SMART METERING: PROVIDING THE FOUNDATION FOR POST METER LEAKAGE MANAGEMENT

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ABSTRACT
Any rise in water demand, usually associated with population growth and drought, challenges the water utility to balance this increase by reducing the amount of water lost in the network and employ demand management techniques to conserve existing supply. Post meter leakage can account for up to 10% of total water consumption particularly in the residential sector. Households identified as having post meter leakage were subjected to a mix of basic and tailored information regarding water loss. The primary aim of the study was to test the effectiveness of communication interventions and the attributed water savings resulting from the repair of household leaks. Moreover, questionnaire surveys were conducted to establish the significant factors, including leak type, demographics and household awareness, to name a few, that will influence the development of a fit-for-purpose post-meter leak rectification policy and program. The paper concludes with some key recommendations for the development of a predictive model for indentifying, classifying, quantifying post meter loss and the least cost planning implications of a leak rectification policy.

INTRODUCTION
The advantage of reducing the amount of water used to achieve any service is important in Australia. Water is conveyed by systems with capacity limitations and as system efficiencies tend to decrease as capacity is strained it is imperative to maximise any efficiency in times of high and low water demands (Brooks, 2006). Post-meter household leakage can occur in any number of different plumbing fixtures or piping within a residential property. Leaks patterns vary considerably and the volume of water lost as a result of leaks is highly variable. The development of policies and programs for the reduction in post meter leakage has received a low priority by water utilities. This situational context has been largely due to their current metering system not being able to provide sufficiently detailed water use information for the effective implementation of such programs.

Information is often used to encourage conservation; many studies in the energy sector encourage households to reduce their energy use on a voluntary basis (Abrahamse et al., 2007). The Home Water Wise Service launched in April 2006 was an initiative to assist in drought management and achieve long term water savings for the South East Queensland. The program based on previous residential retrofit models implemented by Gold Coast Water (Home Watersaver Service) and Sydney Water (Water Fix) (Coates & Bullock, 2008) was voluntary for all residents. An investment of $20 engaged the services of a licensed plumber to install a water saving showerhead, efficient aerators on bathroom and kitchen taps and fix up to 3 leaking taps. Approximately 188,888 household audits achieved savings of 4288 million litres of water when translating similar verified savings from the Canberra Least Cost Planning Study, which indicated that savings of around 20.9 kilolitres per household per annum could be achieved by installing a water-efficient showerhead and aerators as well as fixing small internal leaks (Coates and Bullock, 2008; Turner et al., 2005). In California, Gleick et al., (2003) estimated that indoor residential water use could be reduced by as much as 40% by replacing inefficient toilets, washing machines, showerheads, dishwashers and by reducing the level of household leaks; which accounted for 12% of indoor residential water use in 2000. The report goes onto state that leak rates could be reduced by 80%, inferring that 50% of leaks can be repaired for less than $100 US and 80% for less than $200 US.

Tailored information offers an even more effective way to encourage behavioural changes (Abrahamse et al., 2007; Desmedt et al., 2009). Tailoring originated in health psychology; it
involved a series of interventions designed to change unhealthy habits, using data from or about a specific individual to determine the appropriate information to derive a related outcome (Abrahamse et al., 2007). Mayer et al., (1999; 2004) suggest that leak reduction programs targeted at homes with highest suspected leakage rates would be most effective. A number of utilities in California have experimented with mailing letters and brochures to the highest 36% of residential water users and the highest 10% received a follow up phone call (Gleick et al., 2003).

Prior research by the authors has provided evidence that the characteristics of post-meter flow events may be a reliable indicator of the type of leak e.g. toilet, service pipe, etc. (Britton et al., 2008) However, leak events are dynamic in nature and the decision to rectify them will be dependent on a number of monetary and non-monetary factors. Moreover, the decision will also be dependent on value judgements from the perspective of the water user, utility and government agencies. Nonetheless, one key decision driver to repair specific categories of leaks can be based on their cost and quantifiable water savings.

