/S of Gate	Av. Tailwater depth	Corrected Thiess Test rating error ((1- (822/actual rating)))*100
		ML/day	mm	mm	mm	mm	(% diff. in rating)
REVS Test Nov 2007 - Feb 2008	43	7.9	9.3	425	296	153	-7.5
REVS Test Jan-Feb 2007	10	7.0	7.4	412	370	219	-10.0
Expected change due to the following differences	-	Five of the latest tests had flows between 12-14 ML/d	Three of the latest tests had bottom clearances greater than 16 mm	Six of the latest tests had supply depths greater than 500 mm	Four of the previous tests had depths d/s of the gate greater than 400 mm	Two of the previous tests had tailwater depths greater than 300 mm	-

Because of the interrelations between the changes causing the error there is not a single change that can explain the reason for the reduction in error. The following relationships may however aid understanding.

Tailwater depth on the 2008 tests averaged 66 mm less than the 2007 tests. This will reduce the expected error on average by 0.06 % for each mm change in level or about 2 % in the sample difference.

Flow rates are higher on average by 1 ML/d with five of the 2008 tests having normal operating flows of more than 12 ML/d. Average measurement error on this sample reduces by about 1.5 % per ML/d increase in flow.

Bottom clearance increase**,** on average for this sample, accounts for a 0.6 % for each mm increase in clearance. The 2008 tests had an average increase of 1.9 mm in clearance which would increase the error.

Error is not very sensitive to **supply depth** however there is a slight increase with depth. Once again the 2008 sample had supply depths which were, on average, slightly higher by 13 mm, whereas depths downstream of the gate were on average 74 mm lower.

REVS test LMO revolution count verification was improved in 2008. The possible existence of errors in 2007 could not be verified.

4.1.6. Large Dethridge Meter Maintenance

LMOs are maintained on a periodic basis by replacing bearings, drums and resetting clearances. The majority of the tests conducted (35 out of 43 tests) had not undergone any maintenance in recent times. These tests had a similar average measurement error (7.5 %) to that of the entire population (6.9 %).

4.1.7. Side Clearance

Recent studies by G-MW (Poulton, D 2008, pers.comm., 21 April) indicated that side clearance between the drum and the sides of the emplacement (10 mm for each side clearance) had a minor influence on the calibration of the LMO[7]. For this reason side clearance was not included in this analysis.

4.2. Analysis of High/Low Flow Data for 2008

The main tests were conducted to determine the accuracy of meters under their normal operating conditions (flow, tailwater depth etc.). However, to understand the limitations of each individual LMO meter tested, REVS tests were also conducted at high and low flow conditions and have also been reported and are presented in **Figure 6**.

The graph indicates that there is a large scatter of results, with individual LMO meters subject to high and low flows under measure by an average of -7.2 % and the combined total average of all 2008 tests having an error of -7.1 % for the 133 tests as shown in **Table 3**.

[7] Methodology for determining corrected delivery volume through Large Dethridge Meters, R J Keller & Associates (2008)

Table 3: Analysis of LMOs tested according to flow condition in 2007 and 2008

Flow Condition	2008 REVS tests		2007 REVS tests		Combined 2007 and 2008 REVS tests	
	Reported No. of LMO tests	Average Corrected Thiess Test rating error ((1- (822/actual rating))*100	Reported No. of LMO tests	Average Corrected Thiess Test rating error ((1- (822/actual rating))*100	Reported No. of LMO tests	Average Corrected Thiess Test rating error ((1- (822/actual rating))*100
Nominated	43	-6.9	10	-10.0	53	-7.5
*Other tests at the same sites	90	-7.2	35	-11.6	125	-8.5
TOTAL	**133**	**-7.1**	**45**	**-11.3**	**178**	**-8.2**

*Generally high/low flows, however where the nominated flow is the high or low flow, the other two flows are included.

