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Impact of water management practice scenarios on wastewater flow and contaminant concentration

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ABSTRACT

Due to frequent droughts and rapid population growth in urban areas, the adoption of practices to reduce the usage of fresh water is on the rise. Reduction in usage of fresh water can be achieved through various local water management practices (WMP) such as *Water Demand Management (WDM)* and use of alternative water sources such as *Greywater Recycling (GR)* and *Rainwater Harvesting (RH)*. While the positive effects of WMPs have been widely acknowledged, the implementation of WMPs is also likely to lower the wastewater flow and increase the concentration of contaminants in sewage. These in turn can lead to increases in sewer problems such as odour and corrosion. This paper analyses impacts of various WMP scenarios on wastewater flow and contaminant load. The Urban Volume and Quality (UVQ) model was used to simulate wastewater flow and the associated wastewater contaminants from different WMP scenarios. The wastewater parameters investigated were those which influence odour and corrosion problems in sewerage networks due to the formation of hydrogen sulphide. These parameters are: chemical oxygen demand (COD), nitrate (NO_3^-), sulphate (SO_4^{2-}), sulphide (S^{2-}) and iron (Fe) that were contributed by the households (not including the biochemical process in sewer pipe). The results will help to quantify the impact of WMP scenarios on odour and corrosion in sewerage pipe networks. Results show that the implementation of a combination of WDM and GR had highly increased the concentration of all selected contaminant that triggered the formation of hydrogen sulphide, namely COD, sulphate and sulphide. On the other hand, the RH scenario had the least increase in the concentration of the contaminants, except iron concentrations. The increase in iron concentrations is actually beneficial because it inhibits the formation of hydrogen sulphide.

1. Introduction

Global climate change and rapid growth in population have put many urban water systems under stress. This has led to the implementation of various practices for minimising the use of fresh water, such as the adoption of *Water Demand Management* and substituting fresh water with *Alternative Water Sources* (for e.g. rainwater, greywater and blackwater) (Hurlimann and Dolnicar, 2010; Marks et al., 2006; Radcliffe, 2006; Sharma et al., 2012). The use of more efficient water appliances, installation of rainwater tanks and greywater treatment and storage are encouraged by the Australian Government through rebates and incentives as well as through stringent regulations (Australian Government, 2005; Tate, 1990). These residential Water Management Practices (WMP) are predicted to be increasingly implemented in the future as the fresh water becomes more limited (Brown et al., 2010). For many of these practices, water and wastewater are managed, treated and used at their source to maximize the water saving and environmental protection benefits. These practices are also considered to be technically, economically and environmentally feasible in the long-term to secure water supply (Sharma et al., 2010). Reduction in fresh water demand, could minimize the expansion cost of water supply networks, and reduce the impact of discharged wastewater to the environment, as well as infrastructure savings on the sewerage system have been widely acknowledged as major advantages of WMP (Radcliffe, 2010). Furthermore, looking at the socio-economic impact of WMP on the residents, it has been

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studied that the lower income residents considered the usage of alternative water source could help them to reduce their water expenses (Ryan et al., 2009).

On the other hand, the implementation of WMP scenarios has also been recognized to contribute to negative impacts, which have been highlighted in several studies (Cook et al., 2010; DeZellar and Maier, 1980; Parkinson et al., 2005). These studies have indicated that the implementation of WMPs alters the wastewater characteristics in terms of lower discharge volumes and higher sewage strength. These changes affect the extent of solid deposition and biochemical transformations in sewer networks, thus leading to degradation of downstream infrastructure via blockages, odour and corrosion (Marlow et al., 2011; Swamee et al., 1987).

Installations of water efficient appliances such as washing machines, shower heads, and dual flush toilets are integrated into *Water Demand Management* strategies, and can achieve significant reduction in fresh water use. Some studies have reported reductions in the range of 15–40% (DeZellar and Maier, 1980; Sharma et al., 2009). Fresh water can be substituted with various alternatives which include rainwater, treated greywater or treated wastewater. Among these three alternative water sources, rainwater is the most acceptable source for substituting all indoor water demands except that for the kitchen's water supply (Assayed et al., 2013; Hurlimann and Dolnicar, 2010; Marks et al., 2006). Substituting indoor water demands with collected rainwater can conserve up to 90% of indoor fresh water (Ghisi and Ferreira, 2007; Li et al., 2010; Talebpour et al., 2011; Villarreal and Dixon, 2005). However, the reliability of this alternative water source is often questioned in some studies (Hajani et al., 2013; Rahman et al., 2012), particularly because it is predicted that the mean rainfall in subtropical zones (including southern areas of Australia) will decrease due to global climate change (IPCC, 2007). Treated greywater and treated wastewater have higher reliability when compared to rainwater in terms of supply; however the social acceptance of treated greywater and wastewater use is low when compared to the use of rainwater. In many buildings and households, treated greywater and treated wastewater are used for toilet flushing and irrigation or other outdoor uses (Hurlimann and Dolnicar, 2010; Hurlimann and McKay, 2006). Restricting indoor use of treated greywater and wastewater to toilet flushing limits fresh water savings to a maximum of 20% (Christova-Boal et al., 1996; Chung and White, 2009; Ghisi and Ferreira, 2007).

