Closing the loop on water planning: an integrated smart metering and web-based knowledge management system approach

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Abstract: Australia's climate instigated the need for strategic water and wastewater planning and management. The implementation of water demand management (WDM) and source substitution to save potable water is common throughout the Nation, as is estimating their relative water saving potentials. Smart metering and water end use research is underway to provide accurate data which will assist in the verification and validation of estimations made when developing water saving strategies. Introduced is the framework for a web-based knowledge management system (WBKMS) that integrates smart metering, end use water consumption data, wireless communication networks and advanced information systems in order to provide real-time data to both water corporations and consumers, thus enhancing their current level of understanding of how, when and where water is being consumed. The paper finishes with an overview of the impediments to developing the WBKMS and an associated research agenda to address present gaps in knowledge.
Keywords: knowledge management system; smart metering; water end use

INTRODUCTION

Droughts, changing and unpredictable rainfall patterns, increasing populations and an escalating demand on water resources are common in Australia and to some extent the world. All levels of Australian government have accepted that the greatest challenge we face is how to meet the water needs of future generations. Investment in adequate planning and the adoption of smarter approaches to water management is required now to ensure Australia's sustainable water future.

Governments and public utilities are investing significant funds in the development and implementation of water strategies to ensure future water demands are met. Predictions and estimations of future demand and potential savings through the introduction of demand management strategies or source substitution are common place. Demand management strategies include water restrictions, rebate programs for water efficient devices, water efficiency labelling, water conservation or education programs and pressure and leakage management (Inman and Jeffrey, 2006). Source substitution or 'fit for use' water involves replacing specified potable end uses such as toilet flushing and irrigation with recycled, grey or storm water. Water savings achievable from such programs are calculated through a variety of assumptions but, once in place, limited consideration is given to determining the actual water savings associated with these strategies. It is well documented that '*more data and information should be collated on the effectiveness and sustainability of demand management techniques, to improve long term forecasting*' (Chambers et al., 2005, pp. 35). After decades of inadequate metering of water use, organisations have come to the realisation that if you can't measure it, you can't manage it. Therefore, an innovative water consumption knowledge management system is urgently required to enhance the management of the current water resource challenge faced by scores of countries.

The advent of advanced water metering, logging and wireless communication technologies has enabled the dynamic and accurate measurement and data transfer of abundant useful water end use information (e.g. time and quantity of water use in shower). While smart metering technologies are becoming available and being implemented in an improvised manner, no water organisations on the international stage have yet developed a robust system which can assist both water users (i.e.

households) and managers (i.e. water operations authorities) to be empowered with a range of comprehensive, and instantly available reports, on water consumption patterns and comparisons with peers (e.g. my water use is higher than a comparable household for shower use). Moreover, researchers have to date, failed to proactively provide a roadmap, for the coherent adaptation of this wide range of available technologies as well as the architecture of a suitable web-based information transfer platform, to achieve the rapid advancement of current outdated urban water resource management practices.

The *Gold Coast Watersaver End Use (GCWSEU) Study*, a joint research initiative of Griffith University and Gold Coast Water (GCW), in Queensland, Australia is currently underway. This project is adopting high resolution water meters (72.5 pulses per litre) and data loggers recording data at 10 second intervals for 200 homes. The project has produced an array of valuable data which has instigated this present study to examine the feasibility of developing a robust system for providing real-time high resolution end use data to both water managers and consumers. The formation of data from the above stated study and the industry demand for an integrated system that can provide in-depth analysis on real-time water consumption as well as reports on the effectiveness of demand management strategies and forecasting models, lead to the conceptualisation of a smart web-based knowledge management system (WBKMS). The proposed WBKMS with associated smart meters, loggers and wireless networks allows for the empowerment of individuals by providing them with instant intelligent information. Such information has implications for better targeted rebate programs, informing users of daily/monthly water use from the comfort of their home, regulating water use, leak identification, water infrastructure planning and automated billing, to name a few. A brief overview of the GCWSEU study is provided in the following section.

BACKGROUND

The Pimpama Coomera Water Futures Master Plan

The Pimpama Coomera Water Futures (PCWF) Master Plan (Figure 1) was developed by Gold Coast City Council and GCW to ensure the supply of sustainable water and wastewater services to one of Australia's fastest growing residential areas (Gold Coast Water, 2008). The PCWF Master Plan specifies that up to 84% of the average potable water demand in 2056, based on 2004 water consumption figures, will be met through source substitution or removed through the application of water conservation measures (Gold Coast Water, 2004).