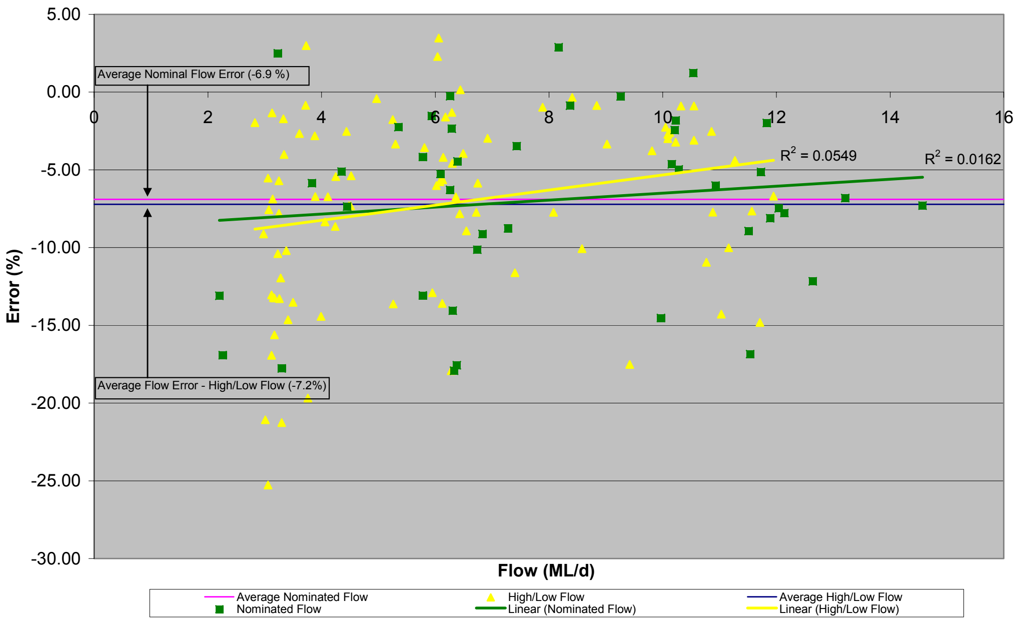

Figure 6: Combined LMO analysis of flow conditions for 2008 tests

4.3. Analysis of All LMO Data for 2007 and 2008

The combined total average error for all LMO data in 2007 and 2008, excluding outliers, was -8.2 % (under measured) as shown in **Table 3**. Analysis of only the nominated flow rates for 2007 and 2008 resulted in a total average error of -7.5% (under measured).

4.4. Other Dethridge Meters

One Small Dethridge meter (SMO) was fully tested and data provided as part of this analysis. The average measurement error from the three tests at that site was -7.5 % for an average flow of 3.6 ML/d.

Similarly, a Dethridge-Long meter (DLMO) was tested and it showed an average measurement error was + 1.3 % and an average flow of 8.2 ML/d over three tests.

Side clearances on SMOs and DLMOs are 6 mm (4 mm less than LMOs). A larger sample size would be required to gain a better understanding of the inaccuracies of these meters and to positively determine whether they have the same error characteristics as the LMO.

4.5. Mathematical Model

One means of defining measurement error is to develop a mathematical model which relates individual supply point parameters (e.g. bottom clearance, effective supply depth and delivery rates) to measurement error.

The Statistical Consulting Centre at The University of Melbourne was engaged to provide advice on the form of the model and determine measurement error resulting from the tests at the Goulburn weir test site in 2007. Four model options were presented and these were tested against the 2008 REVS tests. The results will be reported separately by G-MW.

Model B was the most accurate and preferred Model.

The University of Melbourne Model B equation is as follows:

Gate-in

$$Rating = 697.9 - 45.5rpm + 5.15rpm^2 - 0.21rpm^3 + 185.3MESD - 40.71MESD^2 + 3.28MESD^3 - 3.25CL + 0.88CL^2 - 0.02CL^3 + 40.8 - 1.19rpm - 5.12MESD$$

Gate-out

$$Rating = 697.9 - 45.5rpm + 5.15rpm^2 - 0.21rpm^3 + 185.3MESD - 40.71MESD^2 + 3.28MESD^3 - 3.25CL + 0.88CL^2 - 0.02CL^3 - 40.8 + 1.19rpm + 5.12MESD$$

Where:

MESD = Measured effective supply depth (in decimetres)
CL = Wheel bottom clearance measured in mm
rpm = Wheel speed in revolutions per minute = delivery flow rate

Model B is only accurate if data with the design operating range of the Dethridge meter is used.

Strong correlations have been found for Model B Gate-in and Gate-out predicted and measured ratings based on Magflow measurements for tests done at the Goulburn Weir Test Facility LMO[8].

Gathering the data and applying the model would cost an estimated $240 per supply point (i.e. about 5 % of the about $5,000 per supply point required for REVS).

