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Water Reuse and Recycling

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Managed aquifer recharge in the Botany sand aquifer – part of the treatment train for water reuse?

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Abstract

Stormwater and treated wastewater are possible water sources for managed aquifer recharge (MAR) in the Botany sand aquifer, located south of the Sydney CBD. MAR using leaky structures and injection bores can improve water quality and enhance water supply security. Aquifers may form part of the treatment train for water reuse, given long residence times and a degree of natural attenuation capacity for specific contaminants. Recharge and extraction systems in the Botany aquifer can be designed to achieve desired residence times and incorporate protection zones, based on groundwater flow rates of about 150 m per year. Treatment required prior to recharge would depend on source concentrations and attenuation capacity during the recharge process to ensure protection of groundwater quality and prevention of clogging. In the north-eastern part of the aquifer, groundwater would typically meet drinking water quality guidelines with disinfection and removal of iron. Sustainable groundwater yield could be boosted by MAR, possibly as part of a 'multiple barrier' approach for indirect potable reuse of wastewater. The objective of this paper is to present new information on the north-eastern Botany aquifer including a concept for optimising supplies during dry conditions by low risk pilot MAR tests using stormwater.

Keywords: Groundwater, managed aquifer recharge, attenuation

1. Introduction

The Botany sand aquifer is located within the Botany catchment a few kilometres south of the Sydney CBD (Fig. 1). Approximately 30 metres of unconsolidated aeolian sands are intercalated with minor clay and peat deposits (Fig. 2). The windblown sands fill deep, steep-sided valleys incised into Triassic age Hawkesbury sandstone (Griffin, 1963; Albani et al, 1981). Classed as a highly vulnerable aquifer, groundwater extraction in the southern Botany aquifer is embargoed in Zones 1-4 due to industrial contaminants (Fig. 1A). However, excellent groundwater resources are available in the north-east of the aquifer in the suburbs of Randwick, Kensington, East Lakes, Kingsford and Maroubra. The natural groundwater flow direction is from the recharge areas in the north-east towards Botany Bay at rate of about 150 m per year (Yu, 1994; McNally and Jankowski, 1998).

Water from the Botany catchment, sourced from constructed ponds and Busby's bore was Sydney's second water supply from 1827 to 1869. For over 130 years, sandstone lined stormwater channels have diverted stormwater into inadvertently leaky ponds constructed in Centennial Park. Leakage from ponds may help balance abstraction from a large irrigation bore near the lower park boundary at Kensington pond that was installed and tested by WRL. A new aquifer recharge scheme on the

UNSW campus diverts stormwater into a 1.0 ML subsurface infiltration tank constructed below a sports field. An estimated 160 ML/year of stormwater runoff will be harvested, although performance of the facility is currently subject to assessment. The increased recharge will enable increased groundwater abstraction from 130 to 350 ML/year. The additional groundwater supplies are fit-for-purpose to replace potable water on campus for irrigation, toilet flushing and cooling tower use.

Recharge of treated stormwater and wastewater to shallow sandy aquifers has been practiced at many sites around the world, and is currently being trialled near Perth in Western Australia. Treated river water is used to recharge shallow sandy aquifers that supply Amsterdam in the Netherlands, while river bank filtration is common in Germany. The South African town of Atlantis (population 100,000) has relied on 15 ML/day of potable supply from aquifers that have been recharged with stormwater and treated wastewater for over 30 years. There are now over 400 exploration, production and monitoring bores in the unconfined sand aquifer that is up to 40 m thick (Wright and Parsons, 1994).

Over 70% of Perth's total water use is sourced from aquifers, including 30% of the potable supply. To ensure groundwater sustainability and counteract saline intrusion, treated wastewater from the Subiaco STP has been identified for managed recharge (Radcliff, 2004). The Western Australian EPA issued strategic advice on MAR using treated wastewater for sandy coastal aquifers (WA EPA, 2005). In principle support for the concept and further investigation of MAR using treated wastewater was expressed, while advocating a staged approach starting with trials and projects of low risk. Trails for indirect potable re-use are now in progress using the Gnangara groundwater system, located on the northern margin of Perth city. Wastewater from the Beenyup STP is to be injected at 74 ML/day (27 GL/year) following micro-filtration and reverse osmosis treatment.

2. Hydrogeology of the Botany Aquifer

2.1. *Hydrogeology and groundwater levels*

The Botany aquifer (5,314 hectares), as defined in Fig. 1B, occupies about 84% of the Botany catchment (6,356 hectares). Although much of the upper catchment is underlain by shallow rock rather than saturated aquifer, the area remains an indirect source of recharge.

