Charting a new course for water—is black water reuse sustainable?

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Abstract

The world is facing a water crisis, and Australia is no exception. New regimes for the supply, use, and delivery of water are needed to ensure a sustainable water future. Black water reuse through ‘sewer mining’ or onsite treatment, proposes to be one initiative that may possibly offer a viable and sustainable alternative approach to water provision in many contexts. However, despite the potential benefits of black water reuse, its feasibility is not yet fully understood. In particular, there is much uncertainty surrounding the following issues: (1) community acceptance, (2) policy complexities, (3) performance impacts of these localised systems, and (4) environmental balance over the full life cycle. This paper outlines research needs surrounding black water reuse with a focus on these four major issues. The paper presents a research agenda to address these important issues. This research agenda involves two Australian commercial case studies: the Council House 2 building in Melbourne, and the Bendigo Bank building in Bendigo.

Keywords Community acceptance; life cycle analysis; onsite treatment; performance; policy; recycled water; sewer mining

Introduction

It is widely accepted by scholars, governments and citizens that the world is facing a water crisis. This global water crisis is occurring as a consequence of many factors including: growing world population, increasing urbanisation, increasing per capita water consumption and anthropologically driven climate change. In order to achieve the sustainable management of water resources, a holistic approach is required to development and management of water resources. In many instances this will require a re’vision’ of current water management practices, and a philosophy change from business as usual to management practices requiring sustainable use of water (Hurlimann, 2007). Major changes to the traditional way water is valued, consumed, managed and delivered is required (Hurlimann, 2006a).

In most major urban areas throughout the developed world a centralised and highly risk averse approach to the delivery of water and disposal of wastewater is dominant. The use of alternate regimes is becoming increasingly important in many parts of the world. Black water reuse through ‘sewer mining’ or onsite treatment, proposes to be one initiative that may possibly offer a viable and sustainable alternative approach to the traditional regime of water provision and sewage disposal. Despite the potential benefits of black water reuse, its feasibility is not yet fully understood. There is much uncertainty surrounding the following issues: (1) community acceptance, (2) policy complexities, (3) performance impacts of these localised systems, and (4) environmental balance over the full life cycle. This paper will outline research needs surrounding black water reuse with a focus on these four major issues.
The current Australian water crisis

Australia is in the midst of a water crisis. Many towns and cities around the country are running out of water (Eccleston, 2006; Packham and Williams, 2006). For example, in the state of Victoria, the capital city of Melbourne’s water storages (dams) are at only 34.9% capacity. The city’s 3.6 million residents are facing restrictions to the use of potable water. These restrictions limit outside water use in residential areas to two days a week and only at limited times of the day (early morning or evening). Restrictions to water use also apply to industry, commercial and industrial users. In many regional and rural areas of the state the situation is much worse. For example, in the regional urban centre of Bendigo, water storages (dams) are currently at 6.1% of storage capacity (February 2007). Bendigo is forecast to run out of water in six months’ time. The City’s 97,000 residents, and businesses are on emergency water use restrictions.

The water crisis is not confined to the state of Victoria. Water shortages are having a major impact in six of Australia’s eight states and territories. This has seen policy responses from many state governments promoting the use of recycled water. Western Australia’s State Water Strategy has set a target to recycle 20% of wastewater by 2012 (Government of Western Australia, 2003), and similarly Victoria’s now Department of Sustainability and Environment has set a target to recycle 20% of Melbourne’s wastewater by 2010 (State Government of Victoria, 2002). There has also been significant national water policy development, including the development of a National Water Initiative. This intergovernmental agreement aims to encourage water conservation in cities through better use of storm water and recycled water (Council of Australian Governments (COAG), 2004). However, despite these policy targets for water recycling recycled water at present only constitutes 4% of total water supply in Australia. The potential according to the Australian Academy of the Sciences and Engineering (AATSE) (2004) is that it could supply 50% of the needs of urban dwellers. Thus there is great potential to meet this shortfall in potable supply through substitution with recycled water.

