TAURANGA CITY COUNCIL – WATER METER RENEWAL MODELLING

Ben Davies
Water Supply Network Specialist, MWH

ABSTRACT

Tauranga City Council (TCC) adopted and implemented universal water metering in the early 2000's. The experiences and outcomes of doing so are discussed in detail in J Sternberg's paper "Water Metering – the Tauranga Journey".

Around 39,000 of their fleet of 50,000 water meters have now been in service for nearly a decade. As the fleet of water meters ages, TCC wish to supplement their existing reactive meter replacement program with a proactive program to effectively manage these assets, and to protect the associated revenue stream.

It is well documented that as water meters age, they tend to under-record the volume of water passing through them. MWH has worked with TCC to develop a model which performs the calculations necessary to estimate the ongoing financial cost of this under-recording (known as under-registration), and balance it against the capital costs of replacing meters. The main model output is a meter renewal program.

This paper outlines the requirements, processes and outputs of the model, and presents the results of testing of the first batch of meters replaced according to the model results.

KEYWORDS

Asset Management, Water Services, Non Revenue Water, Domestic Water Meters

1 INTRODUCTION

It is well documented that as mechanical water meters age, wear of the mechanical components leads to increasing under-registration of the water volumes passing through the meter. Where meters are used to generate revenue, this results in a direct negative financial impact on the water supplier. With Tauranga's fleet of approximately 50,000 meters, an inaccuracy of 1% could amount to $100k/year in lost revenue.

The magnitude of under-registration is affected by total throughput and annual throughput. It has been noted that various meter makes and models also perform differently. If the magnitude of the under-registration can be quantified, it can be balanced against the capital cost of replacing the meter, and the whole-life cost of the meter can be estimated for different replacement times. Comparison of these whole-life costs can determine the optimum time for replacement of the meter. It may also provide useful data for future procurement options.

TCC officers have historically relied upon analysis of trends in meter reading and consumption data to identify meters requiring investigation. However, in recent times they have started to explore the possibility of supplementing trend analysis with economic analysis to reduce apparent losses through meter under-registration, and to improve budgeting practices for meter renewals.

2 MODEL DESCRIPTION

The meter renewal model developed by MWH is built and runs in MS Access. It takes inputs (in MS Excel format) from meter inventory and meter readings databases, and combines these with information obtained from meter test results to calculate the likely accuracy and optimum replacement date for each meter in the fleet. Once calculations are complete, the model produces reports which can be printed out or exported to MS Excel spreadsheets for further analysis.

2.1 REQUIRED DATA FOR CALCULATIONS

The model requires 4 sets of data: meter details; meter readings; financial information (including tariff structure, meter replacement costs and discount rate); and meter accuracy curves (in the form of equations).

If supplied in the appropriate MS Excel spreadsheet format, the meter details and meter readings data sets can be imported automatically into the model. The small amount of financial information required is entered manually into the model through an input parameters dialogue box.

Meter accuracy curves are derived from the results of meter testing, and a curve can be created for each meter type in the fleet if testing results are available. In the current version of the model the curves are represented by a straight line, with an equation of the format y = mx + c, as shown below.

Accuracy % = [Coefficient C1] x [Meter Register Value (kL)] + [Coefficient C2]

To create the meter accuracy curves in the model, the two coefficients C1 and C2 are required by the model, and are entered into the model manually.

2.2 DATA ANOMALIES

Once meter information and meter readings have been imported, the model performs a total of 11 data checks to highlight any potential issues with the data. Amongst others, these checks include identification of negative readings, negative average annual consumptions, meters with no readings and meters with no installation date.

Once meters with potentially erroneous readings have been identified, meter readings can then be checked, and if necessary some readings can be excluded from the set the model uses to calculate meter performance. If errors are found to be too pervasive (for example if a meter has no readings at all), then the meter concerned can be highlighted for further investigation and excluded from the analysis altogether.

As an example, a check is carried out for negative meter readings. Where negative readings are found, these can be excluded. Figures 1 and 2 below show firstly the raw meter reading data for a meter with negative readings, and secondly the cleansed data used for calculation of meter performance.