The aquifer is bounded by thick clay deposits in the west, and numerous rock outcrops in the east. Unconsolidated sediments include significant sand deposits, coffee rock and peat, and are increasingly silty and clayey in the western part of the basin. Palaeochannels within these sediments are important groundwater flow conduits, however, depth and channel morphology in some areas are subject to some uncertainty. For example, although the maximum aquifer depth is commonly reported as 80 m, detailed work by Woodward Clyde (1996) indicated the actual palaeochannel depth near Botany Bay is approximately 65 m. There is a need for improved definition of aquifer geometry based on additional geophysical surveys (eg. gravity method) and test holes in key locations.

The Botany aquifer is in a state of dynamic hydraulic equilibrium and, unlike many other aquifers in NSW, has shown no evidence of stress prior to 2003. In other words, groundwater levels fluctuate according to pumping and rainfall recharge, without long term drawdown. No trend is evident in the hydrograph of monitoring bore 42158, located in the north-east of the Botany aquifer since 1974 (Bish et al. 2000). A detailed evaluation of complete groundwater level hydrographs is yet to be undertaken

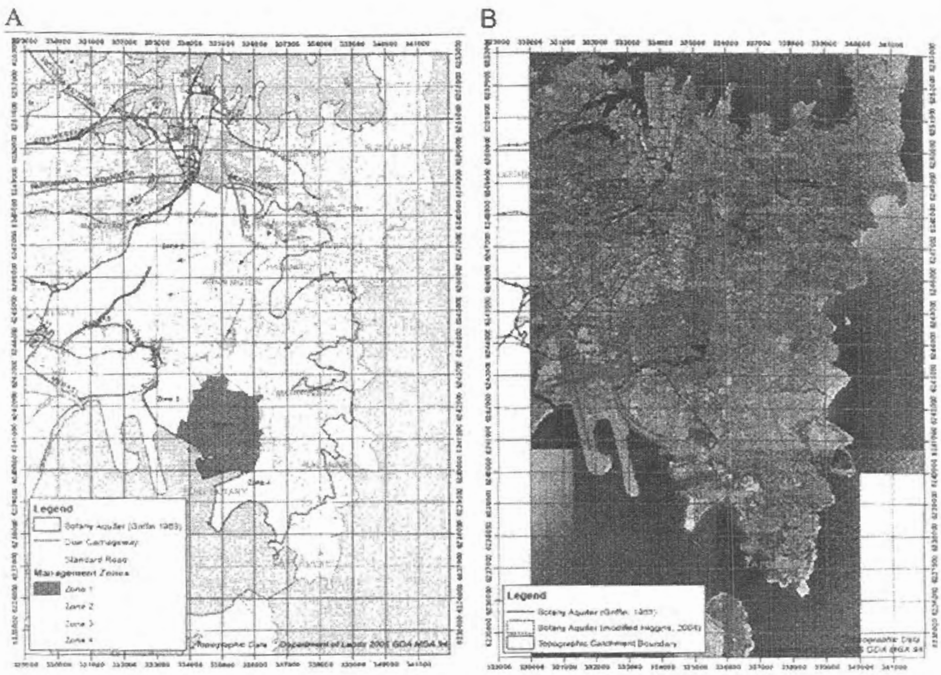

Figure 1 A) Botany aquifer location, management zones and groundwater flow directions and B) catchment and aquifer boundaries.

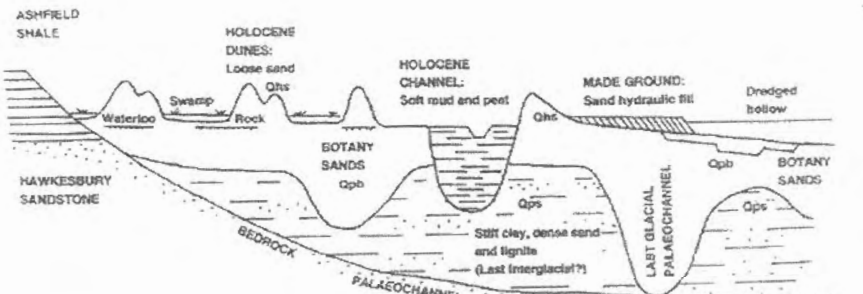

Figure 2 Section through the Botany aquifer north-east to south-west (McNally and Branagan, 1998).