Black water reuse

Black water reuse is the beneficial reuse of domestic or commercial wastewater sourced from toilets, basins, showers and other water normally sent to the sewer. Sewer mining is a process where wastewater is extracted from the sewerage system and treated to a very high standard to be reused in a site specific location in a decentralised manner. Black water reuse occurs both in a regulated and unregulated manner. In many developing nations the reuse of black water occurs without treatment with detrimental impacts (AATSE, 2004; Fatta et al., 2004). The reuse of black water is increasingly seen as a sustainable approach to the provision of water in Australian urban areas. For example black water is treated and reused in Melbourne City Council’s Council House 2 (CH2) building (Othman and Jayasuriya, 2006) through sewer mining and is in trial capacity for many major parks and gardens across Australia including at the Australian Formula One Grand Prix site, Albert Park in Melbourne (PMSEIC, 2003).

Recycled water use in urban areas for non-potable uses is not a new concept. Internationally several countries have been recycling water for decades. For example one project in the USA dates from 1925 set up in the Grand Canyon village as a dual pipe system to conserve water to meet the demand from tourism (Okun, 1997). Urban integrated dual pipe systems have been used in Japan due to serious urban water shortages since 1968 (Asano, 1996). At this time legislation was introduced that required water recycling in metropolitan buildings over a certain size, including tax incentives for developers to carry this out (Lazarova et al., 2004). The Millennium Dome in London is a large in-building water recycling system. Instigated by Thames Water, the system collects grey...
water, rainwater and groundwater from the site and uses this to flush all the toilets and urinals on the site. In 2000 this served over 6.5 million visitors (Lazarova et al., 2003).

Black water reuse feasibility
Preliminary research by the authors has identified four major research needs to address in order to realise the potential of black water reuse. The details of these are now provided.

Community acceptance
While recycled water use is becoming increasingly necessary and promoted in various levels of policy around the world, there are still doubts surrounding the public acceptance of its use. A number of recycled water projects around the world have failed due to a lack of support by the communities involved (Hurlimann and McKay, 2004). Numerous researchers have identified that there is a lack of analysis of community acceptance of and attitudes to recycled water use (Dillon, 2001; Marks, 2003; Po et al., 2003; Jeffrey, 2005; Hurlimann, 2006b). These need to be addressed if the broader policy objectives discussed earlier are to be achieved.

The majority of research related to community acceptance of recycled water use was conducted in the USA in the 1970s by Bruvold and others (including: Bruvold, 1972, Bruvold and Ongerth, 1974). This research was limited to attitudes to use of recycled water for various uses and also acceptability of various treatment processes. Bruvold’s work and that of other researchers around the world has shown that acceptance of recycled water use decreases as the use becomes increasingly personal (McKay and Hurlimann, 2003; Po et al., 2004; Hurlimann, 2006c; Marks, 2006).

Recent research has addressed reasons for acceptance or rejection of recycled water use such as trust in authorities, price, satisfaction, perception of fairness in implementation, communication of information and attitudes to various quality attributes of the recycled water (see Hurlimann, 2006b and Po et al., 2003 for a literature overview and findings). Significant contributions to gaps in our understanding of community attitudes to recycled water use in residential contexts has been made over the past few years but there are still significant gaps in knowledge. A literature search indicates that there is limited information available about community attitudes to sewer mining, black water reuse specifics and very little analysis in relation to the use of recycled water in a commercial environment, apart from a benchmark survey conducted as part of this research project (Hurlimann, 2006c). In 1999 a Japanese study conducted a questionnaire of occupants of 125 commercial buildings using recycled water (mainly for toilet flushing), problems with odour of the recycled water were reported (Yamagata et al., 2003). Another research need is identification of development industry barriers to implementing recycled water systems into development. Further research into public acceptance of recycled water use is needed to ensure the aim of sustainable water use and provision is achieved, in particular the various specific targets for water recycling in previous sections of the paper. This is an international research need.

