A critical evaluation of combined engineered and aquifer treatment systems in water recycling

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ABSTRACT

Australian experience at five research sites where stormwater and reclaimed water have been stored in aquifers prior to reuse, have yielded valuable information about water treatment processes in anaerobic and aerobic aquifers. One of these sites is the stormwater to potable water ASTR project at the City of Salisbury, a demonstration project within the broader EC project 'RECLAIM WATER'. A framework for characterising the effectiveness of such treatment for selected organic chemicals, natural organic matter, and pathogens is being developed for inclusion in new Australian Guidelines for Management of Aquifer Recharge. The combination of pre-treatments (including passive systems such as reed beds) and aquifer treatment effectiveness in relation to source waters and intended uses of recovered water will be described. Advantages and disadvantages of various types of pre-treatments in relation to effectiveness and sustainability of managed aquifer recharge will be discussed taking account of aquifer characteristics. These observations will be consolidated into a draft set of principles to assist in selection of engineered treatments compatible with passive treatment in aquifers.

Key words | groundwater, organics, pathogens, reclaimed water, stormwater

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INTRODUCTION

Water treatment is as old as water supply. Since 4000 B.C. water treatment methods such as straining, filtering through charcoal, and exposing to sunlight were recorded in Greek and Sanskrit manuscripts (Marples 2004). By the early 1800s, slow sand filtration began to be used in Europe, mimicking the treatment observed to be provided by aquifers, mainly to improve clarity, taste and odour. In the 1900s intentional bank filtration, by pumping water from wells adjacent to streams, rather than the streams or lakes themselves, was employed in some European city water supplies (Massmann *et al.* 2005a,b). Similarly for wastewater treatment, many engineered treatments such as lagoons, trickling filters and reed beds were designed because of water quality improvements perceived in the equivalent natural systems where wastes had been discharged (Middlebrooks *et al.* 2005).

As anthropogenic influences on catchments increased and growing urbanised populations began to rely on more centralised systems of water supply and sanitation, the perceived need for water and sewage treatment has grown. This was propelled by rapidly improving knowledge of water-borne pathogens as a cause of disease

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(e.g. Snow 1855) and growth in capability to measure the microbiological and chemical constituents of water. In particular, the rise of chlorination in the early 1900s was in response to the emerging knowledge of bacterial pathogens. In recent decades knowledge continues to grow, particularly concerning viruses, protozoa and an abundance of trace organic chemicals.

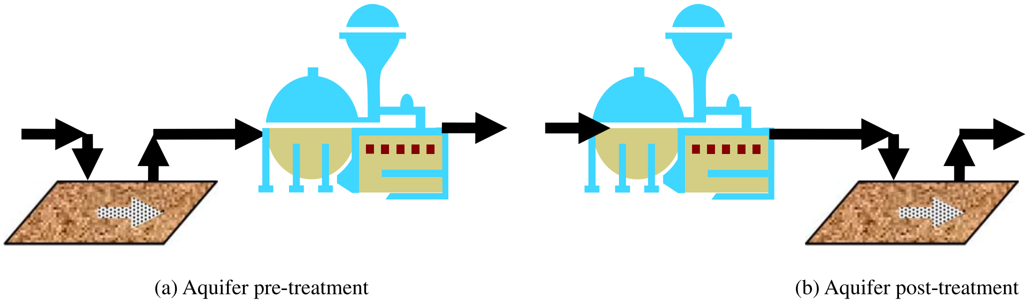
Consequently, treatment processes continue to evolve, and the capabilities of natural treatment systems to cope with increased loading rates and to reduce anthropogenic organics or non-native pathogens must of necessity be scrutinised as for engineered systems. The level of knowledge of natural treatment systems, notably in aquifers, is not as strong as in engineered systems, because the biogeochemical environments present in any aquifer where water quality is modified, almost by definition will vary spatially and usually also temporally within the aquifer. Heterogeneity of particle size and composition within aquifers ensures that systems are more complex than engineered treatments, which are normally optimised by homogenisation of any media present. This diversity is of itself a strength that is recognised within established principles for design of natural wastewater treatment systems (Todd & Josephson 1996).

Systematic accumulation of the body of knowledge of processes in managed aquifer recharge and from passive contaminant remediation studies is expected to provide greater surety of the conditions under which microbial, organic and inorganic chemical attenuation will occur. Processes and rates of biodegradation or inactivation, the sustainability of these, the daughter products formed and their human and environmental health consequences all require assessment in order for confident reliance in natural systems for water treatment, and to understand their place in composite treatment trains. Technologies such as activated sludge wastewater treatment, membrane processes (e.g. membrane bioreactor, microfiltration, reverse osmosis), advanced oxidation (e.g. ozonation) and activated carbon filtration are highly effective for removal of some constituents, so long as the source water quality and the rate of flow remain within defined tolerance limits.