2.2. *Sustainable yield and usage*

Inflows, or recharge, to the Botany aquifer include rainfall, leakage from ponds and probably a minor leakage component from sewers and mains supply. Groundwater modelling has indicated rainfall recharge of 22-44 ML/day during a dry and wet period respectively (Merrick, 1994). It is estimated that 30% of rainfall recharges the catchment area, similar to shallow sandy aquifers at Tomago and below Perth. However, there is significant uncertainty as groundwater models have used recharge values ranging from 6-96% of rainfall. It is critical to determine a realistic recharge rate for sandy parkland, using independent field methods (eg. rainfall simulator and hydrochemical/isotopic methods) to provide confidence in groundwater flow model results.

The long-term sustainable yield (abstraction limit) for the northern aquifer zone between Botany Bay and Centennial Park was estimated by DNR in 2000 to be 39 ML/day (14.3 GL/year) (Bish et al., 2000). At that time, the sustainable yield was defined as 70% of the estimated annual average recharge, a standard approach to allow for the water needs of groundwater dependent ecosystems (GDEs). Annual average recharge was estimated for the northern Botany aquifer assuming 30% of rainfall as recharge over an area of 61.5 km^2. Scientific studies are needed to inform a review of GDE water requirements and sustainable yield limits.

It appears that groundwater usage may be less than the currently defined sustainable yield. Over 600 registered bores are located in the Botany aquifer, with some 70 licensed but mostly unmetered bores. Groundwater usage data, particularly for the many unlicensed bores is not available. Based on the latest groundwater status report (DNR, 2000), the aquifer could probably support ~10 ML/day increased abstraction in the northern zone without the need for MAR. However, this additional available volume is probably within the error margin of estimated sustainable yield and cannot be assumed with confidence.

3. Protecting groundwater quality for beneficial use

The NSW Groundwater Quality Protection Policy states that high value, good quality groundwater resource should not be compromised by development activity (DLWC, 1998). During the process of recharging an aquifer, additional treatment may be achieved. The north-eastern part of the Botany aquifer is generally excellent quality water, and is not associated with contaminated areas to the west and south.

Hydrochemical changes occur along the flow path from recharge areas in north-eastern Botany sands, including a gradual increase in salinity (Acworth and Jankowski, 1993; Dudgeon, 1993). Local contamination from landfills has been documented at several sites south of Gardeners Road (Acworth and Jorstad, 2006). The Water Research Laboratory has assessed groundwater quality in numerous irrigation bores and spear-points over the past 15 years. Groundwater in the north-eastern part of the aquifer is generally low salinity (EC 125-202 μS/cm), slightly acidic (pH ~5.5), with dissolved oxygen at concentrations of <3.5 mg/L. Bacterial indicators and higher nutrient concentrations have been observed near main sewers, unlined landfills and other nutrient sources. Sampling at the UNSW campus (n=9, January 2007) confirmed that groundwater quality is good, though not pristine. Total dissolved salts were 153-315 mg/L, nitrate concentrations 0.5-8.9 mg/L as N, and *E.Coli* <2 to 170 CFU/100 mL. Faecal Streptococci and Enterococci were also detected at low levels (WRL unpublished data).

Other than areas of point source contamination, groundwater in the north-eastern aquifer requires only minor treatment to achieve the beneficial use category of drinking water. With treatment this water meets the beneficial use category of drinking water. Precautionary disinfection using UV for example, and removal of high iron and manganese concentration would be required prior to potable use. It is therefore important that this water is not degraded to a lower beneficial use category. In addition, it is recognised that during the process of recharging an aquifer, some contaminants are removed by natural treatment mechanisms such that groundwater protection may be achieved (Dillon and Pavelic, 1996).

4. Water reuse via managed aquifer recharge

4.1. Water sources for recharge

Recharge water could be provided by additional stormwater diversions or by the addition of high quality treated wastewater. The pre-feasibility assessment by Timms et al. (2006) reported that additional recharge water from sewer mains may be the preferred option for a secure additional source of recharge water that does not depend on rainfall (Table 1). However, the possibility of additional recharge water from stormwater sources from some areas not already diverted to ponds and areas located adjacent to the Botany catchment warrants further investigation.