There is greater customer confidence in the more visual REVS than a "theoretical" modelling approach. G-MW has therefore proposed a process to combine a sample set of field REVS results, with the mathematical model results. The model was developed based on data obtained from a Large Dethridge Meter installed at the Goulburn Weir test site.

8 #2391587—Determination of a corrected delivery volume in the CG1234 Irrigation System" - Goulburn-Murray Water - 4 January 2008

A larger sample size of 100 REVS tests as shown in **Table 6** – would provide confidence level of ± 1.1 % compared to ± 1.6 % for the 53 sites tested to date when the results are extrapolated to 13,205 meters across the GMID. In view of the significantly lesser cost, if the accuracy of individual meters is required it is recommended that the mathematical model be the main method utilised to increase the size of the sample.

Table 6: Difference in LMO Characteristics between January 2007 and the Current Tests[9]

n	95% confidence interval half-width	95% confidence interval width	An example interval based on a mean of 6.9%
43	1.7%	3.5%	(5.2%, 8.7%)
100	1.1%	2.2%	(5.8%, 8.1%)
300	0.6%	1.3%	(6.3%, 7.6%)
600	0.4%	0.9%	(6.5%, 7.4%)

5. Portability of the Results

As indicated in **Section 3.4**, there are a number of factors which influence the measurement accuracy of the LMO. The graphs in **Section 4** show that LMOs with what could be classed as extreme operating conditions were not excluded as being outliers because G-MW advice is that these conditions are not uncommon across the GMID. Some examples of these extreme conditions are:-

i) supply depths as low as 330 mm and as high as 680 mm

ii) flows operating marginally outside the recommended operating range

iii) bottom clearance up to 30 mm and as low as 4 mm

iv) tailwater depths of as low as 60 mm and as high as 275 mm.

The results of these tests can only be extrapolated with confidence to meters which have dimensions and operating conditions which are on average similar to those of the 53 sites analysed. There is insufficient information on the population of 13,205 LMOs in the GMID to be able to confidently say that the average results from this analysis can be applied across the whole of the GMID. However, a larger sample size of at least 100 REVS tests – would provide confidence level of ± 1.1 % as discussed in **Section 4.5**.

To enable the applicability of this result to be better determined, there is a need to collect data on the physical dimensions (including flow rate, supply depth, tailwater depth and clearances) and operating environment for a much larger sample of LMOs across the GMID.

Ongoing testing of a range of meters using in-situ volumetric measurements (REVS) will prove the reliability of the mathematical model and enable it to be confidently used as an audit tool for determining Dethridge meter accuracy across G-MW's entire metering fleet. Over time this model based audit will provide sufficient numbers for detailed analysis of meter accuracy.

The measurement of key parameters, and use of the mathematical model in the GMID, will provide a simple and cheap alternative for validating field accuracy of meters, which can be supported by a quality audit system.

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9 Amended response to brief from "#2441497—Review of Statistical Approach to Determination of Dethridge Meter Calibration Stage 3/4" – University of Melbourne – 1 May 2008

6. Key Findings and Recommendations

A. The following key findings should be noted:

A1. The accuracy with which the Large Dethridge meter measures the volume of water delivered is heavily dependent on its manufacturing tolerances, precision of installation and quality and consistency of maintenance, as well as the environment in which it operates. The results of this analysis can only be extrapolated to other Large Dethridge meters if, on average, the characteristics of the other meters are the same as the sample of 53 analysed for this report.

A2. The results in the Thiess Services report on 53 in-situ field tests of LMOs across the GMID meters show that the sample of LMOs significantly under recorded water measurement by an average of between -7.0 % and -8.0 % (mean of -7.5 %).

A3. The mean of the 2008 tests is about 3 % less than the -10 % (under measured) shown in the Hydro Environmental 2007 report entitled "*Future of the Dethridge Meter*". This difference in accuracy is primarily due to the difference in the characteristics of the test samples with the;

i) mean flow rate being higher by an average of 1.1 ML/d

ii) tail water depth being lower by an average of 66 mm; and

iii) greater difference in level between channel water level and land being watered (i.e. greater command).

For the 2007 report tests, 70 % of the sites had tailwater depths of more than 180 mm whilst only 28 % the 2008 tests had tailwater depths above 180 mm. Drowning of the meter is said to occur when tailwater depths exceed 180 mm, resulting in a significant increase in the under recording of errors.

A4. Each REVS test costs about $5,000, whereas by using a mathematical model developed from a sample of say 100 Large Dethridge Meter REVS tests, the cost of determining the relative accuracy of each Large Dethridge Meter would be reduced to about $240.