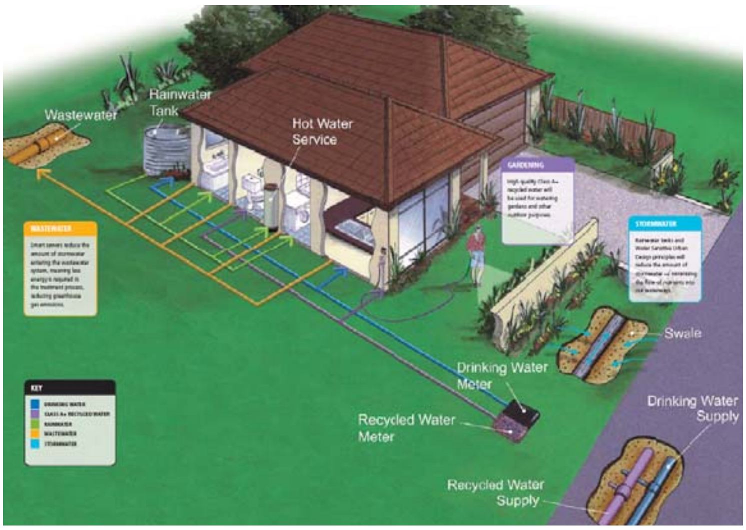


Figure 1 PCWF Master Plan – household water uses (GCW, 2004)

The PCWF Master Scheme is one of the major dual reticulation initiatives in Australia, another is that at Rouse Hill (Sydney Water, 2008). The PCWF scheme was finalised in 2004 with recycled water primed for delivery in early 2009 for use in toilet flushing and all outdoor uses in the region. As with the development of many schemes, complex engineering calculations and modelling were required for the PCWF Master Plan to determine potential water savings from the suggested demand management and source substitution strategies. Research to determine the water demand for both potable and recycled water has not yet occurred; this is a key objective of the GCWSEU Study. This study will assist in the verification and validation of PCWF end use modelling assumptions and will provide data to assist with the determination on the water saving potential of recycled water as well as some demand management strategies.

GCWSEU Study: Pilot trial results

The GCWSEU Study is a collaborative ARC research project between Griffith University and GCW. The purpose of the study is to conduct an investigation of end use water consumption, for 200 homes on the Gold Coast, utilising a smart metering approach. The study will also examine the effectiveness of dual reticulation and education as potable water saving mechanisms. The results of a pilot trial (N=50), which tested the methodology and established initial outcomes of end use water consumption at the Gold Coast (Winter 2008), are displayed in Figure 2.

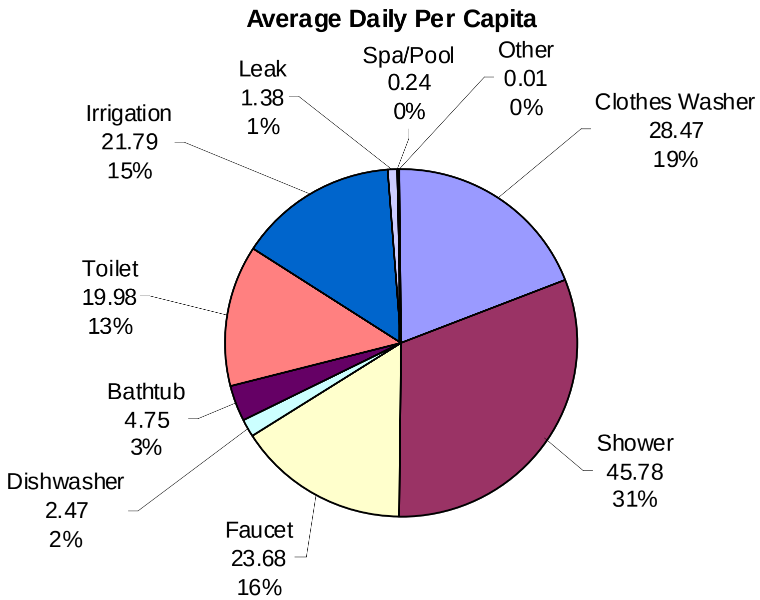


Figure 2 Gold Coast end use water consumption break down (Willis et al., 2008)

Willis et al. (2009) noted the significant variability in volumetric and percentage end use distribution between individual households (Figure 3). Such variability in the water end use of residential, as well as commercial, users prompted the authors to commence developing the framework for an integrated smart metering and information management system that enables individual households to view their own water consumption on demand. As demonstrated herein, household water end use characteristics are highly variable and dependent on a range of demographic, behavioural and seasonal factors. Thus, the provision of a platform that is suitable for both users and water managers to understand where, when and how water is being consumed, on a real-time basis, provides a powerful knowledge repository contributing to the improved management of urban water.