Policy
There are two main research needs related to policy surrounding black water reuse. These are (1) the reduction of policy complexity, and (2) greater policy focus on water in urban planning policy. These issues are discussed in turn. In Australia there is significant complexity in policy applicable to water reuse. Presently appropriate use of recycled water is guided at a National level by the National Guidelines for Water Recycling: Managing Health and Environmental Risks (Natural Resource Management Ministerial Council et al., 2006). These are not mandatory and they exist alongside a number of other state
and territory guidelines. Recycled water quality and safety features are determined on a state by state and often case by case basis. Recycled water use schemes often ignore the national guidelines and guidelines of their state in favour of another states. This creates inconsistency, potentially opening the recycled water manager to a number of legal liabilities (McKay, 2000). In implementing sustainable water initiatives at a local level in Australia there are multiple and complex approval processes at present. Some on-site systems have been given pre-approval by relevant water authorities, while others require lengthy approvals processes by multiple authorities. In addition to Australia, it has also been highlighted that much research is needed into the institutional arrangements for black water reuse in other nations, particularly developing nations (Fatta et al., 2004).

In terms of urban planning policy, it appears that there is a lack of consideration of the limits to a city’s growth water shortages pose. This can be exemplified in the urban policy context of Melbourne. Melbourne 2030 is a strategic plan for Melbourne (Department of Infrastructure, 2002). The plan encourages the development of activity centres and transit cities. It is widely believed that the development of nodes of activity in cities will result in a greater efficiency than concentrating all activity in one Central Business District (Department of Infrastructure, 2002). To date the study of activity centre policy development in Melbourne has focused on the optimisation of public transport use (reduction of 57% per year of transport related emissions per person) and minimisation of urban sprawl. Other benefits which are rarely mentioned are the ability to decrease energy use (0.75T of CO₂ per person per year) and materials impacts (0.8T of CO₂ per person per year) (Australian Greenhouse Office (AGO), 2002). There is no current research on what the efficiency opportunities are in terms of water.

The potential for water savings in activity centres is three fold. Firstly, given the increased density it is possible to integrate a semi-decentralised or decentralized water reuse systems that ensure water use is of a quality fit-for-purpose. Recycled water could provide 50–90% of household water supply through potable substitution (Water Services Association of Australia (WSAA), 2003). Secondly, being a semi-decentralised system, any unaccounted for water in the system (leaks) will be more readily identified. Finally, with increased densities as planned for in Melbourne 2030, there will be an additional load put on the aging infrastructure. Removing most of this by reusing a large percentage of this load reduces these impacts. However, current policy is such that there are no requirements for water efficiency achievements in most new development in Melbourne. Currently the requirement to consider water efficiency is only triggered if land is zoned as residential, and under other specific policy contexts. However, most of these transit cities or activity centres are planned in existing mixed or business zones where there are no requirements to integrate water reduction strategies. This means there is little incentive for developers to consider the incorporation of semi-decentralised water reuse systems in activity centres, and no power for government to require their inclusion.

Performance impact on infrastructure
In the Melbourne metropolitan area 90% of wastewater is treated in two large wastewater treatment plants. Tapping into this resource through sewer mining systems, and reducing its volume by recycling water, has the potential to impact the sewerage system and receiving treatment plants. Sewer mining could range from systems where sewerage is extracted and treated totally on-site, with no waste disposal, to systems where high strength wastewater is disposed back in the sewer. The focus of this research is the potential impact of the latter system, specifically the use of different sewer mining systems of varying sizes and or types on the sewer system particularly the potential
odour and sulfate formation. The impact of potential variation in wastewater characteristics on the receiving wastewater treatment plant will also be discussed.

Water recycling systems that utilize membrane technology such as the multiple water recycling (MWR) systems discharge wastes of high solids concentration from the screening and microfiltration units back to the sewer. At the final stage, the reverse osmosis unit discharges 95%–99% of remaining constituents to the sewer. Therefore, these systems extract water and discharge high strength waste stream to sewer. The transport of these wastes under low hydraulic flow in the sewer system can impose an impact on the sewer pipes, with a potential to enhance corrosion, increase emissions of gases and odour causing reactions associated with high suspended solids (SS) and low flow. Anecdotally these impacts are already being felt in many urban Australia areas that are facing water use restrictions such as Melbourne and Bendigo where there is increased informal reuse of grey water by residents.