B. It is recommended that:

B1. G-MW continues to use the REVS unit as an audit tool to determine field accuracy on a range of large meter outlets.

B2. G-MW compares the results of the key characteristics governing the LMO error for a total of more than 100 REVS tests to ensure that the characteristics of the sample reported in this report is representative of LMOs across the GMID. This will determine whether the mean error of -7.5 % (under measured) is translatable to other Large Dethridge meters.

B3. If the accuracy of individual meters is required, G-MW's development of a mathematical model to extend the results of the in-situ tests by taking measurements of the key characteristics governing the error at each site (e.g. flow, clearance, and supply depth) be continued. The mathematical model would then be used as a simple low cost method to determine the relative accuracy of each meter as required.

B4. The sample size of REVS tests should be increased to at least 100 to improve the 95 % confidence from ± 1.7 % for 43 REVS tests to ± 1.1 % if the results are extended across the 13,205 Large Dethridge Meter outlets in the GMID.

B5. Further in-situ testing be undertaken to determine whether the error characteristics of the Small Dethridge meter and the Dethridge-Long meter are the same as the LMO.

xxxXXXxxx

APPENDIX A

Appendix A – Rationale Behind Omitting LMO Test Outliers

Reference No.	Irrigation Area	Test date	Service point No.		Test Id	Readings & Settings at Test Commencement						Test						
						Recently rehabilitated	Bottom Fin Clearance	U/S Supply depth	Depth D/S of Gate	Tailwater depth	Gate opening	Flow rate from corrected volume & time	Result			Uncertainty	Test comments
						Y/N	mm	mm	mm	mm	mm	ML/day	% Under	% Over	Litres Per Revolution	Result @ 95 % Confidence +/-	
1	CG	16-Jan-08	[redacted]	[redacted]	1.1	N	12.5	711	110	150	128	11.61		13.07	872	0.50	Abnormally windy conditions assisting drum rotation, influencing the results for the first two tests. Higher approach velocity than generally anticipated. Test results abnormal.
2	TIA	30-Oct-07	[redacted]	[redacted]	1.1	N	8	445/435	#N/A	185	370	11.12	-13.44		950	0.50	Dethridge wheel fins damaged, bearings also worn (3 mm), one severly bent vane. Excessive damage to the fins and vanes is uncommon.