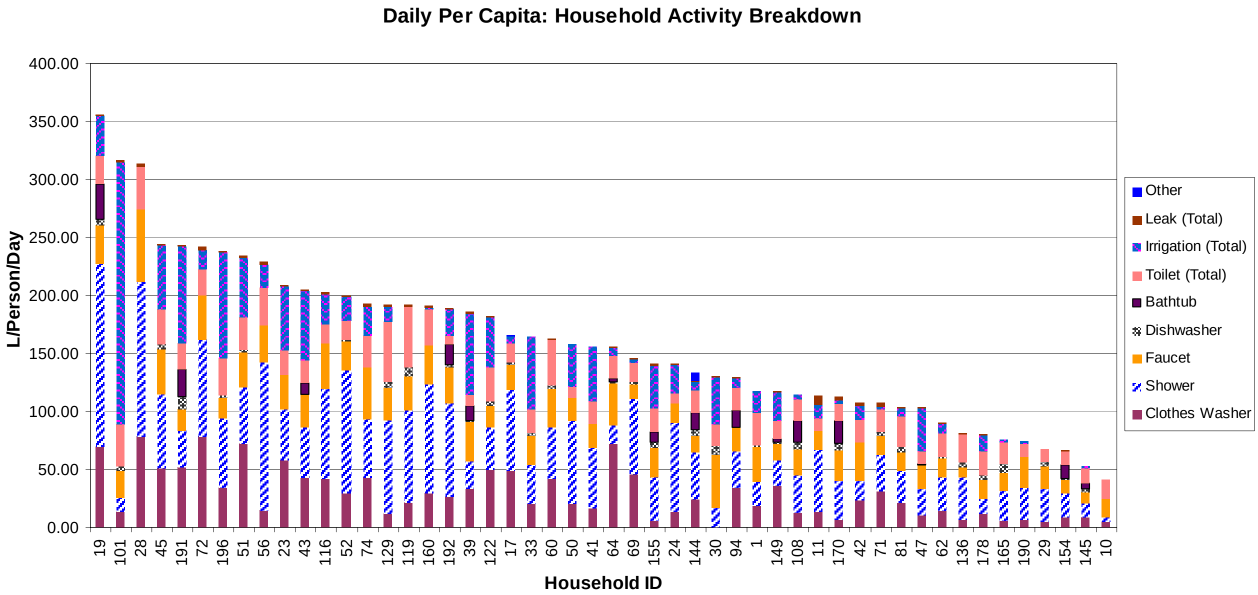


Figure 3 Individual household daily end use per capita (Willis et al., 2009)

GCWSEU Study: Future research

As presented above, the pilot study was the first component of the GCWSEU Study which is currently underway and will be continuing until early 2010. The research will investigate the effect of WDM strategies specifically, dual reticulation and education through an end use water consumption study. The research will record quantitative end use water consumption data as well as obtaining community information on demographics, attitudes, behaviour and perceptions, on the stated WDM strategies. The outcomes of this study include: the establishment of an end use water consumption model for the Gold Coast for both single and dual reticulated homes; exploration of the potable water savings attributed to dual reticulated systems and education programs; and perceptions, attitudes and behaviours of residents towards water. Another significant focus of the research is to provide data to assist in the refinement of assumptions stated in the PCWF Master Plan Water Balance Model.

The abundant data mining and analysis opportunities achievable from an effective smart metering system are imperative for the water industry in the current situational context with respect to water insecurity. However, the current systems and procedures required to collect, process and disseminate end use data are cumbersome and resource intensive. Such deficiencies in the current disaggregated approach triggered the consideration of a WBKMS. The cohesion of the above mentioned natural science data with a smart information system would allow for the delivery of a real time web-based management system which could provide comprehensive information to users and water managers. An overview of standard and smart metering technologies, as well as the proposed architecture for a WBKMS is provided below.

SMART METERING AND ARCHITECTURE FOR WBKMS DESIGN

Current water metering approach

The current metering system in Australia does not provide real-time water consumption data or sufficient data points to determine usage patterns. Conventional water meters used in Australia count each kilolitre of water as it passes through the meter without the ability to record when (i.e. time of day) and where the consumption takes place (e.g. washing machine, leakage, etc.) (Britton et al., 2008). Water consumption readings are generally recorded manually on a quarterly or half yearly basis. Under most situations, a whole year's worth of water consumption data is described by only two to four data points (Britton et al., 2008). No further information is available to draw upon should there be any queries (Hauber-Davis and Idris, 2006). Obviously, this conventional water metering system produces limited, delayed water consumption information. Such a metering system is unable to provide effective support to water planning and management processes. This current metering approach is not adequate to meet the increasing level of government scrutiny on the utilisation of water resources and does not assist society at large to address the pressing water security issues associated with climate change.