Figure 1 - Invalid Data in the Raw Meter Reading Data

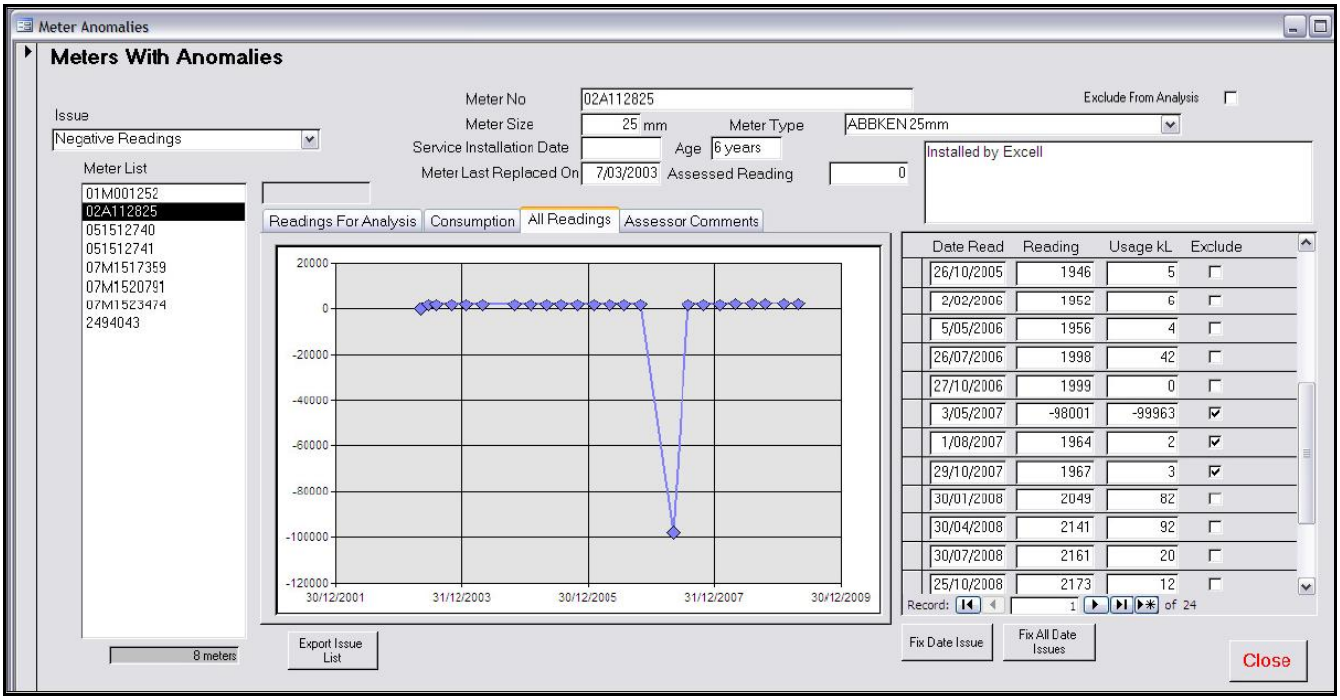
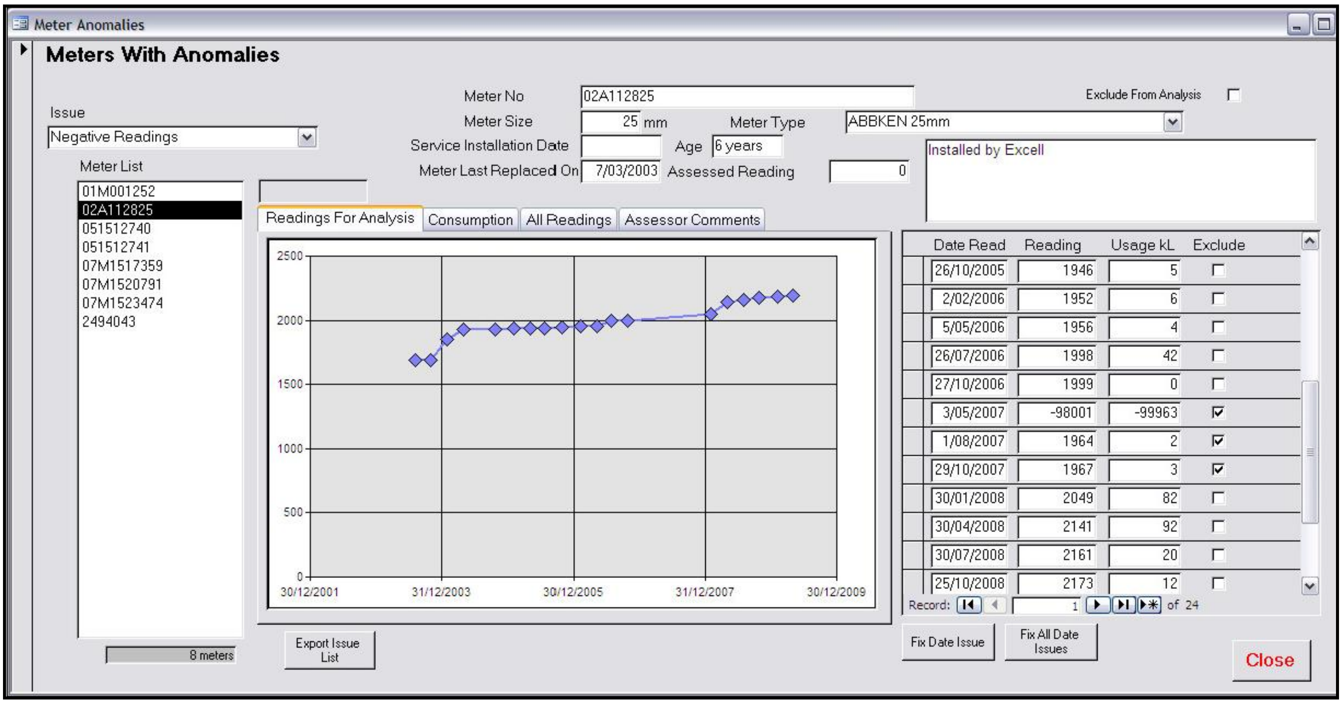


Figure 2 – Exclusion of Invalid Data from the Model Analysis



As can be seen, the first reading in 2007 is clearly erroneous (likely as a result of misreading of the meter, or a data recording error), and is therefore excluded from the analysis. Looking closer, the two subsequent 2007 readings are also found to be smaller than the final 2006 reading. This would result in negative consumption, and so these are also removed from the analysis.

Once erroneous data has been removed, the performance of the meter can be recalculated.

