MAXIMISING REVENUE FOR – METER REPLACEMENT STRATEGY

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ABSTRACT

A domestic meter replacement strategy was required for a Regional Council in Australia. The strategy was to be based on meter accuracies which should ultimately culminate into a financial assessment of an optimum payback period. An initial desktop assessment was conducted on domestic meter replacement strategies that have been reported by utilities and researchers in Australia and internationally and laboratory testing of the accuracy of the domestic meters was to be planned over a secondary project phase.

This paper reports on the findings of the theoretical benchmark phase. The project team considered that the optimum replacement strategy be based on the interfacing the cumulative volumes distribution within Council's database with equivalent extrapolated ages. The benchmarked age related meter accuracies were corresponded with the cumulative volume categories.

An optimum cumulative volume for Council was found at the maximum weighted error which corresponded with a cumulative volume of 3.9 ML. A financial assessment confirmed the payback period to be within one year, based on meter replacement costs and net present value of cash flows.

A practical replacement strategy for Council was mapped using GIS technology wherein meters that were characterised by high cumulative volumes and high average consumption inherited the highest priority.

KEYWORDS

domestic meters, meter errors, meter replacement, GIS, consumption

1 INTRODUCTION

In 2010, Council commissioned the Infrastructure Alliance (IA) to review Council practices relating to water demand management and provide an action plan to improve specific practices. Some of the challenges reported to Council related to aging assets, specifically domestic water meters. Council has taken due intent to actively address the concern as it primarily relates to water conservation and drives Council's strategy to reduce operational costs.

The IA recognises that improvements in the adequacy, consistency and reporting of current urban and non-urban water metering practices reinforces and demonstrates the capacity of Council to acclimatize to the ever increasing water demands and to deal with the demands responsively and fairly. This commitment also reflects on Councils direct accountability to contracted and non-contracted stakeholders. Addressing the concerns surrounding the aged domestic meters is aligned with Council's key strategic infrastructure services priority and its corporate value statements of providing services to communities of Value, and that of Integrity with Accountability and Responsibility.

The IA was commissioned to prepare a domestic meter replacement plan based on technical and financial criteria. The IA Water Demand high Level Strategy Factual Report (2010) yielded the following data summarised in Table 1.

Table 1: Residential metered consumption per Area and as a percentage of total consumption of Council

	Area 1	Area 2	Area 3

	Area 1	Area 2	Area 3
Residential Metered Consumption per Area (Percentage of Total Consumption)	92%	8%	<1%
Residential Metered Consumption as a Percentage of Total Consumption of Council	59%		

A past study tabled the level of Non-Revenue Water (NRW) as a key performance indicator of efficiency. A water balance software was used to compute the water balance and non-revenue water (with its individual components, including apparent losses) while also indicating the level of accuracy of the NRW calculation. A key assumption that was noted in the report was that the water meter errors were based on the age of meters due to a lack of calibration records. Estimates of the meter accuracy ranged from 100% for newly installed meters to 75% for meters that were ten years and older. The final recommendation that was noted in the report was to replace meters that have measured greater than 4000 kl (4 ML) to date. The report further recommended that a sample of meters be tested to determine the accuracy of the readings based on the volume that has passed through the meter. While Council were implementing the sampling and testing program, further justification through a desktop research carried out in order to understand the deterioration of meter accuracy with age and volume.

This paper summarises the approach and research carried out to justify the systematic replacement strategy. A key influence to such a strategy is the over-arching and inherent characteristic of increasing meter error with age and cumulative consumption volumes as recorded by the meters. The paper will highlight results from a desktop research of local and international thinking and practices regarding this complex influence. The financial and spatial assessment produced in order to guide Council on the chosen implementation strategy will be illustrated.

1.1 OBJECTIVES

In the face of the contradicting drivers of growing demands and water conservation, there is an increasing need to ensure that measured consumption volumes of domestic water have minimum error. A corresponding strategy to replace the aged and resilient-compromised domestic meters would be two pronged, viz. focus on financial return to address growing demands and funding of new infrastructure, and a front-end effective reduction of apparent losses.

The objectives of the assessment are summarised below:

- desktop analysis benchmarking of metering error margins
- analysis of domestic meter data base
- GIS spatial representation of analysis
- prepare first principal’s estimate of cost based on meter replacement plan
- analysis of expected revenue gains, NPV and pay back
- GIS spatial representation of replacement plan
- meter specifications, Schedule of Quantities for meter replacement plan.

The assessment area includes the amalgamated townships of the Council which had a combined population roughly around 120,000. The two pronged strategy thus aims to address the amalgamated area synergistically to improve effective demand management through Council.

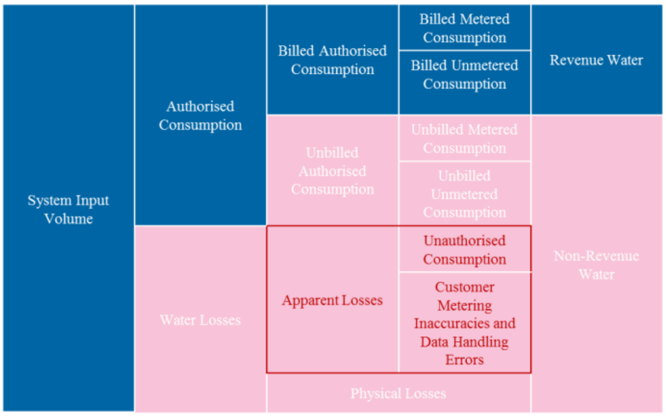
2 BENCHMARKING OF METER ACCURACIES

2.1 WATER METER ACCURACY AND APPARENT LOSSES

Every volume of water that is delivered through a meter, that is not registered, would be considered as supplied free of charge by the supplying Council. In such cases, Council derives no or negative economic benefit for the service provided for that particular custody transfer point. This unaccounted for volume of water has a significant impact in the Councils water balance.

Apparent losses are in many cases the most expensive water losses that a water system would encounter. There are four main reasons for apparent losses; meter accuracy error, data transfer errors, data analysis errors and unauthorised consumption. Water meter accuracy error is considered to be a significant component of the apparent losses in a water system and largely depends on a number of factors, viz. the right choice of meter technology (displacement or velocity type), the correct sizing and installation, the replacement frequency etc. followed by the Council.