This paper firstly outlines the objectives and methodology followed for the study. Results are then presented including leak typologies, water savings attributable to leak alert communications and householder key concerns for and actions taken to address water loss. The paper finishes with study conclusions and an outline of the future directions of our ongoing research.

RESEARCH OBJECTIVES

In brief, the study examined the extent to which the staged dissemination of both generic and tailored information on evident water leaks would result in leak repair and ultimately water savings. As detailed later, households where a leak was reported by the smart meters via a leak alert were subjected to a staged communication process. This involved increasingly detailed leak information letters being sent and meter reads after a reasonable period to allow them to make repairs. The objective of the experimental design is to compare the actions of each group after each communication. The process used to determine the effect of the experiment is the recording of water consumption data pre and post communication and if households responded to the treatment. In summary, the study aimed to collect information that would provide insight on three primary research questions:

1. What are the post-meter leak typologies and mathematical functions to explain them?
2. What are the water savings attributable to each communication intervention?
3. What are householder concerns for and actions taken to address water loss?

RESEARCH METHOD

Study Site
The City of Hervey Bay is situated on the Queensland coast approximately 300 kilometres north of Brisbane. During 2007, Wide Bay Water Corporation implemented an automated ‘smart’ meter reading (AMR) system. All 22,000 domestic water meters were replaced with Elster V100 meters that have a FIREFLY® data logger attached. The loggers record hourly volume (consumption) data, and transmit to a receiver on a hand-held computer or in a drive-by unit. Post meter leakage is identified during the meter reading process when a trickle alert flags continuous use in the previous 48 hours.

Sample
A water meter reading cycle was conducted between March and May 2009, which covered all 22,000 residential households in Hervey Bay. From this reading cycle approximately 4% of residential properties were identified as having a leak according to the above leak alert process. After analysing the households’ minimum night flow (MNF) profile to confirm the leak alert as a real leak approximately 803 or 3.8% of households were retained for further assessment. Of this group a sample of 372 households were randomly selected and notified of a potential leak. The 372 households were divided into 2 groups, named Group A (n=332) and B (n=40), with each group receiving a different communication intervention strategy over a three month period (Table 1). A control group (n = 100) was also selected and received no information during the course of the study.

Communication Interventions
As detailed in Table 1 a series of interventions, feedback and questionnaire survey communications were conducted during the research process. The first communication to Group A involved a basic letter indicating that
Table 1 Communication Interventions

<table>
<thead>
<tr>
<th>Group A (n=332)</th>
<th>Group B (n=40)</th>
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<tbody>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; Basic Letter Fact Sheet</td>
<td>Detailed letter incl. loss per hour, day &amp; year. 1 x graph of consumption over 24hr period. Fact Sheet</td>
</tr>
<tr>
<td>2&lt;sup&gt;nd&lt;/sup&gt; Detailed letter incl. loss per hour, day &amp; year. 1 x graph of consumption over 2 x 24hr periods i.e. week 1 then week 4 of monitoring. Fact Sheet</td>
<td>Letter stating still losing x amount of water. Graphs of consumption over 2 x 24hr periods i.e. week 1 then week 4 of monitoring. An increase in the amount indicated. Rebate offer $100, valid for 21 days.</td>
</tr>
<tr>
<td>3&lt;sup&gt;rd&lt;/sup&gt; Letter stating still losing x amount of water. Graphs of consumption over 2 x 24hr periods i.e. week 5 then week 8 of monitoring. An increase in the amount indicated. Rebate offer $100, valid for 30 days.</td>
<td>Thank you letter with graphs pre and post leak repair.</td>
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<tr>
<td>4&lt;sup&gt;th&lt;/sup&gt; Thank you letter with graphs pre and post leak repair</td>
<td>Survey Questionnaire</td>
</tr>
<tr>
<td>5&lt;sup&gt;th&lt;/sup&gt; Survey Questionnaire</td>
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</tbody>
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their household may have a leak and a fact sheet page featuring information on the capability of the meter reading system, leak alerts after continuous use and a step-by-step guide on how and where to check for leaks was mailed to all households in the sample. It should be noted that the first communication to Group A involved no household specific data analysis. The first communication to Group B involved extended analysis of household MNF water use to illustrate a leak was most likely present. Water meters were read four weeks after each communication allowing householder's time to digest information and decide the appropriate course of action. Other increasingly detailed communications (see Table 1) followed this approach in a similar manner. It should be noted that for the 3<sup>rd</sup> and 2<sup>nd</sup> communication for Group A and B, respectively, financial incentives (rebates) were offered to assist with the cost of leak repair. For the rebate offer of $100 towards plumbing repair; householders could either contact a recommended plumber who would deduct $100 from the bill or arrange for their own plumber and apply for a $100 rebate. Again, Group C (Control) did not receive any communication.