2.3 ASSESSMENT OF ECONOMICS

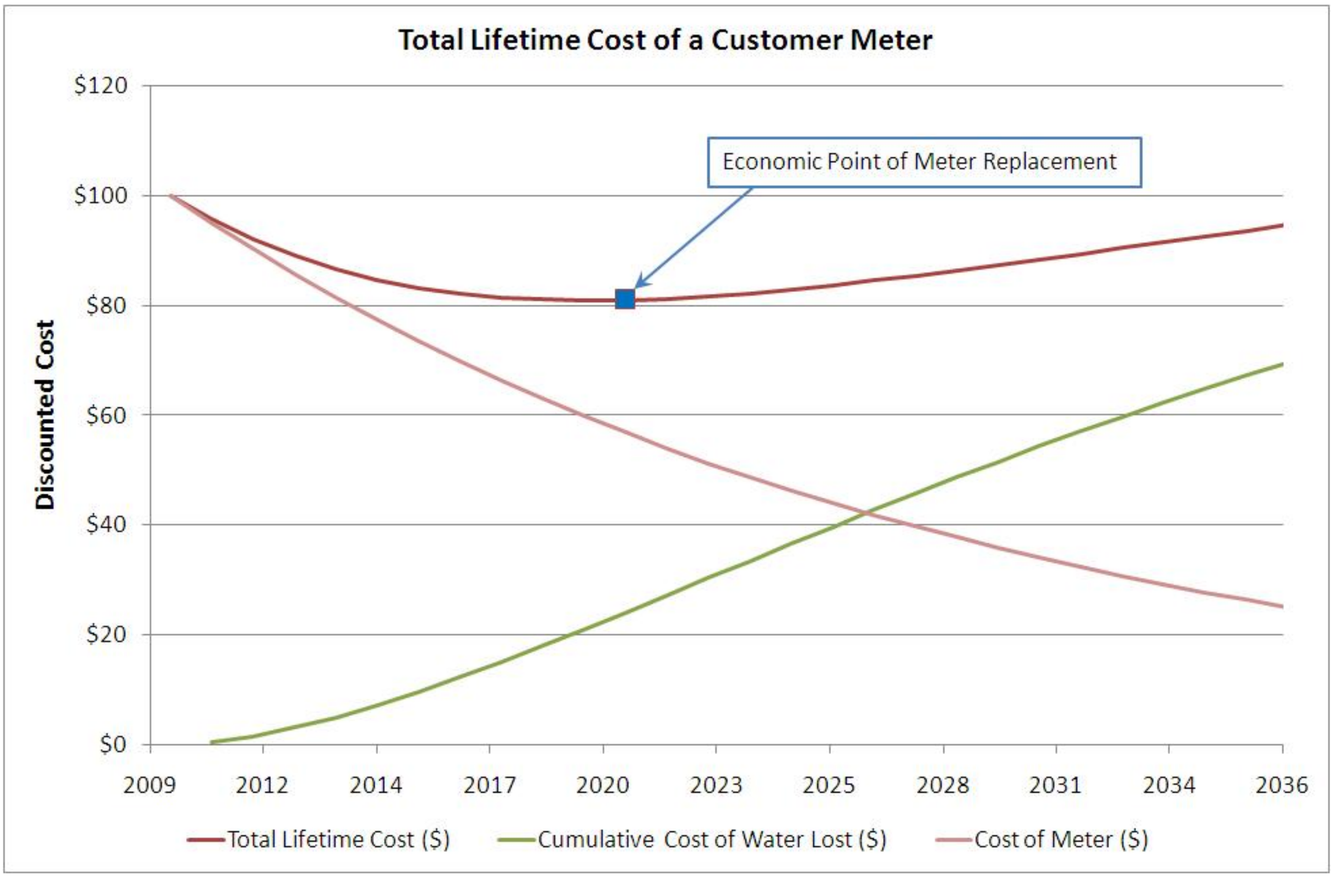
Once anomalies have been dealt with and the set of readings for each meter has been finalized, the model can calculate the most economically beneficial date for replacement of each meter.

The further into the future a meter is replaced, the more the capital cost of replacing it is discounted, and the less the Net Present Value (NPV) of that capital cost is. However, the further into the future a meter is replaced, the more water is lost through under-registration, and the higher the total cost of this water loss. When these two costs are added together, they form the total lifetime cost.

If this total lifetime cost is calculated for meter replacements in each of the twenty years following initial meter installation, it is dominated by the meter replacement cost in early years, and by the cost of water loss in later years. However, somewhere between these two extremes, there is a point where both costs are reduced so that the total lifetime cost is minimized. This is when replacement of the meter is most economic.

Figure 3 below illustrates how meter replacement cost and cumulative water loss costs combine in each year to create a total lifetime cost of a meter. In the example shown, the total lifetime cost is minimized if the meter is replaced in 2020, meaning this is the economic year of meter replacement.

Figure 3 - Example of Economic Point of Meter Replacement for a High-Throughput Meter



Once the data set to be used for modelling has been finalized, the model can be used for calculation of economic replacement dates for each meter. The general process followed by the model for each meter is as follows.

1. The average throughput per year is calculated from available meter readings data, i.e. average annual consumption.

2. This is used together with the registration at the last reading date to calculate the likely current registration, and likely registration in future years.

3. The accuracy curve is used to determine inaccuracy in the current year.

4. The tariff structure is used to calculate the value of water loss in the current year.

5. The cost of replacing the meter is then added to the value of water lost, to give a total lifetime cost of replacing the meter in the current financial year.

6. Steps 2 to 4 are repeated for the next financial year.

7. The Net Present Value (NPV) of water lost in the next financial year is calculated using the discount rate, and added to the value of water lost in the current year to give the NPV of total water lost.