Figure 1: IWA Water Auditing Accounting Standard

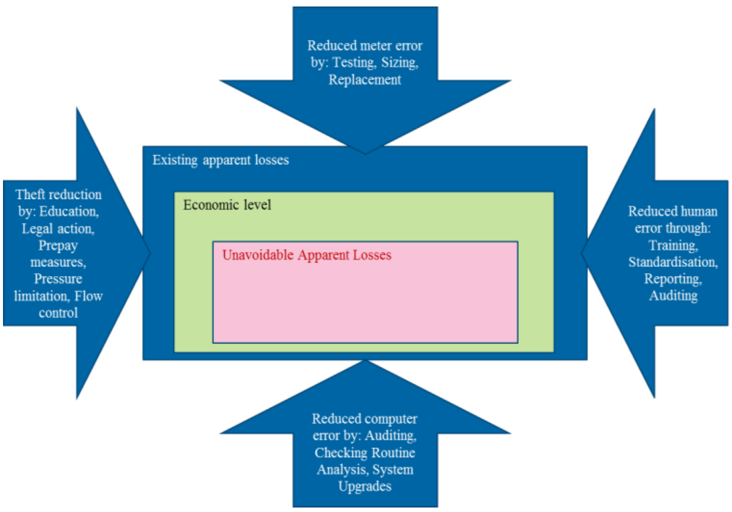


The IWA Auditing Accounting Standard for non-revenue water also recommends a systematic reduction of apparent losses. Figure 1 notes the generic sources of apparent losses. Council intends reducing the identified apparent losses by focusing on appropriate meter testing, sizing and a systematic meter replacement plan as illustrated in Figure 2 below.

2.2 UNDERSTANDING THE CAUSES OF METER UNDER READING ERRORS

In order to validate or justify a meter replacement program based on meter inaccuracies, it is vitally important to understand the possible root causes (failure mechanisms) that lead to meter inaccuracies (failure mode).

Figure 2: Generic sources of apparent losses



The variability and severity of the failure mechanisms determine the level of risk and confidence in the meter inaccuracy.

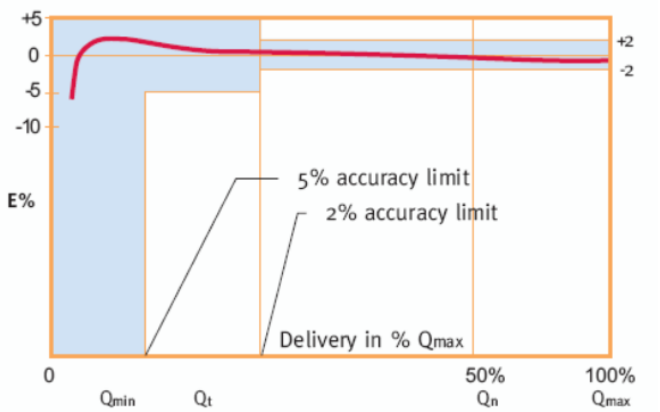
The ISO standard (ISO 4064-1, 2nd Edition, 1993) defines the performance of any type of water meter by reviewing four critical points along the flow range: Qmin, Qt, Qn, Qmax.

- Qmin is the minimum accurate flow, accuracy of ±5%
- Qt is the transitional flow, at which the meter will be stable in performance, accuracy of ±2%
- Qn is the meter's nominal flow
- Qmax is the maximum flow (it is determined as being twice the nominal flow).

Figure 3 shows the ideal scenario for a typical brand new Multi-jet meter. Older meters would have an accuracy curve that is shifted outwards from the ideal ±2% accuracy band. The variability at low flows is much greater than at medium and high flows, the error curve is steep until reaching the minimum flow rate.

Consequently the uncertainty about the real performance of meters at low flows will always be greater than at higher flows. However it should be noted that every meter type has its own rate of decay of the accuracy with time. (Arregui el, 2006).

Figure 3: Error curve of a water meter (Sharon Yaniv)



Water meter error measurements are not constant and independent of flow rate. Two significant parameters influence the degree of meter error:

- The first is the water consumption pattern of the user, which describes the actual flow rate passing through the meter. This parameter requires intensive (and costly) consumption data collection of the individual user on a high frequency sampling rate in order that low, medium and high consumption rates and cumulative volumes are differentiated. Council records consumption data (for billing purposes) on a six monthly basis. This period is considered quite widespread and provides a low level of confidence in the consumption patterns of individual users. It is worth noting that the authors (Arregui et al., 2006) have also carried out water consumption measurements in different cities in Spain and South America. Measurements were made for different types of households in order to identify the consumption behaviour of the users and the flow rates passing through the meters. Another parameter that Arregui et al used for the stratification of the households is the monthly volume of water consumed. The authors also found that the most important value to review in a water consumption pattern is the volume consumed in the lower range. Amongst the elements affecting the volume of water consumed at low flow rates, two of them stand out: private domestic storage tanks and leaks inside the households, usually in faucets and toilets.

- The second parameter is the necessary information about the metrological performance of the meter at different flow rates. Council are currently extracting on a sample basis domestic meters from the supply network, for laboratory testing. The testing methodology would be required to meet the Australian standard for urban and non-urban metering and testing procedures, which regulate the testing process to include low, medium and high flow rates.

In summary, some of the more common contributors to meter errors are:

- Water consumption patterns: As noted above, a favourable consumption pattern, wherein there are negligible consumption volumes at low flow rates, would allow utilities to maintain an in-service domestic water meter for a longer period and improve accuracy of consumption volumes. On the contrary, an unfavourable consumption pattern will increase metering error and meters replacement frequency. Additionally it should be noted that a consumption pattern with high flow rates, close and above the maximum flow rate of the selected meter, the meter would degrade at a faster rate. Detailed water consumption patterns are vital for meter selection procedures.

- Water quality: both velocity and displacement meter types are affected by water quality, especially in the case of suspended solids and depositions build up. The actual effect of water quality is difficult to predict in advance and generally has to be tested for the real conditions of the water supply system (Arregui et al). In-situ volumetric tests tend to be the favoured method for determining the effect of water quality on domestic meters. Positive displacement meters may stop when a particle bigger than the spare space between the piston/disc and the chamber passes through the strainers of the meter. Although this element is designed in such a manner that in theory this cannot happen, practice shows that it is possible. Solids deposition as a result of the system water quality is a contributory factor to the age and efficiency of the meter if maintenance of the meter is not done. The economics of meter replacement when judging on age, generally assumes zero maintenance removal of such depositions.

- Environmental Conditions: Meters installed outdoors are subject to extreme weather conditions. High temperatures may deteriorate plastic components and even deform them. On the other hand, low temperatures, below freezing, may increase the pressure inside the meter above the maximum allowable value.