CG - Central Goulburn Irrigation Area
TIA - Torrumbarry Irrigation Area

Appendix B – 2008 REVS results for Large Dethridge meters

Reference No.	Irrigation Area	Test date	Service point No.		Test Id	Readings & Settings at Test Commencement						Test						
						Recently rehabilita-ted	Bottom Fin Clearance	U/S Supply depth	Depth D/S of Gate	Tailwater depth	Gate opening	Flow rate from corrected volume & time	Result			Uncertainty	Test comments
						Y/N	mm	mm	mm	mm	mm	ML/day	% Under	% Over	Litres Per Revolution	Result @ 95% Confidence +/-	
1	CG	13-Feb-08	[redacted]	[redacted]	1.2	N	13	408	280	180	100	6.38	-17.57		997	0.52	
2	CG	19-Feb-08	[redacted]	[redacted]	1.2	N	6	383	315	187	160	6.26	-6.29		877	0.55	
3	CG	21-Feb-08	[redacted]	[redacted]	1.3	N	10	375	290	190	65	3.30	-17.77		1000	0.56	
4	CG	16-Jan-08	[redacted]	[redacted]	1.1	N	11	687	190	150	163	11.73	-5.14		867	0.51	Upstream Supply Level 687 mm
5	CG	18-Feb-08	[redacted]	[redacted]	1.3	N	9	365	260	167	33	2.26	-16.92		989	0.52	
6	CG	15-Jan-08	[redacted]	[redacted]	1.3	N	5	407	300	184	35	2.20	-13.10		946	0.6	
7	CG	03-Oct-07	[redacted]	[redacted]	1.2	N	9	365/360	200	115	80	5.94	-1.53		835	0.51	
8	CG	17-Jan-08	[redacted]	[redacted]	1.2	N	5	358	280	130	104	5.78	-4.17		858	0.54	
9	CG	10-Oct-07	[redacted]	[redacted]	1.2	N	10	420	#N/A	125/130	#N/A	6.31	-14.06		956	0.51	
10	CG	09-Oct-07	[redacted]	[redacted]	1.1	N	11	450	210/220	135	28	3.83	-5.86		873	0.53	Orders 4 ML/d
11	CG	14-Feb-08	[redacted]	[redacted]	1.2	N	10	440	275	120	114	6.39	-4.46		860	0.52	
12	CG	27-Sep-07	[redacted]	[redacted]	1.3.1	N	5	390/415	400	255/250	out	4.35	-5.12		866	0.63	Recalculated due to fluctuation in supply. Tailwater Depth 252.5 mm
13	CG	04-Oct-07	[redacted]	[redacted]	1.3	N	9	410	340	180	130	5.78	-13.08		946	0.51	Orders 6 ML/d
14	CG	20-Nov-07	[redacted]	[redacted]	1.2	not known	5.5	385/395	160	86/87	65	5.35	-2.25		841	0.72	Orders 5 ML/d
15	CG	13-Nov-07	[redacted]	[redacted]	1.3.1	N	5	375/385	375/385	262/275	out	4.45	-7.36		887	0.5	Tailwater Depth 268.5 mm
16	P-B	12-Dec-07	[redacted]	[redacted]	1.1	N	4	400	330	200	167	10.16	-4.64		862	0.5	
17	P-B	07-Dec-07	[redacted]	[redacted]	1.1	N	6.5	315/340	230/250	110/120	187	9.26	-0.28		824	0.5	Wind assisting wheel
18	P-B	07-Nov-07	[redacted]	[redacted]	1.4	N	9.5	410/405	370/375	255/260	200	6.83	-9.13		905	0.5	Tailwater Depth 257.5 mm
19	P-B	06-Dec-07	[redacted]	[redacted]	1.1	N	10.5	330/340	210/215	85/90	137	8.37	-0.87		829	0.5	Two fins on wheel badly eroded (rusted), however, minimal impact on the overall result
20	P-B	05-Dec-07	[redacted]	[redacted]	1.1	N	7	450	170/175	85/90	88	8.17		2.89	799	0.5	

Reference No.	Irrigation Area	Test date	Service point No.		Test Id	Readings & Settings at Test Commencement						Test					
						Recently rehabilita-ted	Bottom Fin Clearance	U/S Supply depth	Depth D/S of Gate	Tailwater depth	Gate opening	Flow rate from corrected volume & time	Result			Uncertainty	Test comments
						Y/N	mm	mm	mm	mm	mm	ML/day	% Under	% Over	Litres Per Revolution	Result @ 95% Confidence +/-	
21	P-B	04-Dec-07	[redacted]	[redacted]	1.1	N	26.5	360/370	280	105/110	243	9.97	-14.53		829	0.5	Bottom Clearance 26.5 mm
22	MV	30-Jan-08	[redacted]	[redacted]	1.2	N	6	500	175	107	55	6.26	-0.27		824	0.54	
23	MV	31-Jan-08	[redacted]	[redacted]	1.2	N	30	528	277	190	69	6.33	-17.92		1001	0.52	Bottom Clearance 30 mm. Upstream Supply Level 528 mm
24	MV	07-Feb-08	[redacted]	[redacted]	2.2	new bearings	10	403	290	180	123	7.28	-8.77		901	0.51	
25	MV	05-Feb-08	[redacted]	[redacted]	1.1	Y	13	520	320	155	119	12.14	-7.78		891	0.53	Upstream Supply Level 520 mm
26	MV	06-Feb-08	[redacted]	[redacted]	1.1	new bearings	15	477	270	170	118	12.04	-7.47		888	0.51	
27	SIA	21-Nov-07	[redacted]	[redacted]	1.1.1	not known	11	515/520	400	120/125	212	12.64	-12.17		925	0.58	Shortened test result, but ok. Upstream Supply Level 517.5 mm
28	SIA	23-Nov-07	[redacted]	[redacted]	1.1	Y	6	365/370	#N/A	205/210	out	7.43	-3.48		852	0.5	Gate removed during test
29	SIA	08-Feb-08	[redacted]	[redacted]	1.2	not known	12	417	295	177	169	6.74	-10.14		915	0.5	
30	SIA	11-Feb-08	[redacted]	[redacted]	1.1	N	9	388	320	150	294	11.89	-8.12		895	0.5	
31	RIA	22-Jan-08	[redacted]	[redacted]	1.2	not known	7.5	340	315	195	227	6.09	-5.26		868	0.5	
32	RIA	23-Jan-08	[redacted]	[redacted]	1.1	not known	19	485	450/440	200	276	11.54	-16.85		989	0.51	Bottom Clearance 19 mm
33	RIA	23-Jan-08	[redacted]	[redacted]	1.1	not known	13	480	250	180	144	11.51	-8.93		903	0.51	
34	RIA	24-Jan-07	[redacted]	[redacted]	1.2	not known	8	345	260	100	130	6.29	-2.35		842	0.53	
35	RIA	20-Feb-08	[redacted]	[redacted]	1.3	not known	5	362	180	59	44	3.23		2.50	802	0.55	
36	TIA	16-Oct-07	[redacted]	[redacted]	1.3	N	4	385	250	95	97	10.54		1.23	812	0.5	
37	TIA	17-Oct-07	[redacted]	[redacted]	1.1	N	5	380	325	120	308	11.83	-1.98		839	0.5	Culvert directly downstream of wheel
38	TIA	18-Oct-07	[redacted]	[redacted]	1.1	N	4	390	#N/A	220	224	13.21	-6.81		882	0.5	Culvert directly downstream of wheel. Tailwater Depth 220 mm
39	TIA	19-Oct-07	[redacted]	[redacted]	1.1	N	7.5	442/445	230	105	132	10.21	-2.44		843	0.51	Door with automatic control
40	TIA	23-Oct-07	[redacted]	[redacted]	1.1	Y	6.5	540/535	#N/A	100	118	10.23	-1.82		837	0.5	Upstream Supply Level 537.5 mm
41	TIA	24-Oct-07	[redacted]	[redacted]	1.1.1	N	6.5	420/424	315	120	215	10.28	-4.97		865	0.5	
42	TIA	31-Oct-07	[redacted]	[redacted]	1.1	N	5	485	315	170	216	10.93	-6.02		875	0.86	Fibrocrete emplacement
43	TIA	01-Nov-07	[redacted]	[redacted]	1.1	N	9	560/565	315	130	290	14.57	-7.29		887	0.5	5 mm movement on bearing at high flow. Upstream Supply Level 562.5 mm