8. The NPV of replacement of the meter in the next financial year is calculated using the discount rate.

9. NPV of total water lost is added to the NPV of replacing the meter in the next financial year, to give a total lifetime cost.

10. Steps 6 to 9 are repeated for each subsequent year for the desired time span, to build up a curve of total lifetime costs of replacing the meter in each financial year.

11. The financial year in which the total cost is minimized is identified as the optimum economic year of replacement for the meter.

2.4 OTHER CRITERIA FOR REPLACEMENT

Although utilising economics as described above is the most financially beneficial method of identifying meters for replacement, differing constraints on meter life may exist for different water authorities. They may therefore find they need to consider other factors in creating a meter replacement program which addresses all concerns.

To allow the water authority to determine which strategy is most applicable, the meter renewal model can be set to recommend replacement based on four default criteria (including economic analysis):

1. An age limit (yrs) when the assessed life of the meter is reached. This has however been shown to have little bearing on the accuracy of the meter.

2. An endurance limit (kL) when the meter reaches a set registration. This has been shown to have significant bearing on the accuracy of the meter, although changes in water use profile throughout the life of a meter can mean it can have very little bearing on annual water loss.

3. A permissible accuracy limit (-%) when the estimated accuracy of a meter (based on test results from similar meters) reaches a set figure. As above, changes in water use through the life of the meter can mean this has little bearing on water loss.

4. Economic analysis as described in Section 2.3.

If all of these four criteria are activated, the model can generate a replacement date for each. To avoid leaving meters outside these acceptable criteria in the ground, the recommended replacement date produced by the model will then be the earliest of the four replacement dates (or however many criteria have been activated).

3 OUTPUTS

The two key outputs of the Model are a prioritised list of meters for replacement, and a list of meters with anomalous readings for investigation. Use of these two outputs is assisted by the availability of reports on individual meters and meter fleet statistics.

3.1 METER REPLACEMENT PROGRAM

The replacement program produced by the model contains:

- For each year, a list of meters identified for replacement.

- For each meter, the meter number, address, make and model, most recent registration and a number of modelled outcomes such as age at replacement, estimated lost revenue and estimated accuracy of the meter.

This report is in a format which can be issued directly to a work team to carry out the replacements. The model also makes it possible to order the meters in a number of ways, for example by suburb, by manufacturer or by lost revenue. In practice, multiple years worth of replacements might be grouped together for issue to a contractor for tender.

3.2 METER ANOMALY REPORTS

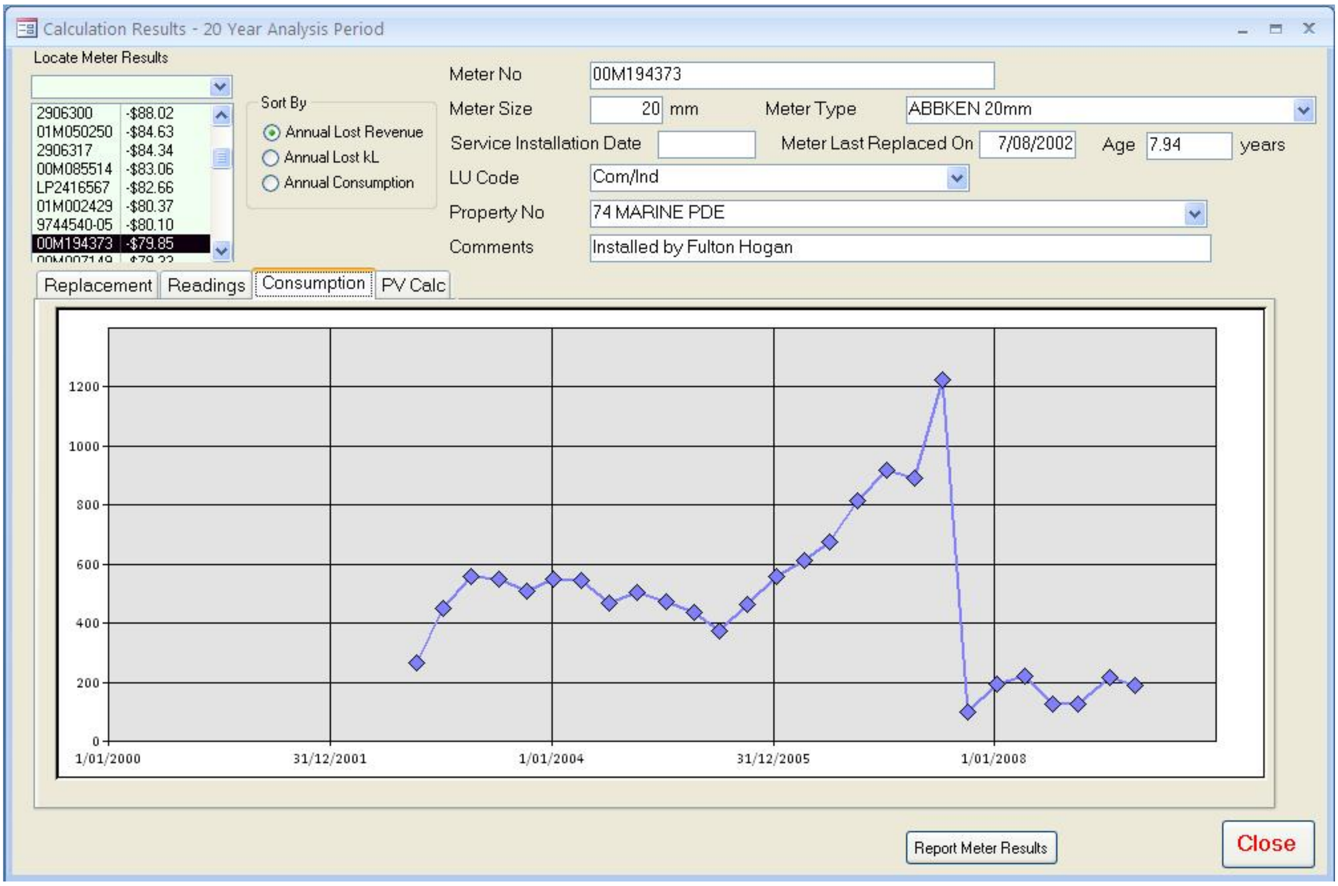
Once anomalies have been identified, the model can export a list of the meters containing each anomaly to a spreadsheet. These can then be targeted for investigation.