There limited literature on the impact of water recycling systems on sewer systems and receiving wastewater treatment plants. A recent paper by Kalavrouziotis and Apostolopoulos (2007) looked at the development of urban waste water and reuse treatment plants. They investigated the following elements: bacteria, protozoa, helminths, heavy metals, specific metal concentrations of As, Mn, Zn, Ag, Be, Cr, Cu, Li and Se and organic chemicals such as benzoyl, oils, tar, phenolics, petroleum, aldehydes. Specifically the paper discussed the impacts these systems can have on existing infrastructure such as concrete pipes and summarised the research on the effect of acids, metals, organic substances and biological activity.

The aim of this research is to assess the potential impact of increased numbers of onsite MWR systems on infrastructure and performance of receiving wastewater plants. The focus will be on the effect of variations in the concentration of the sewage SS, organic (measured as biochemical oxygen demand) and inorganic on the sewer infrastructure and performance of receiving wastewater treatment plants. In using recycled water for non-potable use in building issues that need to be monitored regularly are: pH, BOD, turbidity, coliform and chlorine. The US EPA recommends measuring of these at rate respectively of: weekly, weekly, continuously, daily and continuously.

Life cycle assessment (LCA)

In making decisions on the introduction of new technologies, it is crucial to get insights into their broader environmental and economic impacts and benefits over their entire lives (Hes and Grant, 2002). Applying LCA to water recycling systems is relatively new. Nevertheless, there are several studies that have been done since 1995 looking at various aspects of water and waste water treatment (Emmerson et al., 1995; Dennison et al., 1998; Tillman et al., 1998; Lundie et al., 2004; Tangsubkul et al., 2005; Grant et al., 2006a,b). This research will specifically place two systems - mechanical/membrane Multi-Water Treatment plant and mechanical/biological system called the Heal-AST Waste water treatment plant? being used in the case study buildings (detailed later in the paper), in the context of these existing studies.

The study carried out by Tangsubkul and colleagues (2005) is specifically interesting as they looked at the LCA of a Continuous MicroFiltration (CMF) system, a Membrane Bioreactor with Reverse Osmosis (MRB/RO) system and a Waste Water Stabilisation Pond (WSP) system. These LCAs looked at irrigation as the end use of the water, the proposed case studies in this research will specifically investigate the use of the treated water for non-potable internal uses, with only limited use for irrigation. The life cycle stages looked at in this study were: contribution of construction, energy use in operation, chemical usage, effluent reuse and biosolids application. The environmental impact
categories covered were Global Warming Potential (GWP), Eutrophication Potential (EP), Human Toxicity Potential (HTP), Freshwater Aquatic Ecotoxicity Potential (FAEP), Marine Aquatic Ecotoxicity Potential (MAEP), Terrestrial Ecotoxicity Potential (TETP) and Salination Potential (SP) (Tangsubkul et al., 2005).

The results of the Tangsubkul study showed that over the whole of the life cycle, based on the LCA inventory, the WSP performed best, followed by the MBR/RO and CMF on all aspects except salination potential. Over the whole of life, construction of the MBR and CMF systems only represented a quarter to a third of the global warming potential (mainly caused by energy use over life). Their most significant conclusion was that the level of resources, and resulting environmental impact, being used to treat the water did not represent the treatment level required for its application - the water was over treated to gain the confidence of those using the water. As such the CMF option performed very poorly because of the operational energy requirements and chemical usage for water which was being used for irrigation. The limitations for using LCA were also discussed in the Tangsubkul study demonstrating why the actual monitoring and modeling of the case studies is a crucial: (1) LCA does not address long term accumulation of toxic substances, (2) human health effects of possible pathogens are not taken into account, (3) average and typical data is used, and (4) there is significant data quality disparity.

The other paper that underpins the case study research is the Grant et al. (2006a) work which looked at the LCA of alternative water and sewage servicing in Melbourne. Specifically, this looked at the whole of life environmental and cost burden of options for alternative water provision such as rainwater tanks, grey water reuse and storm water reuse. It also looked at new urban fringe development and inner urban infill development. Apart from putting into context various water provision options this study showed that there are potential synergies between water conservation, reuse and other environmental goals relating to global warming emissions, energy use and water pollution (Grant et al., 2006a). For centralized systems the energy use associated with moving water and waste water around a large city dominate the greenhouse and energy results, while capital equipment is generally small component. This is inverse to the life cycle costing which is dominated by capital expenditure and maintenance with energy costs being relatively minor. For onsite reuse either at a building level or for a group of building the infrastructure impacts increased, but were partly offset when the reuse was in an area with limited capacity in existing sewer and water infrastructure, and the area is undergoing growth in demand through population increase. Grant et al. (2006b), found that the modeling of sewage treatment plants in LCA was not sophisticated enough to determine the benefits of reducing volume of waste water without reductions in total nutrient loads as is the case with water recycling projects which send filtered contaminant to existing sewer networks. This is a research need.