Table 1 Comparison of MAR Water Sourced from Stormwater and Sewer Mining

Characteristic	Stormwater harvesting	Sewer mining
Security of supply	Not reliable	Reliable
Available volume	High coastal rainfall but flashy urban runoff. Available volume could be supplemented with stormwater from adjacent catchments.	Constant volumes of water imported from outside the catchment. Available volumes from nearby sewer lines currently unknown.
Infrastructure requirements	Diversion and relatively large retention storage of stormwater to match MAR capacity	Access to Sydney Water sewer mains, treatment plant and balancing storage
Treatment required	None or basic treatment for suspended solids, nitrate and metals, particularly for first flush.	Advanced wastewater treatment technologies
Relative cost	Moderate	High

Extraction of wastewater can occur before or after the sewage treatment plant (STP). Sewer mining is the process of extracting wastewater from a sewerage system and treating it for a specific end use (Sydney Water, 2006). There are a number of sewer mining projects under development in Sydney following the success of the schemes at Olympic Park and at Kogarah, however, no sewer mining has yet been developed in NSW in conjunction with MAR.

Sewer mining generates recycled water, grit, screenings and other by-products including a more concentrated version of the extracted sewage. In addition to an extraction connection, a connection is also required for return of approved concentrated wastes to the sewer. Sewer flows are maintained year-round, in contrast to infrequent and limited duration of stormwater. As sewers are operated using mains supply imported from catchments outside the Sydney CBD, the use of sewer mining combined with MAR would represent an importation of water to the Botany catchment. Although sewer mining volumes would vary somewhat diurnally and seasonally, this water source would be relatively reliable and mostly independent of climatic factors (Table 1).

There is limited publicly available information on opportunities for sewer mining in the north-eastern Botany basin. The volume and characteristics of sewage that may be harvested from these sewers near possible MAR sites would require an assessment by Sydney Water in regard to minimum flow rates that are required in the sewer mains. Sewer discharges in the area would be mainly residential and can be approximated at an average rate of 250 L/day/person and 2.2 persons per residence. This equates to 1 ML/day from approximately 10,000 residences.

If concept development and testing of sewer mining appears favourable, and it is decided to proceed with a sewer mining scheme, council approval and an agreement with Sydney Water is required prior to construction, connection and operation. Sewer mining schemes that generate more than 1.5 ML for irrigation purposes require approval from the Dept. of Planning and an Environmental Impact Statement (Sydney Water, 2006). At the concept development stage, further investigation would be required of potential sewer mining sites, suitable treatment technologies, the volume of extraction required, end uses and water quality requirements.

4.2. *Potential types of recharge systems*

Managed aquifer recharge is already practiced (often inadvertently) in the Botany aquifer. Other potential types of MAR could be developed in the Botany aquifer, subject to detailed feasibility assessment. The key features of each of these systems and potential applicability to the Botany aquifer are outlined in Table 2.

Table 2 Features of Potential MAR Systems

Type	Features	Comments
Infiltration tanks	Using porous structures (eg. recycled plastics) to maximise storage capacity and infiltration.	Used for Water Sensitive Urban Design (WSUD) or MAR depending on design intent. Protection of water quality over the long term requires assessment.
Recharge pits	Using natural porous media such as graded gravels and course sand to increase recharge.	Long term hydraulic performance (eg. clogging) and water quality protection requires assessment.
Ponds or basins	A spreading type of MAR usually with a number of basins used in rotation. Clogging problems can be managed by smart design, intermittent drying and scrapping of the pond and primary sedimentation treatment of source water.	Large area of land may be required. There are already many ponds with variable leakage rates in the area.
Porous pipes	Technology yet to be assessed for large scale MAR projects.	Long term capacity for contaminant removal requires assessment.
Filtration media	A range of natural and recycled porous media that could be incorporated with other MAR types (eg pond liners) that would be designed to enhance hydraulic performance and water quality treatment.	Long term capacity for contaminant sourcing and removal requires assessment.
Soil aquifer treatment	A spreading type of MAR using treated wastewater. Infiltration through soil and sediments decreases concentrations of nitrogen, phosphates, metals and organic carbon.	Attenuation capacity of the soil and unsaturated sediments in the Botany aquifer is unknown but maybe limited. Advanced wastewater treatment would be required to protect groundwater quality.
Underground dam	A subsurface modification that detains water in alluvial channels. A trench is constructed across an underground channel, keyed into basement rocks and backfilled with low permeability material.	Required further assessment. May be suitable in a few locations, particularly where there is unused storage (ie. relatively deep watertable).

Type	Features	Comments
Drilled wells and boreholes	Advantageous when land is scarce. Aquifer storage recovery (ASR) where the well/borehole is used for both recharge and abstraction. Aquifer storage transfer recovery (ASTR) where water is injected and recovery some distance away to take advantage of water treatment and delivery capacity of the aquifer.	Either ASR or ASTR could potentially be developed and would be advantageous in terms of minimum land footprint required.