3.3 INDIVIDUAL METER REPORTS

Once the model has been run, it is possible to interrogate the data with regards to individual meters. This is a useful tool once the replacement program had been generated, as it allows the details behind individual meter assessments to be verified, and allows the user to ensure that meters identified for replacement are free of data errors and are in fact operating as the model has assessed.

Take the example of a meter which has been registering high flow for a long period of time, but in the last year water use has changed (for example the owner may have changed or a leak on the property may have been fixed) and water use has significantly dropped. In this situation, annual lost revenue through under-registration will be significantly over-estimated by the model. Figure 4 below shows a report from the model where this has occurred.

Figure 4 – Individual Report Showing Drop in Consumption



As identification of issues such as these are not yet possible in the model, interrogation of the individual reports in the model is a good final check before the replacement program is finalized.

3.4 METER FLEET STATISTICS

As well as a replacement program and individual meter reports, the model is able to produce statistics on the meter fleet as a whole. These can be useful for building up a picture of the meter fleet, or in identifying any areas or types of meters which could be of particular concern.

Reports on meter fleet statistics include average, minimum and maximum registrations, estimated accuracies and revenues lost for each meter model and size. Graphs can also be produced showing number of meters in bands for annual consumption and registration, and a graph is available showing required expenditure in each financial year if the replacement program is implemented.

It is also possible to export the results of the modelling for each meter into an MS Excel spreadsheet. Although the resulting file can become quite large, it allows all the flexibility and presentation options available in MS Excel.

4 TCC CASE STUDY

4.1 OVERVIEW

Before modelling could take place, an understanding was required of conditions under which the meters operate and how the Tauranga fleet of meters is deteriorating over time.

To assess this, TCC logged a selection of customer meters to assess the range of flows typically experienced by customer meters in Tauranga. Alongside this, testing of a sample of meters at three different flow rates was carried out. The results of this testing were then collated, and a single accuracy curve was created for the fleet of meters.

With this accuracy curve, the MWH Meter Replacement Model was then able to produce an estimate of the likely inaccuracy of each meter, based on its total throughput. Previous readings were then used to calculate the average annual throughput, and therefore the likely cost to TCC of the under-registration. This was then balanced against the capital cost of replacing the meter.

The model then produced a recommended replacements programme. A number of the identified meters were then retrieved and tested on an ISO-compliant testing rig, to begin building up a data set with which to assess the effectiveness of the modelling.

4.2 DATA COLLECTION

4.2.1 METER TESTING

TCC have obtained meter test results from two sources: in-house random testing of meters undertaken in December and January 2007/08; and ongoing in-house testing of meters flagged by billing as potentially faulty.

Testing was carried out on a purpose-built rig in Tauranga by TCC. This rig was not certified under ISO 4604, but to assess whether the testing was accurate, some of the tested meters were sent to an independent testing authority, where they were tested again on a certified ISO 4604 testing rig. The results confirmed a good correlation with the in-house testing results.

Results were used from 622 tests carried out on random meters. Results were also used from 2,792 tests carried out on meters flagged by billing as possibly requiring replacement. It should be noted that as the accuracy curve is applied to “healthy” meters, test results from faulty meters would skew the resulting curve. For this reason, any results falling outside the -10% to 10% accuracy band were excluded from the results.

Tests on each meter were carried out at three rates of flow: 1.7 l/min; 10 l/min, and; 50 l/min. After each test at each flow rate, the volume registered by the meter was compared to the volume by weight measured on scales, and the error for that meter at that flow rate was recorded.