- Mounting position: Some velocity meters may deteriorate if they are not installed in the correct position. An incorrect mounting position of the meter may increase the friction of the moving parts. The effect on the effective drag torque may be more significant at low flows. (Arregui et al). The authors of a meter mounting position test compared the impact of a 45 degree angled mounting against the same set of test meters mounted horizontally. The error of thirty five meters mounted at 45 degrees, ranged between -37.9% to -2.6%; when the same meters was positioned horizontally, the meter errors ranged from -5.7% to +1.5%. The authors noted that the friction increment caused by the mounting position varied depending on the design of the impellor bearings used in each meter. It was also noted that if the mounting position is not in accordance to the manufacturer recommendations, it may lead to a higher degradation rate of the meter.

- Velocity profile: velocity profiles are largely influenced by the proximity of pipe bends and pipe diameter upstream and downstream of the meter. These changes in pipe configurations contribute to a change in velocity profiles, shifting the flow regime from a laminar to a turbulent zone. Velocity meters are influenced in a higher or lower degree depending on its design. Manufacturer specifications are very clear on these critical parameters and would be required as part of the COUNCIL new meter specifications for the meter replacement plan.

- Seasonal water use: Some water supply systems have a seasonal variance in use, for example summer vacation homes. Domestic meters in this case remain stopped between eight or ten months resulting in the mechanical moving components being possibly jammed. It is uncertain the extent of this impact in Council.

- Tampering: Not all meters can be manipulate as easily as some meters are protected against tampering more effectively than others. This is considered to be a risk that should be managed by Council as the opportunity to audit each meter may be taken when meters are read for billing purposes.

- Partial blockage of inlet strainer: some meters are sensitive to the momentum of the water impacting the impellor on the turbine. A partial blockage of the inlet strainer could consequently affect the accuracy of the meter. This may be regarded as a planned maintenance item for utilities in cases where the strainer is easily accessible. In water systems where regular shut downs occur and thus the possibility of the water quality being affected by contaminant ingress from pipe breaks or unclean reservoirs, the frequency of the planned maintenance of meter strainers should be increased. It is noted planned maintenance may very well be limited to closer monitoring of meter readings with consumption patterns soon after the completion of a system shut down in order to determine whether the meter or strainer has been affected.

- Leaks and user's storage tanks: Under low flow conditions, where the measured errors are much larger, the energy transfer from the water to the components within the meter is very small to negligible. Any increase in friction, caused by any factor, may stop the impellor at these low flow rates. The resulting under-registration in these circumstances is very high, including situations where a user's private storage tank float control valve is not well maintained.

The combination of the effects of all variables mentioned above is difficult to quantify. It is industry practice to carry out laboratory and field tests to determine actual meter performance. These tests particularly the field test, inherently include the impact of the common contributors to the meter errors.

2.3 BENCHMARK TRENDS IN ESTABLISHING METER ERRORS AND ASSOCIATED METER REPLACEMENT PLANS

In his assessment of international utilities, Davis found that generally most water utilities utilize a range of service lives for domestic meters, ranging between 10 and 20 years. The decision to change the meters are noted as a response or perception to decreasing accuracy with length of service (age of meter).

Davis also found that some utilities have adopted a multiple selection criteria involving life cycle costing. In this instance, it is expected that meters are tested for accuracy on a frequent basis (annually) in order to factor in the revenue loss during financial year.

In his assessment of an American District utility in Arizona Davis notes a replacement strategy based on cumulative volume rather than specific age. He discusses at length the impact of low flow rates have on meter accuracy as cumulative flow volume increases. He demonstrated in his paper that cumulative flow volume of the meter combined with the percentage of average water used by residential customers at low flow levels within the District was the driving factor for meter replacement.

The principle advantage of the method employed by Davis is that the method accounts for the specific water use conditions for various utilities and can be utilized by any water utility collecting the relevant data. Davis however ultimately found that in order to determine the appropriate cumulative volume impact at low flows, the water utility would need to rely on accurate monthly water usage data. Founded on this premise, Davis suggests that the optimum cumulative volume for meter replacement combined with the percentage of average water used by residential customers at low flow levels for the District was the driving factor for meter replacement. The District officially adopted the cumulative volume based program of 5.3 ML for the replacement of domestic meters in its supply zone. From a local perspective, Sydney Water generally tends to replace meters at 3.5 ML (or 10 years at low flow rates). Martin is his assessment records that the Queensland Environmental Protection Agency and Wide Bay Water Corporation (2005), noted that the rate and degree of wear and tear seems to be directly related to the volume of water consumed and recorded by the meter; for an average meter with typical consumption patterns the intervention point for programmed replacement is 3 to 4 ML of consumption or a meter age of eleven years.

Arregui et al noted in their assessment of international utilities that quite often water utilities simultaneously use a great variety of meter models, brands and technologies for measuring domestic consumption. The authors note that the diversity in meter range tends to lead to difficulties when determining the amount of water not registered or registered in excess by the meters. These are particularly noted for meters in the 1-5 year age groups (Table 3-1). The authors suggest that continuously assessing the meter error curve is an improved approach to determine the meter performance in the medium to long term. In this manner, though intensive, an appropriate quantity of meters of all ages (possibly versions) will be tested every year. In any event Arregui et al do publish results Table 2 for two models of domestic meters with varying ages. The authors also compares the errors for installations for two cases, viz. directly to users and meters installed upstream of user storages. The latter results are directly related to large data sets of low flow rates.

Table 2: Meter error distribution (Arregui et al)

	Age	Meters which serve water directly to the user	Meters installed upstream of storage
Model 1	1-3 years	-7%	-12%
	4-5 years	-8%	-16%
	6-8 years	-7%	-17%
Model 2	8-9 years	-11%	-23%
	10-11 years	-13%	-28%
	12-14 years	-12%	-26%

The meter errors reported by Arregui et al appear to be quite excessive particularly the first five years of service. This may be attributed to their concern that of low flow testing at the 4-5 year age. The authors however note the stability of the error at 6-8 years which compensates the high value at year 4-5.

Water utilities in Italy tend to replace meters on a run-to-failure mode. Fantozzi noted in his assessment that there are no mandatory requirements for meter replacement in most countries. As a consequence of this regulatory stance combined with weak asset management practice, domestic meter resilience is generally not tracked with age and cumulative consumption. Fantozzi also notes that there is limited research to determine optimal replacement for domestic water meters.