Smart water metering

The concept of smart metering embraces two distinct elements; meters that use new technology to capture water use information and communication systems that can capture and transmit water use information as it happens, or almost as it happens (New York State Energy Research and Development Authority, 2003). Smart water meters essentially perform three functions; they automatically and electronically capture, collect and communicate up-to-date water usage readings on a real-time (or nearly real time) basis (Idris, 2005). Hence, a smart meter is a high resolution water meter (e.g. 72 pulses per litre) linked to a device (a data logger) that allows for the continuous reading of water consumption. The information is available as an electronic signal, it can be captured, logged and processed like any other signal (Britton et al., 2008). In addition, today's data distribution technologies make it possible to bring this signal readily to any computer (Hauber-Davis and Idris, 2006). For example, a wireless 'Global System for Mobile (GSM)/General Packet Radio Service (GPRS)' modem with a microcontroller interface can be activated via GPRS mobile phone technology. When interrogated, the data logger downloads the water consumption data to a server, giving a value of water consumption of the required period (Idris, 2005). In this way smart meters can communicate the captured data to a broad audience, e.g. utility managers, consumers and facility authorities. Figure 4 illustrates the components of a typical smart meter set-up for a residential household, and Figure 5 shows its' set up on site. In summary, smart metering is established technology which is now cost-effective enough to be applied in Australia to collect, store and distribute real-time water consumption data (Hauber-Davis and Idris, 2006). An automated meter reading system with this capability provides benefits for both consumers and water authorities for monitoring and controlling water consumption (Britton et al., 2008).

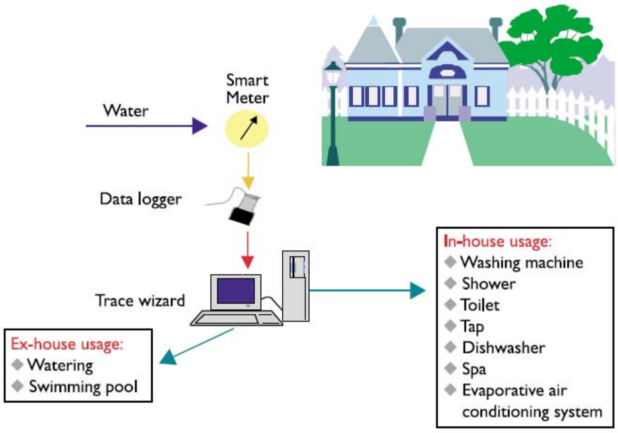


Figure 4 Typical smart meter set-up in residential household (Loh and Coghlan, 2003)

Figure 5 Smart water meter arrangement on site (Loh and Coghlan, 2003)

Enhanced modelling of water conservation measures

Traditionally, predicted water savings associated with demand management and source substitution interventions have been calculated through modelling a variety of poorly defined variables that are often assumptions, resulting in inaccurate water saving projections. Whilst, models such as the American '*National Water Saving Model for EPA WaterSense*' are complex in design and include the required variables to make a determination on achievable water savings, they should be refined to suit the particular end use characteristics of the demographic being targeted with a WDM program. By refining and constantly updating such models with up-to-date water end use data they will be far more powerful in their ability to predict water savings achieved by regulated or strategic WDM programs. Therefore, a smart metering and associated information management system, that can effectively integrate collected end use data with previously developed water modelling and management techniques and tools, will add substantial value to the water industry, both nationally and globally.

Web-based knowledge management system

The proposed water consumption WBKMS is an extension to the existing architecture of the smart water metering system, and designed as a powerful tool to support an integrated water conservation management system, in order to sustain water savings. The WBKMS can actively monitor water consumption and provide real-time information about what, when, where and how water is consumed. The primary functions of the WBKMS include, but are not limited to, collecting real-time water consumption data through a smart water metering system, transferring and storing the data into a knowledge repository and analysing the data, and producing a wide range of reports which can be accessed on-line by a broad range of users (e.g. consumers, water utilities, government organisations, etc.). The WBKMS will provide tailored analytical tools and reports for each specific group of users. Figure 6 provides a diagrammatic illustration of the structure of the WBKMS.