After Dillon (2005) and Gale and Dillon (2005)

4.3. Groundwater residence time and protection zones

Recharge and extraction systems in the Botany aquifer can be designed to achieve desired residence times and incorporate appropriate protection zones, based on groundwater flow rates of about 150 m per year. Typical conventional treatment systems incorporate sand filtration with residence times of <10 hours. Proposed residence times in the Botany aquifer would be orders of magnitude greater than these systems. A minimum residence time of 50 days has been adopted in Australian guidelines for injecting undisinfected water in aquifers where water is to be used for irrigation or recreation (Dillon and Pavelic, 1996).

Protection zones are required for extraction bores, as the vulnerable aquifer is shallow and sandy. For example, Zone I (50 day travel time) and Zone II (400 day travel time) around an extraction bore are specified in guidelines (DLWC, 1998). Protecting the capture zone of bores would provide protection from diffuse contaminants or accidental spillage. It is noted that abstraction from the Tomago sand aquifer has grown to provide up to 10-30% of Newcastle's water supply, despite the presence of a National Highway and several large industries within the aquifer catchment. Another risk management approach HACCP (Hazard Analysis and Critical Control Points) provides an overall catchment to tap framework for identifying and managing hazards to human health and the environment. HACCP is currently being applied to a stormwater recharge project in Adelaide.

4.4. Attenuation of contaminants during recharge

Residence time in aquifers is becoming an acknowledged part of the treatment train in water reuse (Dillon, 2005). Whilst the north-eastern Botany sand aquifer is comprised mostly of quartz sand, the sediment would also contain trace quantities of iron minerals, silt, clay and shell fragments. Geochemical reactions would therefore be expected during mixing of recharge waters with native porewaters. The sand aquifer would likely act as an effective filtration and attenuation medium for a range of specific contaminants.

MAR could provide additional treatment for stormwater (eg pathogens and trace metals) and for treated wastewater (eg persistent chemicals of concern, COCs). Aquifer recharge could therefore be an important component of a 'multiple barrier' approach to water reuse, provided that beneficial use of the aquifer is not compromised. For example, predictive measures for attenuation of pharmaceutically active compounds (PhACs) have been developed by Khan and Rorije (2002) for Australian secondary treated effluent. While adsorption of PhACs to aquifer sediments was generally insignificant, most were predicted to biodegrade under the anaerobic conditions normally apparent in aquifers. Detailed assessment of the fate of specific pathogens and

COCs in simulated groundwater conditions is required to determine opportunities and risks for water reuse through MAR in the Botany aquifer.

5. Knowledge gaps and recommendations

The conceptualisation of MAR in the Botany aquifer represents the first step assessment of the technical suitability of the aquifer, recharge sources and treatment required, and demand for groundwater supplies. Limitations and assumptions of this rapid first-pass assessment were outlined by Timms et al. (2006), along with recommendations for an updated status assessment of groundwater quantity and quality.

A staged program of aquifer investigation has been outlined including refined groundwater flow modelling based on targeted geophysical surveys and test drilling, 3D geological modelling, independent recharge measurements using hydraulic, hydrochemical and isotope techniques, and identification of ecological water requirements. Laboratory and numerical modelling studies are required to demonstrate aquifer capacity for attenuation before proceeding to low risk field tests using water quality markers. Successful MAR schemes using stormwater should be demonstrated to protect environmental and human health, prior to any use of treated wastewater.

A sustainability assessment was recommended in conjunction with detailed feasibility assessment to ensure a best practice approach. A sustainability assessment would adopt a 'triple bottom line' approach that could compare various MAR options, such as recharge using stormwater or treated wastewater. For example, the WSAA (Water Services Association of Australia) Sustainability Framework includes life cycle assessment, quantitative risk assessment and cost comparison.

6. Conclusions

Integrated water management using MAR in the Botany sand aquifer as part of a treatment train may present an opportunity for providing additional water sources that are 'fit for purpose'. Managed aquifer recharge using stormwater and/or treated wastewater could optimise water use from an important aquifer resource that has until recently, been overlooked. Sustainable groundwater yield could be boosted by MAR, possibly as part of a future 'multiple barrier' approach for indirect potable reuse of wastewater. Detailed feasibility assessment is now required on many aspects of a possible MAR scheme, confirming technical feasibility, deliverable volumes and defining the needs of groundwater dependent ecosystems. Research on attenuation mechanisms for specific contaminants and a 'triple bottom line' assessment incorporating a life cycle assessment should proceed in parallel with feasibility assessments. Water supplies could be optimised during dry conditions by proceeding with low risk pilot MAR tests using stormwater.

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