From his assessment of four water Italian utilities, Fantozzi notes the following in a research of 738 meters (as a statistical sample of around 141.000 meters) which were tested for accuracy:

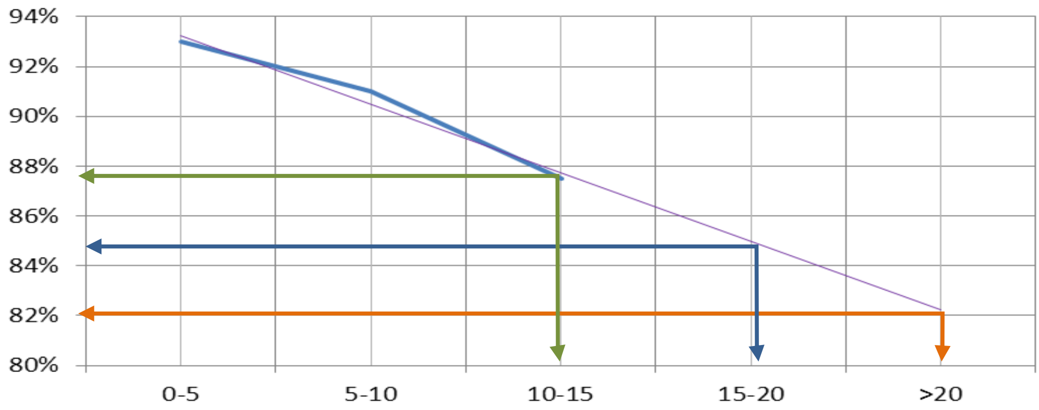
- a replacement policy should be based on a revenue loss/gain calculation based on deterioration of meters accuracy, meter replacement costs and economic data such as sale price of water
- the optimal replacement for an in-service domestic water meter was formally calculated by using the Net Present Value of the Revenue Lost or Gained
- the test results indicated that at the 11th year it is convenient to replace the meter, in case of installation of batch flow regulator at low flows
- in the four case studies analysed, optimal replacement periods calculated by using the Net Present Value range between 9 and 19 years.

The project team considers that:

- Davis' recommendation for the optimum domestic meter replacement strategy, viz. cumulative volume, is sound. The cumulative volume changeover as applied to the District in Arizona however is based on low flow rates. His emphasis of achieving such analysis is based on an intensive assessment of a large database at a high frequency basis in order to differentiate low flow rates from nominal. The underlying principle of cumulative volume does however give the advantage of rationalizing the specific water use conditions (such as water quality, environmental conditions, mounting positions, pipe configurations, etc.) for the specific utility. The cumulative volume approach is thus considered as a valid contributor to the development of an overall strategy for replacing meters.

- Assuming a linear trend in the meter accuracy deterioration, a graphical plot of the meter errors found by Arregui et al (for meters supplying users directly), yields an approximate negative 3% trend per five year period.

Figure 4: Benchmarked and linear projected meter error with age (Arregui et al)



The error margins per age group (for those meters older than 10 years) found by Arregui et al represents a reasonable guide to developing a strategy for meter replacements in the absence of detailed data on consumer consumption patterns. In consideration of the equivalent impact of suspended particles to both displacement and velocity type meters on the degradation of the water meter error curve, the errors noted that Arregui et al are considered as a reasonable guide. The finding by Martin in respect to characteristic degradation of both displacement and velocity meters supports the decision to use the error margins by Arregui et al as a guide. The errors margins for supply to user's private tanks (thus representing low flow supply), are excessive and should strictly be used for low flow rate assessments. These errors are however aligned with the consumption pattern influence on meter errors demonstrated by Davis, as well as the generic principle meter errors being at its largest at low flow rates.

The assessment by Fantozzi in respect to a financial assessment based on deterioration of meter accuracy, meter replacement costs and economic data such as sale price of water, is a reasonable method in which to establish meter replacement strategies. Fantozzi expressly recommends that annual financial assessments be carried out based on meter testing results. While this frequency recommendation appears to be extreme, the fundamental principle of a financial assessment is sound as it yields a better understanding of the exacting conditions the meter is exposed to for that utility and the impact of degrading meter accuracy. The assessment of the Italian utilities that ran the meters to failure which yielded a time frame to replace meters between the 9 to 19 year period, is expected considering the extent of meter errors that may result during this in-service period (as reported by Arregui et al).

In consideration of the finding of Davis, Arregui et al, and Fantozzi, Council considers that a suitable meter replacement strategy be formulated through an interfacing of meter age, financial assessments and cumulative volume assessments. This combination would also mitigate the paucity of data in respect of detailed consumer consumption patterns, environmental conditions, mounting positions, pipe configurations etc. The integrated impact of these specific water use conditions is complex and the expense to establish these may be prohibitive.

3 ANALYSIS OF COUNCIL'S DOMESTIC METER DATA BASE

A database of the domestic metering records was provided by Council. Key data of that was of particular relevance to the meter replacement analysis was location, type, age and consumption. The database references were:

- **location:** street address

- **type:** meter type description
- **age:** meter installation date
- **consumption:** last meter reading and date
- **consumption:** previous meter reading and date
- **consumption:** total consumption.

Plotting the street address of the meter directly to a geographic information system (GIS) enables a spatial location assessment of the different age categories of the meters. The relevance of the meter type is important as different meter types, models, makes and technology inherently have different error rating and the different mechanisms of error deterioration. The meter installation date is used for determining the age of the meter, while the last and previous meter readings determine the consumption. The total consumption is the totalized volume through the meter. The age of the meter and the totalized volume are considered to be significant data points in determining an optimum meter replacement strategy.

3.1 DATABASE CHALLENGES

There were a few but important challenges that were encountered during the database mining, cleansing and assessment. These were discussed with Council and specific direction on the assessment was agreed to, viz.:

- due to the database changeover challenges from the separate small rural Councils to the amalgamated Council metering database systems.
- due to irregularities in the database, regarding the difference between the "Total consumption" and the "Last read" values (ideally the difference should be zero):
    - any difference greater than 40,000 is to be ignored
    - those differences between 40,000 and 500, the "Total consumption" values are to be used
    - for differences below 500 (including the negative values), the "Last read" values are to be used.

Comment: *In the discussion with Council staff, it was noted that the irregularities found in the database were largely attributed to the meter readings being rolled back to match the final reading of the replaced meter (replaced presumably due to meter malfunction). The roll back was done in order to 'sequentially continue' the meter reading. This technique has resulted in the total consumption value of the custody transfer point being regarded as irregular. Under ideal conditions, the "Last read" value should equal the "Total consumption" value; hence the difference between these values should be zero. After a thorough review of the database, it was found that 2080 readings were considered to be irregular where the difference between the "Last read" value and the "Total consumption" value was either too large (greater than 90,000, or negative).*

- average consumption for Council is approximately 250 kl/year, but it is to be verified through the current assessment.

Comment: *This cumulative consumption translates to 0.25 ML/year or 2.5 ML per ten years, 3.75 ML per 15 years and 5 ML/ twenty years.*

- The "Date of install" value to be used to calculate the age.