**Questionnaire Survey**
The purpose and objective of the survey was to understand the types of leaks occurring and residents concerns for and actions taken to address water loss. All survey recipients were informed that their responses would help better detect leakage, develop and enhance leak prediction models and devise effective policies to reduce this type of loss. Respondents were mailed a survey form and given a date by which to respond and enter a prize draw. There was also a web link provided to complete the survey online. The questionnaire structure consisted of six sections to solicit information:
1. Information for respondents;
2. Opinion on water conservation;
3. Billing and Information, asking for thoughts and opinions about the way in which water is currently billed;
4. Water leaks, the type of leak and the concerns and motivations when deciding to repair;
5. Quality of information, covering opinions on information supplied to them and what type of information could influence other households in the future; and

The scope of this paper limits questionnaire survey results to those collected from sections 4 and 5 of the questionnaire.

**DATA ANALYSIS AND RESULTS**

**Extracting Leak Data and Typologies**
Firstly water use data is reviewed to confirm if a leak exists, then leak typology, flow rate and volume loss are determined for each leak resulting in a unique leak profile for each household. The purpose of the leak profile is twofold; firstly to see the impact of each communication and secondly to understand the progressive nature and volume of water loss. It is also hoped that in the future, when enough
typologies have been analysed, we can predict the causative agent of the leak and pass this information on to the household to make leak rectification more efficient. When identifying total leakage post meter, the leakage component must be separated from consumption. The minimum night flow between 1am - 4am is converted to a graph, illustrating a pattern. Pattern recognition for identifying leakage characteristics can be based on frequency and volume in data organisation - that is, the category of leak in terms of constancy and the flow rate of the leak in terms of variability are both immediately apparent in graphed data (Britton et al., 2009). Night time irrigation is evident when studying water use profiles; a typical example is usage of >300 L/hr between 1am and 4am repeatedly on alternate or every 3 to 4 nights. For the purpose of this study data has been normalised and does not include any major irrigation events. The continuous nature of the flow is assumed leakage and any spikes in use are considered elements of legitimate consumption. The average flow rate minus consumption is the average leak rate per hour. (Britton et al., 2008; 2009). Leak categories are established to better understand the way in which different post-meter leakage typologies behave. It had previously been determined that post-meter leaks could be classified into 5 main categories: Constant; Rate of Rise; Erratic; 48 Hour Leak; and Intermittent. Sub-categories also existed, branching from Constant and Rate of Rise. (Britton et al., 2009). Table 2 illustrates the refined categories of post meter leakage.

<table>
<thead>
<tr>
<th>Previous Leakage Categories</th>
<th>New Categories</th>
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<tbody>
<tr>
<td>Constant Leak</td>
<td>Constant Leak</td>
</tr>
<tr>
<td>5 – 20 L/hr</td>
<td>5 – 20 L/hr</td>
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<tr>
<td>20 – 50 L/hr</td>
<td>20 – 50 L/hr</td>
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<tr>
<td>&gt;50 L/hr</td>
<td>&gt;50 L/hr</td>
</tr>
<tr>
<td>Rate of Rise Leak</td>
<td>Rate of Rise Leak</td>
</tr>
<tr>
<td>&lt;50 L/hr</td>
<td>Linear</td>
</tr>
<tr>
<td>&gt;50 L/hr</td>
<td>Polynomial</td>
</tr>
<tr>
<td>Erratic Leak</td>
<td>Exponential</td>
</tr>
<tr>
<td>Leak started within 48 hour period</td>
<td>Erratic Leak</td>
</tr>
<tr>
<td>Intermittent leak</td>
<td></td>
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</tbody>
</table>