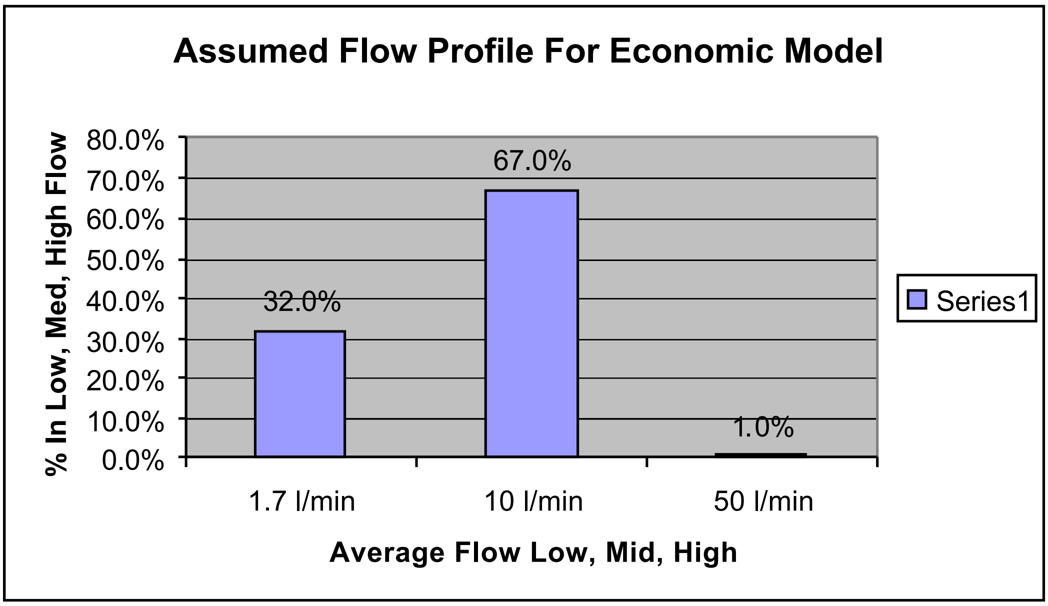
4.2.2 CUSTOMER USE PROFILING

TCC used methodology outlined by Omundsen (2007) to transform the three different flow rate tests outlined above into one overall meter accuracy figure. To accomplish this, a profile of the flows experienced by the average meter in Tauranga is required. From this profile, each of the three tested flow rates were then weighted to create a Total Weighted Accuracy-Deviation (TWA). This represents the overall accuracy of the meter when subjected to the average Tauranga flow profile.

Customer use profiling was carried out in Tauranga by logging a representative cross-section of customer meters installed on the network. Loggers were initially set to record at 1-minute intervals, but logging has since been repeated at shorter intervals to increase accuracy.

Customer profiling results were used to estimate how much of each of the test flow rates obtained in Section 4.2.1 should contribute to the TWA. This is shown in Figure 5 below.

Figure 5 – Results of Customer Use Profiling



As can be seen, very little of the flow in the average Tauranga household is as high as 50 l/min. For this reason, the high flow rate test for meters has recently been reduced from 50 l/min to 35 l/min. This will in future lead to a change in the calculation of the TWA.

4.2.3 METER ACCURACY CURVES

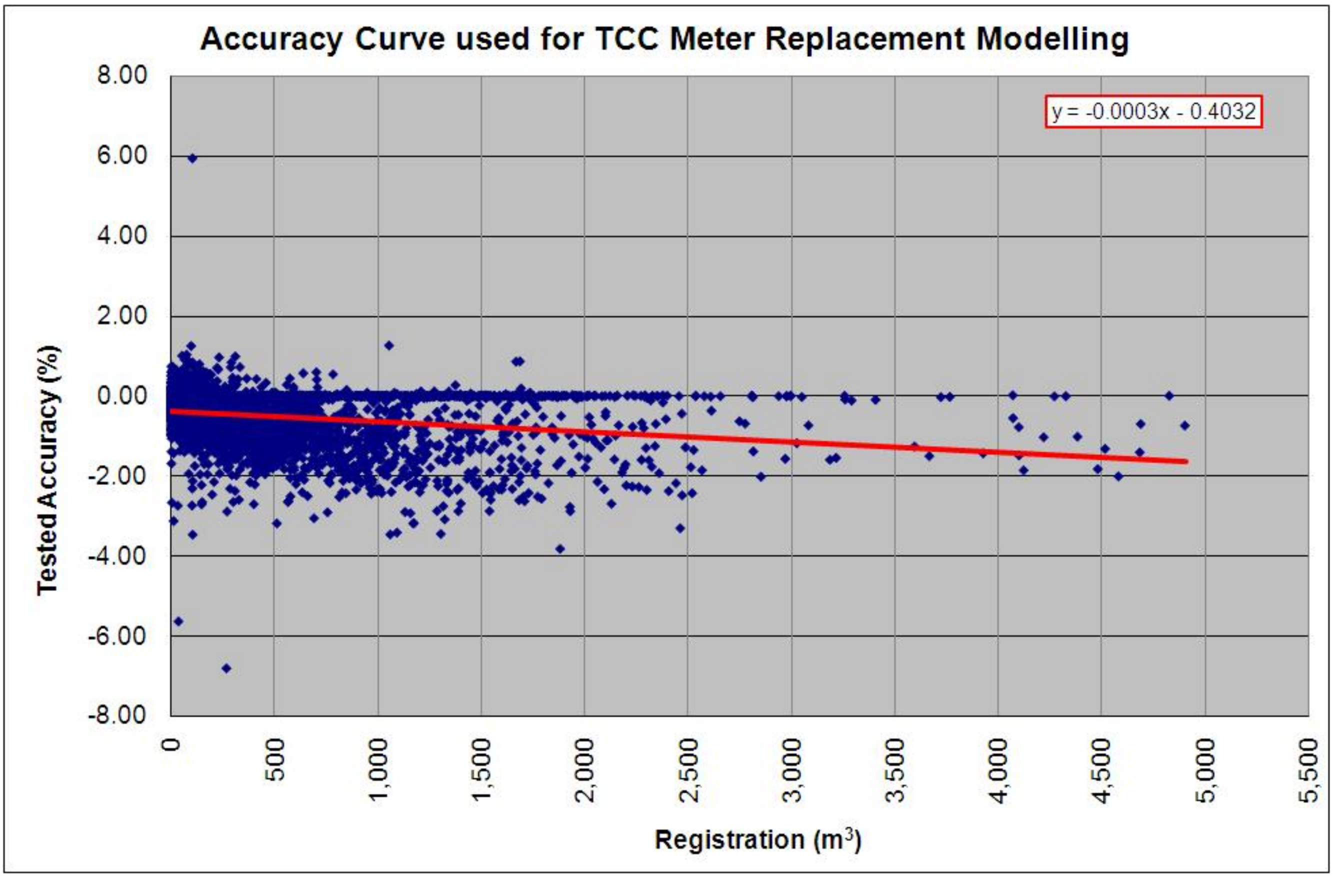
As mentioned in Section 2.1, the accuracy equation used by the model requires values for C1 and C2 to be entered for each meter make and size.