3.2 METER DIVERSITY AND VARIETY

As noted previously in the Arregui et al assessment, in which a great variety and diversity of meter models, brands and technologies were tested and that which lead to qualifications being declared by the authors, viz. the difficulty in determining errors distributions. In analyzing the Council meter database, it is noted that Council has 44 different types of the 20 mm diameter in-service meters. However, 95% of the 44 different meters attribute to only seven different meter types or 84% attribute to only three different types of meters. The diversity and range of different types of meters in Council is thus considered to be a low risk to the current assessment and development of a suitable meter replacement strategy.

3.3 METER AGE AND CUMULATIVE VOLUME ASSESSMENT

An assessment was carried out of the cumulative volumes for each meter in the database in accordance with the data cleansing protocol agreed with Council. The cleansing process of the data involved the removal of irregular data which were as a result of meter readings being rolled back to match the final meter reading of the replaced meter. The roll-back of the meter reading was done in order to 'sequentially continue' the meter reading. This practice is regarded as abnormal and should not be permitted for the following reasons:

- meter readings are fundamentally meant to be turned by the energy of the media passing through it and not by any artificial means.
- meters suppliers may not validate the meter warrantee once the meter reading has indeed been artificially interfered with.
- the meter, or custody transfer point, is essentially the cash register for any utility. Any artificial interference with the meter reading may be regarded as illegal and contestable in court.
- the custody transfer point should be a highly regulated asset in any business. It is a requirement to comply with various standards, contracts and regulations, and as such should be treated with an equivalent level and duty of care. Custody transfer points generally impact on or by:
    - industry standards
    - national metrology standards
    - contractual agreements between custody transfer parties
    - government regulation and taxation.
- rolling back a meter reading also complicates the:
    - assessment of historic performance of the asset
    - historic consumption patterns for the custody transfer point.

For the purposes of the current assessment of the database excluding the number of meters with irregular data is not considered as severe and presents a low risk to the overall strategy. COUNCIL nonetheless recommends that these meters be assessed for data accuracy in the future and follow the principles adopted in the current strategy.

The age spread of the Council 20 mm meter asset base is indicated in Table 3. There is an approximately 25/75% split between those meters that are less than or greater than 10 years of age. Applying the estimated error distribution found by Arregui et al and projecting a linear error distribution yields an error degradation rate of 3% per five year. This results in an average error of 14% for the 10 to 20 year aged meters, while an overall average 10% error for all age groups. The meter accuracies up the age of 10 years range up to 94% (error of 6%).

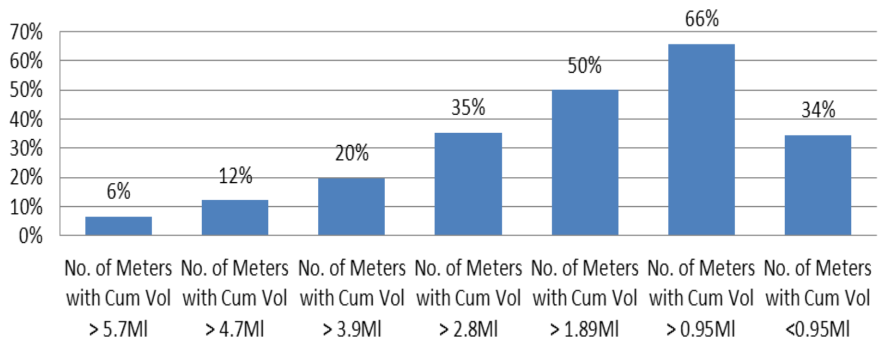
Table 3 Age spread versus estimated accuracy as per Arregui et al

Age (Years)	Percentage Distribution (Excl. Sarina and Irregular Meter Reads)	Accuracy Estimates (Arregui et al)	Error for >10 years (Fantozzi)	Overall Error

Age (Years)	Percentage Distribution (Excl. Sarina and Irregular Meter Reads)	Accuracy Estimates (Arregui et al)	Error for >10 years (Fantozzi)	Overall Error
0-5	15%	98%		
5—10	9%	94%		
10-15	56%	88%		10%
15-20	19%	85%	14%	
>20	0%	82%		

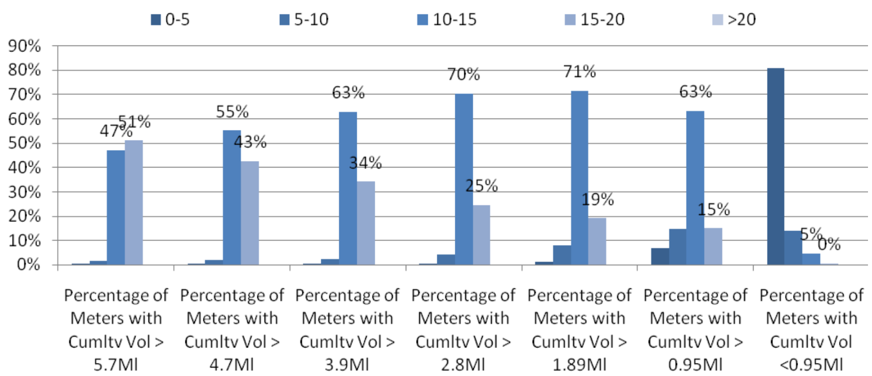
Cumulative volumes of all meters are graphically represented in Figure 5.

Figure 5 Number of meters per cumulative consumption volume category



Although independent from each other cumulative volumes should not be assessed in isolation of age. Low cumulative volume meters may very well be greater than 15 years of age, or high cumulative volumes meters may be less than 15 years of age. Cumulative volume categories are graphically represented against each age category in Figure 6. It can be noted that the 10 to 15 year age group of meters range between 47% and 63% for a cumulative volumes greater than 0.95 ML, while the 15 to 20 year age group steadily increases from 15% to 51% for cumulative volumes categories greater than 0.95 ML.

Figure 6 Meter age distribution versus cumulative volumes



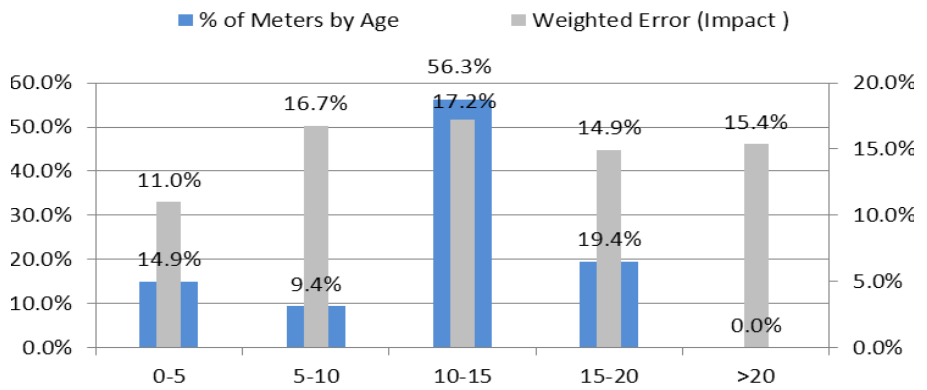
It can also be observed from Figure 6, that for cumulative volumes greater than 1.89 ML, meters that are in the 10 to 20 year age group comprise a minimum of 90% of the total number of meters.