Rate of rise leaks follow a very distinct pattern as they will increase over time. This leak type is dramatic; it can rise at a very slow to a very rapid rate. Previously, these leaks were classified in the same manner as constant leaks and placed into a rate of rise sub-category of either; <50L/hr or >50L/hr. These sub-categories were inadequate as recent leak analysis determined that these leaks behave in quite a distinctive manner. Three new descriptive and more suitable sub-categories were created, which include: Linear (Figure 1a), Polynomial (Figure 1b) and Exponential (Figure 1c) Rate of Rise Leaks.

Once a rate of rise leak has been classified into one of the sub-categories, a line of best fit is added to the graph, providing a leakage consumption rate of rise equation for each leak. These predictive equations are useful as they provide insight into the maximum water loss if the leak goes unrepaired. By inserting the day number for the variable \( t \) into the rate of rise leak’s equation, a relatively accurate leak volume can be calculated. For example, the equation for the linear rate of rise leak in graph (a) of Figure 1 is:

\[
Q_t = 0.2917t
\]

If the potential average leakage volume needed to be
calculated at 200 days from leak commencement, then \( t=200 \) resulting in a potential leakage rate of 58.34L/hr.

Whilst each household may have a unique volume loss and leak pattern, when all household leaks are collectively analysed it appears that the collective group conform to a rate of rise, as in Figures 2, 3 and 4. This now suggests that a leakage volume equation could be applicable to predict citywide leakage levels.

**Affect of Communication Interventions**

The effectiveness of communication interventions and savings in water are reported and then preliminary results of the survey \((n = 137)\) responses received presented. Figures 2, 3 and 4 display each study groups average minimum night flow (MNF) for the period 30 June 2008 to 30 June 2009. All three groups show a distinctive rate of rise until the first intervention. Basic calculations indicate that Group A and B lost a respective 18.06 mega litres (ML) and 3.40ML (Total = 21.46ML) of water during a period of 275 days.

**Water Savings**

Tables 3, 4 and 5 illustrate the hourly water loss prior to each intervention and reductions in loss attributed to each communication. Communication 1 to Group A (Table 3) resulted in the sample baseline hourly leakage rate reducing from 4009L/hr to 2644L/hr or 34%. Communication 2 resulted in another 56% reduction (i.e. 2644L/hr to 1169L/hr). Communication 3 resulted in a further 58% reduction (1169L/hr to 494L/hr). The entire intervention communications to Group A resulted in a total sample hourly leakage reduction of 88% (i.e. 4009L/hr to 494L/hr).

Communication 1 to Group B (Table 4) resulted in a 38% hourly reduction whilst communication 2 achieved a significant 91% reduction (i.e. 1356L/hr to 120L/hr). Combining the samples, Group A and B final post-intervention hourly losses associated with leakage only accounted for 11% of the baseline value indicating a substantial reduction (89%). This provides solid evidence that the large majority of households addressed household leaks.

**Group C (Table 5)** experienced a decline in hourly leakage at meter read 3 (Figure 4) indicating that some households in the control may have located and repaired leaks. However, repairs are outweighed by leak rates of rises over time resulting in an overall 52% increase in hourly leakage between the 1st and 4th meter read.