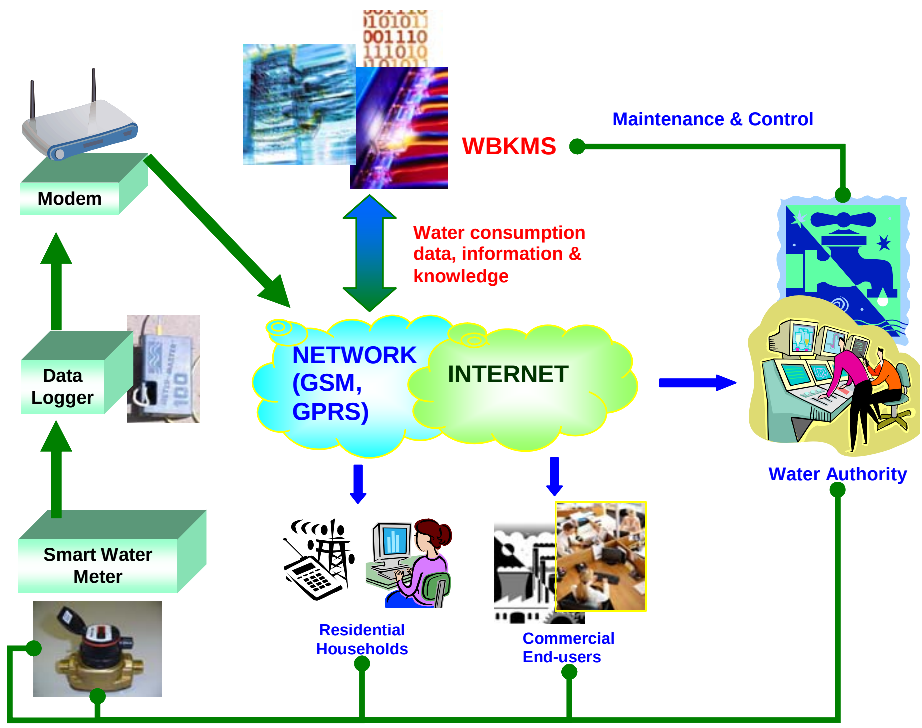


Figure 6 Structure of the WBKMS

One application of the WBKMS allows for individual consumers to log into their user-defined water consumption web page to view their daily, weekly and monthly consumption tables as well as charts on water use patterns for categories of water end use (see Figure 7 and 8). Moreover, cumulative water billing can be updated daily or even hourly and on-line alarms will be generated to indicate potential causes for excessive water use (e.g. internal leaks). This will help consumers to take corresponding water saving actions.

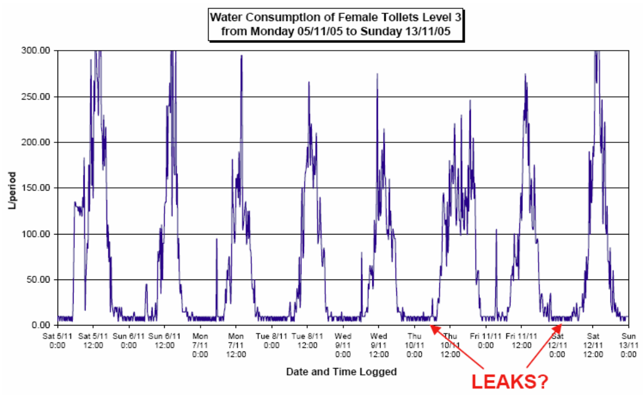


Figure 7 Commercial water consumption report (Idris, 2005)

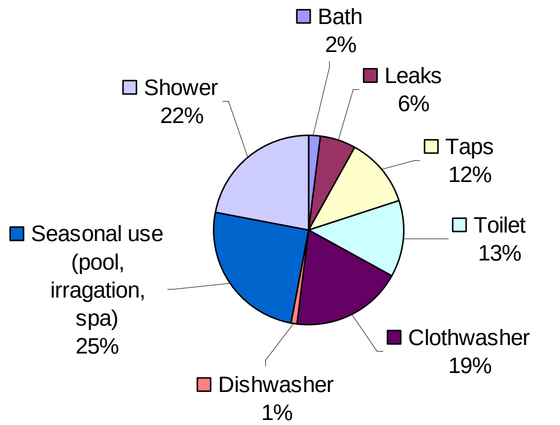


Figure 8 Residential water use break down (Roberts, 2005)

This system also enables water utilities to intervene as soon as an exception alarm is raised for end uses such as major water leaks; leaks going unnoticed for months on end will becoming a thing of the past (Britton et al., 2008). The analytical report generated by the system will also be able to help utilities to identify the water consumption patterns of different types of consumers. Figure 9 presents an example of analysis on monthly water usage of different groupings of households. As demonstrated by this example, it will be possible to dynamically correlate stored demographic data with water consumption patterns enabling deeper understanding of different categories of water users. This type of information will allow water authorities to develop targeted education campaigns relating to conservation and water use, and an opportunity to develop different tariff systems to influence consumption behaviour. The most powerful function of the WBKMS is to transfer water consumption data and information into water consumption knowledge.