Case studies

These four issues identified and discussed above, will be investigated in the context of two Australian black water reuse case studies. Both case study sites are commercial office buildings located the state of Victoria: the Council House 2 (CH2) building in Melbourne and the Bendigo Bank Building in Bendigo. Each of the case study sites is now described.

The CH2 building · Melbourne

The City of Melbourne’s (CoM’s) innovative Council House 2 (CH2) office building is located in the Melbourne Central Business District (CBD). The building completed construction at the end of 2006 and was occupied by City of Melbourne Council staff in October 2006. While newly occupied, it is anticipated the building will achieve
significant savings in energy and water use, provide a high quality indoor environment for office workers and conserve resources in the process of construction. In 2005 the Green Building Council of Australia awarded CH2 a ‘six green star rating’ which represents world leadership in office building design (further details can be found at www.melbourne.vic.gov.au). A major intention of the CH2 building is efficient water use. In addition to water efficient fixtures and appliances, the design of the CH2 building includes a ‘sewer mine’. About 100 kL of wastewater a day will be extracted from the sewer (Othman and Jayasuriya, 2006). This sewage, along with sewage generated on site, will be treated to a standard suitable for all non-potable (non-drinking) uses and will meet all Class A water criteria through a separate water supply system (Othman and Jayasuriya, 2006). The recycled water will supply the CH2 cooling tower system, plant watering and toilet flushing needs and is also intended to be used for street cleaning and street tree watering within the CBD.

**The Bendigo bank building - Bendigo**

The Bendigo Bank Headquarters is an innovative building that is currently under construction in the Bendigo CBD. It is anticipated that construction will be completed in stages with the first occupancy commencing at the end of 2007. The building incorporates ecologically sustainable principles in its design and construction. It is estimated to save 51% of energy use, 1175t CO₂e/annum and around 17,000 L of water per day (Sustainability Victoria, 2006). Reducing reliance on reticulated water was a key design consideration for the building due to Bendigo’s drought-vulnerable water supply (Sustainability Victoria, 2006). A recycling water treatment plant will treat both black and grey water, providing Class A water for non-potable use to flush toilets and irrigate gardens (Sustainability Victoria, 2006). Bendigo Bank is a community focused bank which is highly regarded for its social responsibility. They have a commitment to sustainability, demonstrated by their reduced home loan interest rates to help customers build homes incorporating energy efficient design features (www.bendigobank.com.au).

**Conclusions**

Integrating the actual performance of the two case studies — energy use, chemical used, effluent make-up and impact on corrosion (issue 3) — placing the results within a LCA framework (issue 4), looking at the attitudes of those using the case study water, and...
those of the general community (issue 1), reviewing policy and regulations (issue 2) and speculating on the applicability of semi-decentralized systems will provide a holistic set of data for decision making regarding water infrastructure now and into the future. Figure 1 shows how the four components of the research will work together to answer the questions:

1. Is there a point of optimum integration of sewer mines in the current infrastructure within the CBD? This will lead to a kilometres squared per sewer mine scenarios based on cost, environmental impact, concentration of key constituents, etc.

2. Are there distinct factors which influence the viability of sewer mines in city areas (policy, perceived need and attitudes, future scenarios such as climate change and increase in energy costs, cost of water, future cost of infrastructure and maintenance)?

3. Given the water pressures in regional areas are different to those in urban areas will this make sewer mining more viable in these areas, particularly from a scarcity and attitudinal perspective?

This paper has discussed a framework that will assess two black water reuse systems so as to determine if they are a sustainable and effective approach for the management of water resources. The approach drawing from a multidisciplinary team of people is generic and applicable not only to Australia but throughout the world.

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References