Values for C1 and C2 were produced by plotting test results from Section 4.2.1 above and observing the relationship between meter accuracy and meter register value.

In the first run of the model, for the purposes of simplicity, no distinction was made between makes or sizes of meters, and test results from all tested meters were combined to create values for C1 and C2. The resulting equation was applied to all makes, models and sizes of meters. As the meter fleet is predominantly 1.5 m^3/hr Kent MSM models on 20 mm manifolds, it is thought that the results should be reasonably representative of these meters.

Figure 6 shows the results of this exercise, including a trend line with an equation showing values for C1 and C2. This curve and equation corresponds reasonably well with studies of meter fleets of similar size and composition from Australia.

Figure 6 – Results of Meter Testing



4.2.4 METER INFORMATION

A template Meter Information spreadsheet was supplied to TCC, which specified the format in which data was required. Fields in the spreadsheet related to meter ID number, age, make and model, size, location and the date of installation in its current position.

The required information was all available from TCC's Hansen asset management system. The required information was exported to Excel and imported to the model without issue.

4.2.5 METER READINGS

A template Meter Readings spreadsheet was also supplied to TCC, and this was used to import each meter reading. Each line in the spreadsheet required a meter number, date of reading and register value.

TCC meter readings are stored in an Origen-Ozone financial system. This data was exported to Excel and imported to the model without issue. A number of anomalies and inconsistencies within this data were highlighted once the data was imported, and these were highlighted for investigation as discussed in Section 2.2.

4.2.6 FINANCIAL INFORMATION

For the model to be able to carry out financial analysis, the current charging regime and capital costs of replacing the meter were required. In addition, a discount rate is required, so that operational and capital costs deferred into the future could be quantified as a Net Present Value.

These global factors were entered into the model without issue.

4.3 RESULTS

4.3.1 SUMMARY OF MODEL FINDINGS

The overall system results for the -5% to 1% accuracy range are presented in Table 1 below.

Key results were an average -1% accuracy, an estimated 69,278 kL of unaccounted for (lost) water per annum, corresponding to around $100,000 in revenue per annum.

A total of 33 meters deemed to have an extreme accuracy value, that is outside the adopted accuracy tolerance limits, are excluded from the analysis as their calculated potential lost water and revenue is unrealistic.

Table 1 - System Statistics from TCC Meter Replacement Modelling

Total Number of Meters Analysed	47,777
Total Meter Replacement Cost	$5,993,243
Meter Age	
Average	6.1 yrs
Maximum	29 yrs
Registration Values	
Minimum	0 kL
Average	3,062 kL
Maximum	80,720 kL
Accuracy Rate	
Minimum	-5%
Average	-1%
Maximum	0%
Estimated Total Annual Un-Accounted For (Lost) Water	69,278 kL
Estimated Total (Potential) Revenue Loss	$97,119 per year

The previous strategy for meter renewals was roughly based on throughput (2,000 kl) and age (10 years). There has as yet been no calculation of the potential financial benefit of changing to an economics-based strategy, but this calculation has been recommended is can be carried out by the model. It is hoped that this will be completed soon.

4.3.2 TESTING OF REPLACED METERS

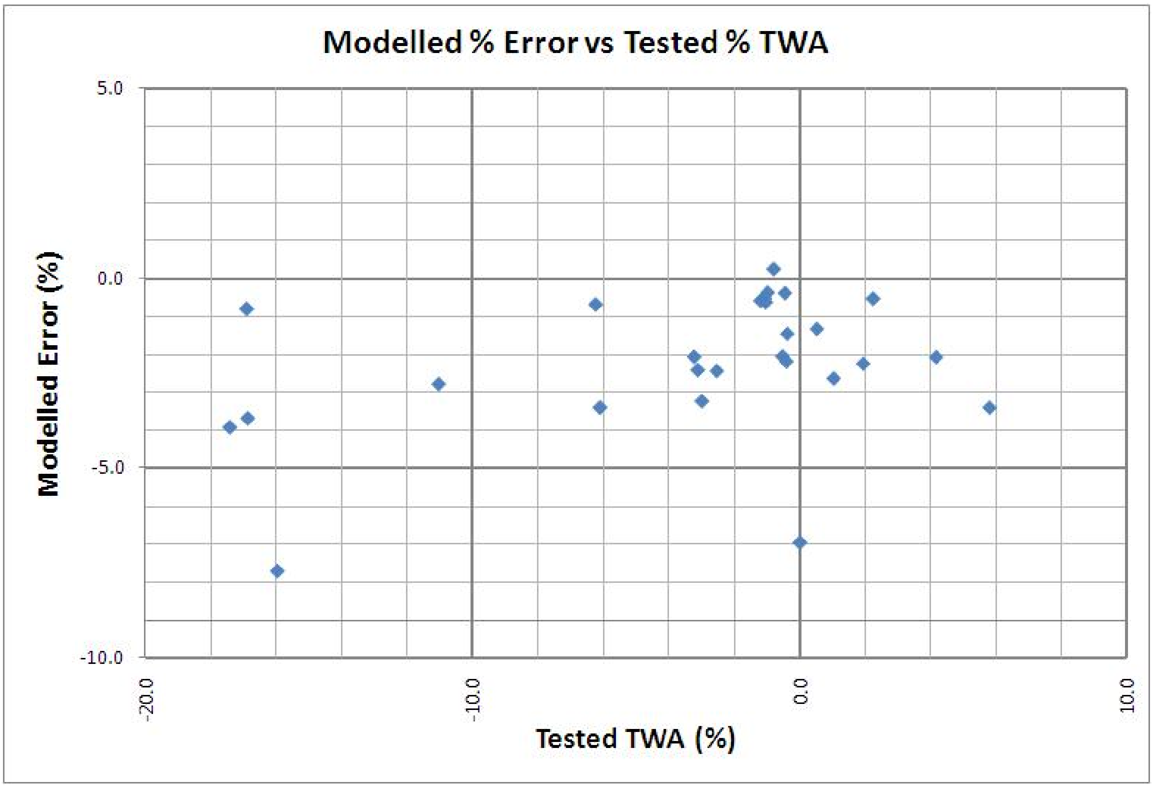
For TCC, the model produced a program of 280 meters for replacement in the 09/10 financial year. TCC was able to retrieve and test 32 of these on a test rig conforming to ISO 4604 standards.