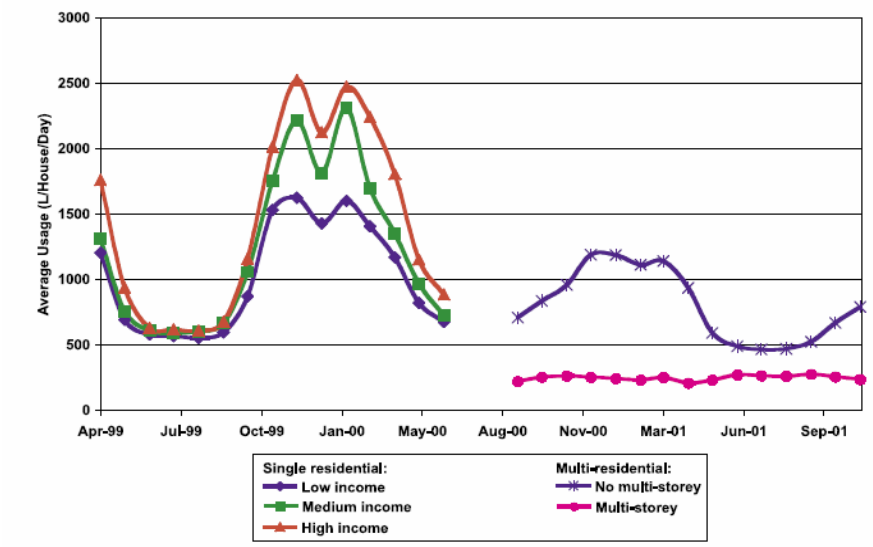


Figure 9 Average monthly usages of different households (Loh and Coghlan, 2003)

Based on the detailed water consumption data and analytical output, future water consumption trends can be forecasted and water conservation opportunities identified, thus ultimately enabling better understanding of water consumption behaviours. This rich knowledge can provide additional effective and efficient support for formulating water demand strategies and targeting funds at the ones that provide the highest yield at the least cost. Specific benefits for infrastructure planning, demand management and water consumers are discussed below.

WBKMS FACILITATING SUPERIOR PLANNING AND MANAGEMENT FUNCTIONS

Infrastructure planning and management

Water and wastewater infrastructure planning and management are primarily focused on long-term strategic planning including: developing strategies for holistic catchment water management; system modelling; development assessment and conditioning; priority infrastructure planning; infrastructure charges, policy and schedules; growth management; process assessment; research and development; and regional planning. Obviously, there are some significant implications of the WBKMS for improving current practices of infrastructure planning and management. The provision of demand and supply data from water and wastewater systems and households can assist system modelling through:

- Identifying leakage within houses and in the distribution system;
- Providing real-time diurnal pattern data of water demands at a household level (e.g. Figure 10) which will assist with understanding required supply quantities, storage needs, excess supply available for resale or distribution, and discharge volumes; and
- Real-time end use data related with prior knowledge on the typical waste constitute materials associated with such uses, will provide better predictive models on waste water system requirements (e.g. treatment processes, seaway and river impacts, etc.).

The WBKMS can improve infrastructure planning through:

- Better modelling of water and wastewater systems and improved identification of upgrade requirements for stressed infrastructure;
- A comprehensive understanding on the expandability of a particular region (with existing infrastructure) and management of growth based on water demands; and
- Most effective priority infrastructure planning and regional planning.

The data from a WBKMS will also provide significant insight into the development and effectiveness of WDM strategies.

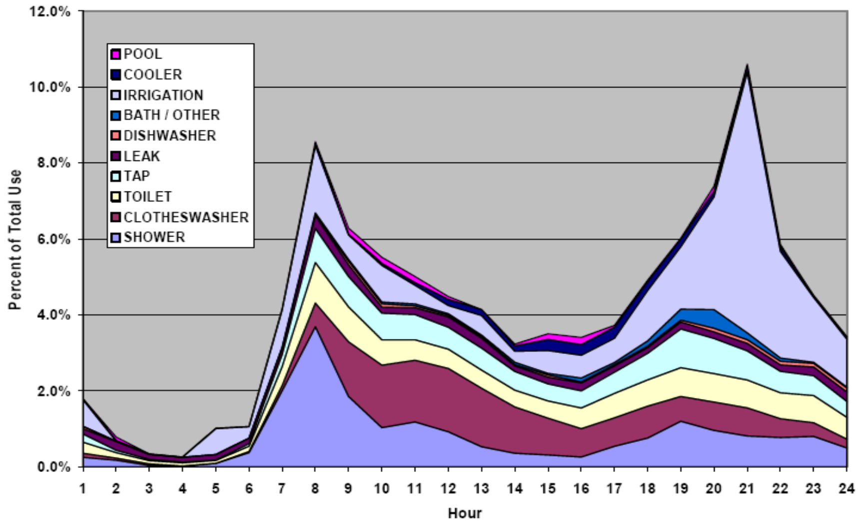


Figure 10 Diurnal pattern: break down at an end use level (Roberts, 2005)

Water demand management

WDM is defined as the practical '*development and implementation of strategies aimed at influencing demand*' (Savenije and van der Zaag, 2002, pp 98). The five categories of WDM include engineering, economics, enforcement, encouragement and education (Gold Coast City Council, 2005). The application of a WBKMS could significantly improve on current decision making relating to the development of WDM strategies as well as provide empirical verification on achieved water savings from such programs. The application of real-time end use data, for both water authorities and consumers, will undoubtedly revolutionise the current ad-hoc approach to water demand management. Some of the benefits of a WBKMS for enhancing current demand management functions include:

- The ability to monitor the effect of enforcement or restriction levels on water consumption;
- Ability to immediately quantify the effect of targeted education programs (e.g. to particular demographic, shower time, rebate program, etc.) on their intended water end use(s).
- Capacity to establish the water savings resulting from implemented engineering applications such as efficient water appliances (e.g. washing machines, shower roses, etc.) and pressure and leakage management.
- The provision of real time water consumption data provided to water users/customers resulting in an increased level of knowledge and understanding of personal water consumption and how this compares with others.
- Enables for definitive financial analysis of the cost and water saving benefits of implemented WDM programs, ultimately driving a least cost planning agenda; and
- Easy identification of leakage in the household or business.