**Questionnaire Survey Results**

Analysis of the questionnaire surveys \((n=137)\)
received revealed that some households experienced no leak (n=16), the majority of households confirmed one leak (n=79) and the remaining households found two (n=25) or three leaks (n=17). Overall, 180 leaks and 16 different leak types were confirmed. 68% (n=94) of the respondents were owner occupiers and 32% (n=43) were property investors. Respondents stated the nominated repairer and the reason for that choice. Plumbers undertook repairs in 46% (n=56) of the households. 35 households indicated a natural default to call in a professional for the job. 16% of households either tried to fix the leak or could not locate the leak and opted to employ a Plumber. 29% (n=35) of households repaired the leak themselves stating cost, knowledge of how to and ease of repair as the major factors. Friends and family (n=17) were responsible for repairing 14% of leaks; plumber, builders and tradespeople were known to or referred by other family members. Nearly 70% of the leaks were fixed for $200 or less. In total, only six leaks (5%) had repair bills ranging from $1501 to $4000 mainly due to leaking hot water systems (HWS). These leaks were considerably more expensive as they involved concrete/wall excavation and replacement of internal copper as well as underground polyurethane pipes. The median cost per household repair (n=121) was $272.85 and the total cost for sampled all households that repaired leaks was $34,654.50.

When informed of the leak, 31% of respondents did not think the leak would be too costly to repair and 48% disagreed with the statement "I do not have time to repair". Only 26% of respondents were concerned with the cost of employing plumbing services and only 6% of respondents discounted the leak amount or considered that it was too insignificant to deal with. Possible damage and flooding was cited by 52% as the main concern when first receiving notification of a leak (Figure 5a). When the decision was made to repair, 73% of respondents said they felt obliged and 69% agreed that they would have to repair the leak in due course; this could possibly indicate that leaks were already known to many householders. Only 27% thought the water authority may enforce repair. 71% stated saving money as a main motivation and an encouraging 93% of respondents cite the main driver was preventing further unnecessary loss. Figure 5b. 91% of respondents were happy to be informed and 85% would like more information of this kind in future. Interestingly, 62% would like the water authority to acknowledge that repairs had been undertaken and 75% said the information prompted affirmative action (Figure 5c).

When asked what would help other households decide to fix a leak (Figure 5d), assuming that each household received a basic letter, 92% of respondents stated that a detailed letter with water loss amount in litres and dollar value plus a graphical display would be the preferred form of information. 83% would like an indication of the leak type and 74% wanted a prediction of cost and loss if no action was taken. An incentive for repair was favoured by 73% and only 35% were against a penalty notice. A staged communication strategy to householders (n=372) regarding post meter leakage was found to reduce hourly water loss collectively by 89% over a period of three months. 70% of the leaks were repaired by householders for less than $200 and 50% for less than $100. Householders were happy to be
Figure 5 Questionnaire Survey Result
informed of a leak and expressed a desire for future information of this nature. No particular barriers to repair were highlighted by survey respondents ($n=137$). Environmental motivations for conserving water and reducing loss was higher than cost saving motivations. Another major finding of this study is that by classifying rate of rise leaks by curve shape rather than volume size, it is now possible to establish average leakage loss rate predictive equations. Such equations facilitate accurate predictive estimates on future postmeter leakage consumption rates.

**FUTURE WORK**

**Developing Predictive Models**

The next stage of work involves developing a series of models in order to provide predictions about post meter leakage. The first of which can determine total water loss due to post-meter leakage for a city or town and the second which can predict the water loss and cost to households if no action is taken. The models will be a simplified representation about the phenomena of post meter leakage and optimised to provide adequate representation of the processes affecting this type of water loss (Ascough et al., 2009).

**Least Cost Planning**

During times of constrained supply and drought the above mentioned models will allow a Water Utility to understand the nature and volume of loss. However the investment of time and budget on the part of the utility is also a significant consideration. This study involved a detailed record of time, resources and money dedicated to each communication intervention. This account coupled with anticipated reductions in production, pumping and treatment costs will allow the real cost of this water loss strategy to be determined using Least Cost Planning principles.

**Post Meter Leakage Policies**

The final research outcome will be to propose a policy framework for post meter leakage; involving a combination of policies such as standards, grants and incentives for water service providers through to end users. A policy theme of particular importance is the dissemination of information regarding post meter leakage and the value of Water Utilities providing subsidies to customers to reduce household leakage.

**ACKNOWLEDGMENTS**

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