The meters were tested at 1.7, 10, and 35 l/min, and the resulting errors at each flow rate were recorded. The Total Weighted Average of these readings (as described in Section 4.2.1) was then compared to the model predictions. Tested accuracies outside the -20% to +10% range were excluded from the assessment to eliminate any failed meters.

It should be noted that although the tested high flow rate was 35 l/min, for simplicity the 50 l/min weighting was applied to obtain a TWA figure. This could lead to some minor inaccuracies, but for the purposes of this early study it was thought to be sufficient.

The tested TWAs were then plotted against the predicted accuracies, and the results can be seen in Figure 7 below.

Figure 7- Comparison of Modelled and Tested Accuracies



As the sample size is small, it is hard to draw any conclusions from this data. It should also be noted that 19 of the 32 meters retrieved and tested had a registration of over 10,000 kL. This is in excess of any of the meters previously tested, and the ability of the model to predict accuracy in these extremes is therefore thought to be limited.

However, as testing of replaced meters continues, the patterns that emerge can be used to further refine the accuracy curves used in the model.

4.3.3 FUTURE MODEL DEVELOPMENTS

As with all models, the meter replacement model will become increasingly useful and accurate if the results of testing are fed back into the model.

It was understood from the start that using only one accuracy curve was overly simplistic. One of the first changes will be to investigate the use of separate curves for different meter makes and sizes, and for different levels of annual throughput. These accuracy curves can then be further refined, as results of further testing are incorporated. In addition, investigations will be undertaken into the use of an alternative accuracy curve (instead of the current single straight line). It is thought this might produce a better fit for the test data, especially at higher registrations.

The model has also highlighted anomalies in the metering database. Causes of these are being investigated and addressed internally at TCC.

To predict future consumption, the model currently averages consumption over the lifetime of the meter. It has been recognized that this fails to take changing circumstances on the customer side into account (as discussed in Section 3.3), and it has therefore been suggested that the model should predict future consumption based only on the last year or two of data.

Previous testing has been largely confined to meters with a registration value below 5000kL. Further testing of meters at the higher end of the curve is required to determine the actual performance and likely accuracy values.

As well as alteration of the accuracy curve (discussed above), consideration is being given to removing the endurance limit criteria as a means for identifying meters for replacement.

Potential improvements have also been identified in post-processing of the renewals program. In Tauranga it was found that a significant proportion of the replacements were due to take place between 2019 and 2023. It has been suggested that if some of these meters were replaced earlier than 2019 or later than 2023, increased costs in terms of economics could be offset by reduction in logistical and management issues. Ways of bringing such factors into the model are being investigated.

It is also thought that there could be cost reductions in replacing meters in a certain area at once, and that these might offset financial costs of replacing meters before or after their optimum replacement year.

4.3.4 INTEGRATED METER MANAGEMENT STRATEGY

Although this paper has focused on proactive identification of meters to be replaced, reactive identification of meters requiring replacement will continue to be an equally important part of the meter replacement program.

TCC's current use of billing data to identify failed meters will continue, and statistical methods for recognizing meters with unexplained reduced consumption will continue to be developed. It is thought that it may be possible to use the model supplied by MWH to assist with this if procedures can be sufficiently automated.

4.4 CONCLUSIONS AND RECOMMENDATIONS

Following the first round of meter renewal modelling, it is clear that although there is room for improvement, there will be significant benefits from the exercise. It has not yet been possible to assess the purely economic benefits of the exercise, but historically the renewals strategy was a conservative program based on replacement when a meter reached 10 years of age or 2,000 kL throughput.

Comparison of this existing renewals strategy and the economics-based strategy is currently being undertaken. With estimated potential revenue loss is in the order of $100,000/year, TCC are very optimistic that significant savings will result from the economic approach.

ACKNOWLEDGEMENTS

I would like to thank Chris Egbars and Kevin Atkins of MWH Australia, and John Sternberg and Celia Bowles of TCC for their support and assistance.

REFERENCES

Omundsen, C (2007) 'Optimal Replacement for Domestic Water Meters'