The cumulative volumes should however be contextualized in terms of the water supply regime at Council. With the paucity of data in respect to detailed consumption patterns, it is assumed that the average annual consumption to be calculated from the total volume that passed through a meter from the meter installation date. The average consumption computed from the Council database is 276 kl/year. Over a 10 year period, this is equivalent to 2.8 ML. Comparing the cumulative volume categories to the average annual consumption, yields equivalent ages for each of the cumulative volume category as tabulated in Table 4. The equivalent ages were verified by mathematical extrapolation of typical cumulative volume and age groups from the Council database. The equivalent ages were thus related to the meter equivalent accuracies. Moving average weighted errors were computed for each cumulative volume category which yielded the optimum meter replacement milestone.

Table 4 Comparison of weighted error impact to cumulative volume categories

Cumulative Volume (ML)	Category Weighted Error (Impact)	Equivalent Extrapolated Age
0-0.95	13.0%	2
0.95	9.3%	3
1.89	11.0%	7
2.8	16.7%	10
3.9	17.2%	13
4.7	14.9%	15
5.7	15.4%	18

Figure 7 Percentage of meters and associated average weighted errors within age groups



It may thus be concluded that:

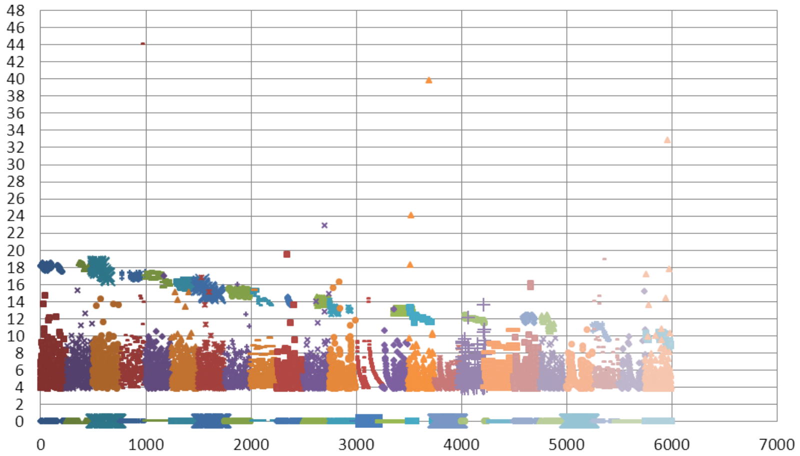
- The assessment of age and cumulative consumption provides an equitable indication of meters that require replacement, based on the comparative studies of Davis, Arregui et al, and Fantozzi
- In the Council meter database, at an average annual consumption of 276 kl/year, a cumulative volume of 3.9 ML reflects an equivalent age of approximately 13 years, while a cumulative volume of 2.8 ML reflects an equivalent age of approximately 10 years
- The 10-15 year age group has the maximum percentage of meters in the Council meter database (Excl. Sarina) as indicated in Figure 7
- Based on the distribution of the number of meters and cumulative volumes in Council, it is observed that the maximum impact of meter error (moving average weighted error) occurs at 3.9 ML cumulative volume (within the 10-15 year age group)

- Thus it was considered that 3.9 ML be the trigger point for meter replacements within Council.

Figure 8 displays the distribution of the meter cumulative volumes in comparison with a prioritized reduction of meter age. The density of approximately 6000 meter data at the 4 to 8 ML cumulative volume remains fairly constant irrespective of a general reduction in age distribution. It is clear that there is no pattern or trend that defines a distinct relationship between age and cumulative volume. The computation of equivalent age in establishing the optimum replacement trigger point was thus strictly determined for the purposes of applying equivalent meter accuracy and thus estimating the payback period.

Interfacing the intelligence of meter age and its cumulative volume together with its distribution in Council, a financial assessment may be carried out to establish suitable payback periods and net present value of culminated cash flows.

Figure 8 Scatter Chart Indicating Lack of Relationship between Age and Cumulative Volume



4 ANALYSIS OF EXPECTED COST SAVINGS, NPV AND PAY BACK PERIOD

An assessment of the potential revenue gain, net present value and payback period was implemented. The assessment was directed primarily at a replacement strategy based on those meters that had a cumulative volume greater than 3.9 ML (average age 13 years).

Input data for the financial model were received from Mackay Regional Council:

- average selling price of water $1.60/kl
- official discount rate 10%
- water tariff escalation rate 5%

Overall system water losses were recalculated for Council, based on the average meter error derived from a desktop benchmark survey (Arregui et al). As agreed with Council, one area was excluded from the assessment due to the extent of the meter reading database anomalies for this supply zone. The water balance model yielded the following:

- Zone 1 2,365,817 m^3/year
- Zone 2 34,089 m^3/year
- total water loss due to meter error 2,399,906 m^3/year

Although the age of a meter is independent of the cumulative volume that passes through it, equivalent ages were extrapolated from the Council database in order to compute the time based financial criteria of cost savings and net present values.

- The cumulative volume and equivalent age comparison yielded a best fit estimate of meter accuracies.
- The accuracies from the lower to the higher cumulative volume categories enabled computation of water savings per equivalent age. The annual water volume savings were computed by:
  - Establishing the impact of meter accuracy differences for each increasing cumulative volume category greater than 3.9 ML,
  - Progressively comparing the existing meter accuracy estimates with newly replaced meters accuracies for each cumulative volume category.

Table 5 Comparison of estimated accuracies with cumulative volume and extrapolated age

Cumulative Volume (ML)	Estimated Accuracy (based on Arregui et al)	Equivalent Age by extrapolation
0-0.95	0.98	2
0.95	0.98	3
1.89	0.94	7
2.8	0.94	10
3.9	0.88	13
4.7	0.88	15
5.7	0.85	18

Of the 29 894 meters that were accounted for in Zone 1 and 2 supply zones, approximately 20% of meters were triggered for replacement at 3.9 ML cumulative volume. The total cost of a unit meter replacement (including the meter and installation costs) was assumed at $120.00. The estimated cost for replacing all 20 mm meters that have cumulative volumes of greater than 3.9 ML was computed as $740,000.00.