Recently, some studies have attempted to investigate the impact of WMPs on sewer blockages (Parkinson et al., 2005), however no studies have been conducted to study the impact of WMPs on sewer odour and corrosion (Marleni et al., 2012). Hence, this paper presents a preliminary analysis that aims to assess the impacts of various WMP scenarios on wastewater flow and contaminant load for predicting the extent of odour and corrosion in sewerage networks. Various WMP scenarios were developed in this study and the Urban Volume and Quality (UVQ) model was used to estimate the water and wastewater flows and their associated wastewater quality parameters for the developed WMP scenarios. To analyze the potential impact of WMPs on sewer odour and corrosion, wastewater parameters that influence these two sewer problems (caused due to the formation of hydrogen sulphide) were selected. These parameters are wastewater flow, chemical oxygen demand (COD), sulphate (SO_4^{2-}), sulphide (S^{2-}) nitrate (NO_3^-) and iron (Fe).

2. Case study

The case study site selected was a residential area in Glenroy (a suburb in northern Melbourne, Australia), which comes under the jurisdiction of Yarra Valley Water (water retailer). The area consisted of mostly detached houses that are occupied by families (more than 1 person per house). Fig. 1 presents the location of the selected residential area in the Glenroy sewer subcatchment.

The total number of households in this area was estimated to be around 3750 households (McDonell, 2010). According to the Australian Bureau of Statistics and a study by Roberts (2005), the household size in the study area was 2.55 persons per household. The total area of the study site was 425 ha, in which a typical residential size block was assumed to be in the range of 125–790 m^2, comprising a roof area of 63–467 m^2 and garden area of 43–274 m^2. It was assumed that all the households had a paved area of 50 m^2. The road area for the case study site was calculated to be 41.6 ha with an open space area of 271 ha. The WMPs that have been implemented in the case study area are *Rainwater Harvesting* and *Greywater Recycling*. Around 30% of the residential households in this area have rainwater tanks, but only about 3% of them use rainwater for toilet/laundry purposes. For *Greywater Recycling*, only around 3% of households in the study site have the *Greywater Recycling* facilities (Locke, 2011).

3. Development of the WMP scenarios

The WMP scenarios were developed using a matrix that was constructed using two WMPs, namely, *Water Demand Management* (i.e., reduced water consumption) and the type of water source (alternative and traditional) (please refer to Fig. 2). *Water Demand Management* and the type of water source were considered to be independent and unrelated WMPs. The four quadrants of this matrix indicate the four types of WMPs that are developed, which are the *Base Case*, *Alternative Water Use*, *Water Demand Management*, and *Sustainable Practice*. As can be seen in Fig. 2, the first quadrant of the matrix represents the *Base Case* with usual (or current) *Water Demand Management* and with traditional water sources (i.e., potable water from the water mains). On the other hand, the opposite quadrant (the third quadrant) represents *Sustainable Practice* with high *Water Demand Management* and with the use of alternative water sources.

A detailed description of each of the four WMP scenarios indicated by the four quadrants of the matrix is presented below:

i) *Base case*

The *Base Case* scenario consists of conventional households with water use based on reported monitoring data. This scenario considers that usual *Water Demand Management* has currently been adopted for water saving purposes. In this study, usual *Water Demand Management* refers to a condition where mostly three-star water saving appliances have been installed within a household. The water source is assumed to be potable water from the water mains. Based on information from Yarra Valley Water (Locke, 2011), the WMP of *Rainwater Harvesting* and *Greywater Recycling* have been adopted by several households in the study area (30% and 3% of the total households, respectively). Therefore, the *Base Case* includes these existing WMPs.

ii) *Water demand management* (water consumption reduction)

To reduce potable water demand, people have been encouraged to decrease their water use through installation of water saving appliances. In this study, *Water Demand Management* (WDM) is described as an action meant to reduce water consumption without the utilization of *Alternative Water Sources*. This scenario assumes that households in the study area have installed high water saving appliances (above three-star water rating). Water is still being supplied by the piped water mains.

For this scenario, three sub-scenarios with different water consumptions were considered. These sub-scenarios were