The WBKMS will allow for the instantaneous quantification of the effect of WDM strategies on water consumption. This will lead to significant improvement on the development and delivery of such measures, thus closing the loop on demand management strategies.

Water customers

As discussed earlier the current metering and billing system only provides a single water consumption data figure to customers on a rates notice. The WBKMS provides a platform, for extensive knowledge transfer of water consumption data, directly to consumers. The WBKMS will offer an easily accessible system which allows users to log on and see: where and when they are consuming water; how they are consuming on a per capita basis; how their consumption compares with others of a similar demographic makeup; information on current water restriction levels; and allocations (i.e. regulated water target split to end uses) and tips on how to reduce water consumption in areas of high use. Users will be directed to pay their water bill through the WBKMS thus providing the need for people to use the system which instigates an understanding of how consumption behaviour translates into charges on their water bill. The functionality requirements for the WBKMS include:

- Users logging onto their Water Companies web site with their specific login and password for their property (water account). The screen will then take them to a *Welcome Page* that provides a water use summary for their property.
- The summary of water use includes water used yesterday, last week, quarter, year to date and associated costs. A summary of developed end use reports for each week, quarterly period, etc will also be available.
- The user can compare their use with the 'average' or 'usual' end use consumption in their region and for their demographic situation (once this type of private information is consensually entered into the system by householders).

- If there are situations where a household is using above average volumes of water in a specified end use (e.g. clothes washing) they will be provided with some recommendations/downloadable fact sheets on ways to reduce consumption in that area (i.e. clothes washer – rebate; shower – shower rose; etc.).
- The current water restriction levels set by the governing water body (e.g. Queensland Water Commission, Australia) will also be detailed.
- The reports and recommendations could also provide cost implications over a particular timeframe for reducing water in their home (e.g. the purchase of a water efficient clothes washer at *x* cost will result in a *y* number of year's payback).

The provision of such a system will facilitate consumers in taking a higher degree of ownership of their water use instead of the water utility or government. Ultimately the proposed WBKMS will be a valuable tool for knowledge and awareness transfer to users, allowing for the current level of government regulation and enforcement to be reduced over time. Figure 11 shows an illustrative example of the potential output achievable from the customer interface.

WATER UTILITY: WEB-BASED KNOWLEDGE MANAGEMENT SYSTEM

Welcome: 5 Smith Street, South Brisbane, Queensland Log out

Please make a selection from the following:

News

My Usage

Consumption Break Down

Comparative Usage

Rebate Schemes

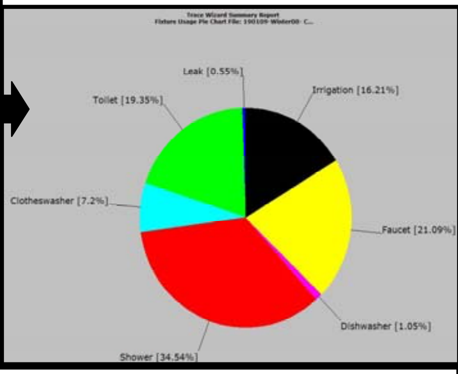
Reduce your Consumption

View / Pay Bills

View Statements

F.A.Q's

Period 2, 2009 Report: 12-25 January – 2 weeks)



Fixture category	Water Usage (L)	Percent (%)
Leak	15.28	0.55%
Toilet	539.08	19.35%
Clothes washer	200.59	7.2%
Shower	962.21	34.54%
Dishwasher	29.20	1.05%
Tap/Faucet	587.52	21.09%
Irrigation	451.54	16.21%
Total	**2785.42**	**100%**

Quick Summary: My Usage

Target Usage Per Day: 170 L/p/day Yesterdays Usage: 162 L/p/day

Last Weeks Average Daily Consumption: 210 L/p/day

Last Months Average Daily Consumption: 172 L/p/day

Figure 11 WBKMS water customer interface illustative example

APPROACH TO DEVELOPING AN EFFECTIVE WBKMS

Impediments to developing WBKMS

Whilst the proposed WBKMS can be achieved with the current level of metering, data logging, data transfer technology, information systems, as well as some adopted techniques from the artificial intelligence area, there are still a number of impediments to achieving a tried and tested system suitable for the water industry. Such barriers, which have informed the below described research agenda include:

- Creating robust wireless sensor networks. These wireless sensor networks require the ability to transfer 1000's of data points a day back to a remote server for all Australian homes. Whilst the networks are available, issues with respect to wireless network reliability, black spots, power source, damage by users, water proofing, cross connections, to name a few, need to be resolved.