A comparison of the cumulative volume categories, estimated accuracies and equivalent age extrapolated is made to associated commercial savings and net present values are tabulated below in Table 6. This demonstrates that once meters having a cumulative volume greater than 3.9 ML are replaced, these new meters will inherit the estimated accuracies as they progressively increase in cumulative volumes and age, thus yielding associated savings. It is noted that the NPV is calculated over a period of 15 years where after the water savings reduce to zero (water losses commence). The payback period is within a year.

Table 6 Commercial savings and net present values in respect of progressive cumulative volumes and equivalent age

Cumulative Volume (ML)	Estimated Accuracy	Equivalent Age by extrapolation	Commercial Savings	NPV to the year beginning
0-0.95	0.98	2	$ 1,564,145.78	$ 2,918,230.66
0.95	0.98	3	$ 1,564,145.78	$ 4,278,632.06
1.89	0.94	7	$ 987,132.66	$ 7,339,919.58

Cumulative Volume (ML)	Estimated Accuracy	Equivalent Age by extrapolation	Commercial Savings	NPV to the year beginning
2.8	0.94	10	$ 987,132.66	$ 9,289,672.29

The payback period is considered reasonable considering the number of meters that are triggered for replacement. More importantly these meters have the yielded significant cumulative volumes over its lifecycle and should be replaced based on this principle.

5 PREPARATION OF A METER REPLACEMENT PROGRAM

5.1 A SYSTEMATIC REPLACEMENT PROGRAM

The current jurisdiction of the Council extends over an area of 7261 square kilometers. The wide spread locations of these meters, as indicated in Figure 9 dictates the complexity of determining an optimum replacement plan.

Figure 9 shows the distribution domestic meters by age, indicating that the concentrations of older meters (greater than 16 years old) are located in the North. Similarly Figure 9 shows the distribution of meters showing the cumulative volume measured by the meter. Once again the areas of highest cumulative volumes (greater than 3.9 ML) are in the north) and also in the south.

The following criteria were used in considering a replacement plan in which the identified meters would be replaced in an optimum manner in order to minimize water loss and maximize revenue cash flow for Council:

- Location - sequential location zones would improve logistics and:
  - minimize interruption of the process flow of the replacement intervention
  - minimize contractor re-establishment costs which would be ultimately transferred to the project
  - maximize the possibility of replacing similar meter type installations
  - maximize the possibility of similar site constraints
  - minimize residential owner notification logistics
  - maximize quality assurance logistics
  - maximize possible operational planning should there be a need for simultaneous asset maintenance planning and shutdown
  - minimize project costs.
- Revenue - targeting the higher average consumption meters would render improved cash flow for Mackay Regional Council:
  - categories of high to low average consumption include > 1 ML/year, 0.75 to 1 ML/year, 0.5 to 0.75 ML/year, 0.25 to 0.5 ML/year, 0.1 to 0.25 ML/year, <0.1 ML/year.
  - the average consumption per year calculation assumes that consumption patterns are consistent over the lifetime of the meter.

Figure 9 shows the distribution of average consumption throughout Mackay to allow the Council to target highest revenue gains with meter replacement.

The Council plan to institute a laboratory testing program of 5% of its 20 mm diameter meters. The program aims to verify the accuracy levels of the selected meters.

This practical measure would enable Council to extrapolate age, cumulative volume and meter accuracy based on the specific water supply regimes within Council.

In order to ensure that relevant data are collated during the testing program, it is essential that an appropriate balance of cumulative volume and age are met. The following table aims to balance these two criteria's by considering 5% of each age and cumulative volume category:

Table 5-1 Comparison of weighted error impact to cumulative volume categories

<table>
<tr><th colspan="9">No of Meters within Cumulative Volume Categories for laboratory testing</th></tr>
<tr><th>Age</th><th>> 5.7ML</th><th>4.7ML-5.7ML</th><th>3.9ML-4.7ML</th><th>2.8ML-3.9ML</th><th>1.89ML-2.8ML</th><th>0.95ML-1.89ML</th><th><0.95ML</th><th>SUM</th></tr>
<tr><td>0-5</td><td colspan="8">Ignore due to low risk and low numbers</td></tr>
<tr><td>5-10</td><td>2</td><td>2</td><td>4</td><td>16</td><td>38</td><td>85</td><td>71</td><td>218</td></tr>
<tr><td>10-15</td><td>46</td><td>55</td><td>87</td><td>186</td><td>160</td><td>86</td><td>25</td><td>644</td></tr>
<tr><td>15-20</td><td>49</td><td>28</td><td>24</td><td>29</td><td>12</td><td>5</td><td>2</td><td>149</td></tr>
<tr><td>SUM</td><td>97</td><td>85</td><td>115</td><td>230</td><td>210</td><td>176</td><td>98</td><td>1011</td></tr>
<tr><td></td><td colspan="3">296</td><td colspan="4">715</td><td></td></tr>
</table>

In the interim, the replacement strategy of the 20 mm meters within Council would involve the following strategy:

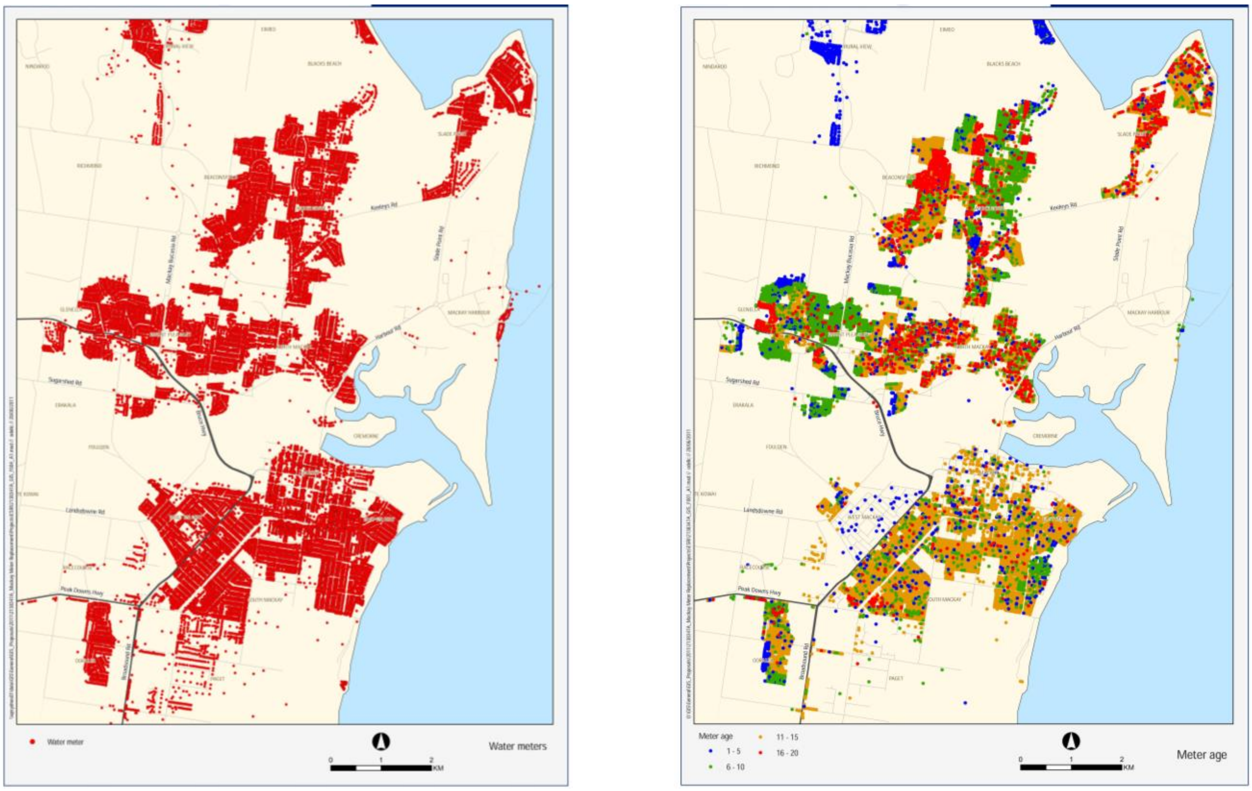
Specific criteria were used in considering a replacement plan in which the identified meters would be replaced in an optimum manner to minimize water loss and maximize revenue cash flow for Council:

- Location - sequential location zones would improve logistics and:
  - minimize interruption of the process flow of the replacement intervention
  - minimize contractor re-establishment costs which would be ultimately transferred to the project
  - maximize the possibility of replacing similar meter type installations
  - maximize the possibility of similar site constraints
  - minimize residential owner notification logistics
  - maximize quality assurance logistics
  - maximize possible operational planning should there be a need for simultaneous asset maintenance planning and interruption of supply
  - minimize project costs
- Revenue - prioritising the higher average consumption meters would render improved cash flow for Council:

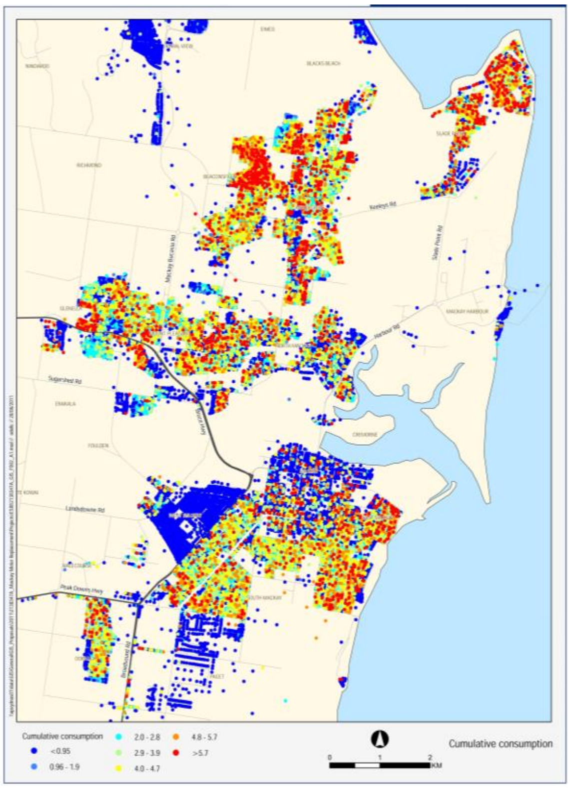
- categories of high to low average consumption include > 1 ML/year, 0.75 to 1 ML/year, 0.5 to 0.75 ML/year, 0.25 to 0.5 ML/year, 0.1 to 0.25 ML/year, <0.1 ML/year.
- the average consumption per year calculation assumes that consumption patterns are consistent over the lifetime of the meter

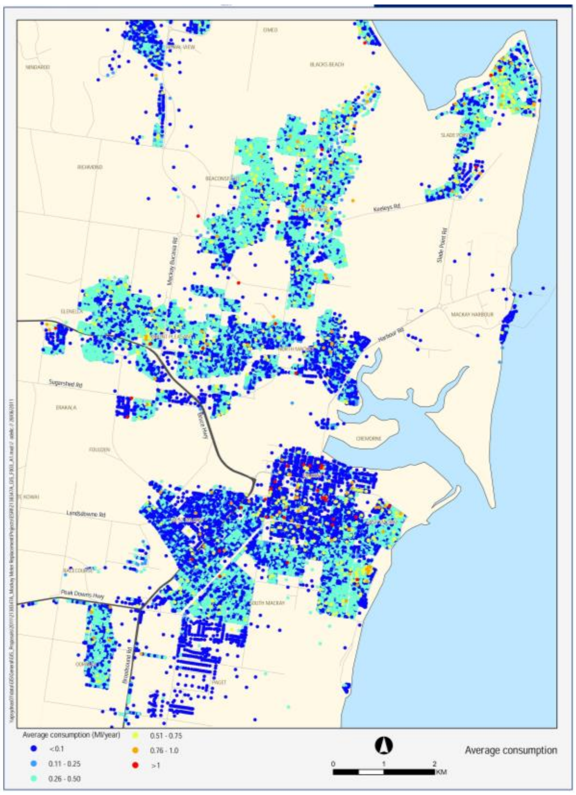
- Target meters that have a cumulative volume consumption greater than 3.9 ML
- If practical, prioritise the oldest meters within the above criteria
- Contain the meter replacement numbers to 3000 in order to render a balance between a meter replacement program based on benchmarked estimated meter accuracies and an intelligence gathering program (derived from the laboratory meter testing).

Figure 9 Spatial representations



Meter Locations　　Meter distribution by age (Years)





Meter distribution by cumulative consumption (ML) Meter distribution by average consumption (ML)

6 CONCLUSIONS

The project team considered that the optimum replacement strategy be based on the interfacing the cumulative volumes distribution within Council's database with equivalent extrapolated ages. The benchmarked age related meter accuracies were corresponded with the cumulative volume categories. An optimum cumulative volume for Council was found at the maximum weighted error which corresponded with a cumulative volume of 3.9 ML.

A financial assessment confirmed the payback period to be within one year, based on meter replacement costs and net present value of cash flows. A practical replacement strategy for council was mapped using GIS technology wherein meters that were characterised by high cumulative volumes and high average consumption inherited the highest priority.

ACKNOWLEDGEMENTS

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