CG - Central Goulburn Irrigation Area
P-B - Pyramid-Boort Irrigation Area
MV - Murray Valley Irrigation Area
SIA - Shepparton Irrigation Area
RIA - Rochester Irrigation Area
TIA - Torrumbarry Irrigation Area

APPENDIX C

Appendix C – 2007 REVS results for Large Dethridge meters

Reference No.	Irrigation Area	Test date	Service point No.		Test Id	Readings & Settings at Test Commencement						Test					
						Recently rehabilitated	Bottom Fin Clearance	U/S Supply depth	Depth D/S of Gate	Tailwater depth	Gate opening	Flow rate	Result			Uncertainty	Test comments
						Y/N	mm	mm	mm	mm	mm	ML/d	% Under	% Over	Litres Per Revolution	Result @ 95% Confidence +/-	
1	CG	18-Jan-07	[redacted]	[redacted]	1	not known	8	475	475	275	475	9.80	-12.98		943	0.50	
2	CG	17-Jan-07	[redacted]	[redacted]	1	not known	8	380	330	150	280	9.50	-8.40		896	0.50	
3	CG	23-Jan-07	[redacted]	[redacted]	2	not known	7	405	330	180	50	2.97	-17.22		992	0.82	
4	CG	30-Jan-07	[redacted]	[redacted]	1	not known	11	402.5	380	252.5	180	4.35	-24.05		1081	0.51	
5	CG	29-Jan-07	[redacted]	[redacted]	1	not known	9	426	426	310	426	5.41	-7.79		890	0.50	
6	CG	22-Jan-07	[redacted]	[redacted]	1	not known	4	397.5	397.5	235	398	7.43	-1.46		833	0.55	
7	CG	24-Jan-07	[redacted]	[redacted]	1	not known	7	500	495	340	500	4.33	-8.58		898	0.50	
8	CG	01-Feb-07	[redacted]	[redacted]	1	not known	7	380	355	210	380	5.47	-8.20		894	0.50	
9	CG	19-Jan-07	[redacted]	[redacted]	1	not known	7	400	310	160	400	10.99	-5.92		873	0.51	
10	CG	31-Jan-07	[redacted]	[redacted]	1	not known	8	350	200	80	350	9.80	-5.59		870	0.50	General conditions windy

CG - Central Goulburn Irrigation Area