- Information systems that can collect and store water end use information. Servers capable of collecting all data in a logical manner for analysis are essential.
- Automated and reliable processing of flow traces into end use data categories. The development of pattern matching algorithms can achieve highly accurate categorisation once development and training with end use data sets of a number of different homes has been completed. This is the most critical impediment requiring urgent research attention as the current approach to water end use analysis requires time consuming manual processing.
- Development of automated reporting tools that utilise processed information to create tailored reports for individual or groups of homes at the request of the water utility and/or user.
- Development of a user friendly web-based interface that can be accessed by the water utility or individual user to access required information.

The above listed impediments all require further research and investigation. A summary on the research agenda currently occurring to address such impediments is provided below.

Research agenda/program for WBKMS

The following staged research agenda is planned to address the above mentioned impediments and to formulate the architecture for the proposed WBKMS:

- *Stage 1 - Recommend national standard for smart water meters and data loggers*: Many water authorities, both nationally and internationally, are trialling different types of smart meters and data loggers with varying degrees of accuracy and suitability for purpose. The selection of these meters has been largely ad hoc without careful holistic consideration on how they will be utilised for improved water resource management. This stage aims to research the advantages and disadvantages as well as the cost-benefit of different meters and data loggers with the view to develop a recommended list of appropriate products that are fit-for-purpose for the level of water end use reporting required for effective action by both water users and managers.
- *Stage 2 - Determine the most suitable system for data transfer from smart meters to the remotely located knowledge management system of the water organisation*: Whilst there have been many advances in wireless network communications, many issues still exist which are associated with the implementation of these systems for dynamically collecting large volumes of water end use information from the many thousands of smart meters controlled by the water organisation. Issues include energy supply constraints, limited node capability, variability of the links and network topology. Methods to address these challenges include intelligent distributed control protocols, node redundancy and coordination, to name a few. Out-of-box thinking is required to deliver the promise offered by wireless networks for the remote collection of smart water meter data. The outcome of this stage will be a robust data transfer system which conveys digital signals to the remote server.
- *Stage 3 - Develop the structure of the knowledge management system*: Each water user (i.e. households, businesses, etc.) managed by a particular water authority will have thousands of data points being transferred to the remote server, detailing accurate water use on a second-by-second basis. Also, the demographic information associated with each user will need to be maintained (e.g. household makeup) to ensure that certain trends can be developed. The hierarchical architecture of the WBKMS and its various sub-sets will need

to be developed in this stage to ensure that information is efficiently stored and can be accessed with limited redundancies and time.

- *Stage 4 - Data compilation and analysis for intelligent decision-making*: Storage of millions of data points is useless unless such information can be compiled into a useable form for reporting. Thus, this stage aims to develop the approaches and algorithms for compiling stored data into useable up-to-date reports for intelligent decision making by water users and managers. Existing tools such as TraceWizard© and SPSS© could be utilised for some aspects of the processing of natural science or statistical data but other new algorithms and tools will also need to be developed.
- *Stage 5 - Web-based interface architecture formulation*: Similar to PeopleSoft and other enterprise management systems, the framework for the architecture of the web-based interface will need to be developed in such a way that the various users with their different logins can easily access the variety of reports offered in a user-friendly manner. This stage will require consultation with the various possible users of the system to ensure that all necessary elements for a user-friendly interface are included in the system.
- *Stage 6 - Model utilisation of system and potential water saving and other benefits*: Armed with up-to-date information, both water users and managers will be able to better manage Australia's scarce potable water supplies. This will have a wide range of benefits, including, changing user behaviours, better targeting rebate programs, regulating water use, peak/off-peak water pricing, water infrastructure planning, to name a few. In this stage, the research team will model the predicted water savings attributable to the implemented WBKMS and associated technologies. The predicted savings will act as benchmark key performance indicators that the WBKMS can be measured against once implemented. Essentially it is envisaged that such a system could save a further 10-20 per cent to the current levels of water consumption which equates to greater than 60 mega litres or 1200 swimming pools of water per day for South East Queensland alone.

CONCLUSION

Current research in the smart metering and end use field demonstrates a need for the development of a WBKMS. The creation of such a system poses numerous benefits for infrastructure planners and WDM managers. The system also provides detailed information to users which will vastly improve their current level of knowledge and understanding on their water consumption. Knowledge is power, and when customers are armed with real-time water end use data at their fingertips, they will be able to proactively address their consumption levels. The development of a WBKMS could ultimately lead towards more informed infrastructure planning, strategically developed and monitored WDM strategies and a vast improvement in awareness of where, when and how water is being used, by both water utilities and consumers.

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