One role for passive treatments, including aquifer treatment, is to buffer variations in source water quality prior to engineered treatments (Figure 1a). Dispersive mixing within the aquifer produces much more stable water quality, for chemical as well as physical attributes (such as temperature) than is typical of streams, where water quality can vary with flow rate and season, and due to catchment disturbances. In addition passage through an aquifer can reduce biodegradable organic matter and turbidity which is helpful for the operation of membrane and activated carbon processes. It will be shown that adequate storage time in protected aquifers also eliminates pathogens, alleviating the need for chlorination (aside from biofilm prevention in distribution systems in warmer climates).

Another role, and an increasingly important one in reuse of water for drinking supplies, is for aquifers to provide an additional barrier after sewage or stormwater treatment (Figure 1b). The treated reclaimed water stored in an aquifer increases the time span of the recycling, and assists in public acceptance of reclaimed water for drinking (Leviston *et al.* 2006). It has been a long held view that communities prefer recycled water for drinking which is drawn from a natural environment rather than directly from the discharge of the water reclamation plant (Asano *et al.* 2007).

With growing international commitment to reducing greenhouse gas emissions and to benefits of emissions


(a) Aquifer pre-treatment

(b) Aquifer post-treatment

Figure 1 | Two main configurations where (a) aquifer is used to stabilise water prior to engineered treatment, and (b) where aquifer is used as a natural barrier prior to water reuse. (a) and (b) may also be combined in either order, i.e. aquifer pre- and post- treatment, or engineered pre- and post-treatment for aquifer storage.

trading, utilities will receive an economic incentive to utilise passive natural systems such as aquifers for water treatment where these can substitute for more energy intensive engineered processes. The minimum land requirement for aquifer treatment is also a factor that will become increasingly appealing for treatment plants with limited ability to expand to address increasing loads or tightening discharge quality requirements. Urban stormwater harvesting for treatment and reuse to substitute for mains water supplies for irrigation (Dillon *et al.* 1997), and even for drinking water (Rinck-Pfeiffer *et al.* 2005) will also gain impetus where climate change is reducing the security of traditional sources of urban water. However, managed aquifer recharge (MAR) can only become part of the recycling process if suitable aquifers exist in economic proximity to the sewage or stormwater reclamation plant or en-route to locations of demand for recycled water. Secondly, the use of any aquifer for treatment purposes, needs to protect existing beneficial uses of the aquifer beyond the attenuation zone at all times, and within the attenuation zone on cessation of use of the aquifer for water treatment. Water recycling guidelines for MAR are currently in development in Australia (Dillon & English 2007).

TREATMENT PROCESSES IN AQUIFERS

Treatment processes in aquifers considered in this paper are only those that are sustainable, such as biodegradation where environmental conditions in the aquifer will continue to support competent microbial populations. Pathogen inactivation is also considered in this light and it has been shown that the rate of inactivation of a number of viruses, protozoa and bacteria is influenced by the indigenous micro-organisms present in the aquifer (Toze & Hanna 2002; Gordon & Toze 2003), and that biodiversity of these can be robust (Reed *et al.* 2007). Adsorption is not considered a sustainable attenuation process, as without biodegradation of sorbed species, sorption sites will eventually become fully occupied and contaminants will break through to recovery wells or to wells of other users or groundwater-affected ecosystems, such as streams or wetlands.

The potential for substances to be reduced or oxidized within the aquifer, termed the redox status of the aquifer has been found to have a major influence on the rate of degradation of pathogens and organics introduced into aquifers. Generally confined aquifers are preferred targets for storage of water for reuse, because the confining layer provides protection to groundwater from overlying land use and waste management activities. Generally, but not always, such aquifers are anaerobic and only species that are biodegraded under anaerobic conditions will be degraded. However, often the water that is injected *via* wells will be aerobic and there may be a small aerobic zone around the injection well in anaerobic aquifers. Residence time in this zone will not usually be long and so in the absence of field data should not be relied upon for aerobic biodegradation.

Geochemical processes may also change the composition of the recharged water during subsurface transport and storage. For example the presence of pyrite and/or sediment-bound organic matter in anaerobic aquifers can lead to the reduction of nitrate contained in injected water (Prommer & Stuyfzand 2005). However these or other reducing agents will be successively depleted and the aerobic zone surrounding the injection well will grow over time (Stuyfzand *et al.* 2005). Under this scenario nitrate removal is not an enduring process. Furthermore, those species that are biodegraded under anaerobic conditions only, such as chloroform, may ultimately become persistent due to the changed redox status of the aquifer. Hence, geochemical modelling of aquifer processes is recommended in order to determine the longevity of specific facets of aquifer treatment.

With stormwater ASR there will be extensive periods where there is no injection and during such times strongly reducing conditions may be established for long periods around the injection well due to oxidation of particulate organic carbon that was trapped in the aquifer on the perimeter of the well (Greskowiak *et al.* 2005; Vanderzalm *et al.* 2006). Hence, reducing conditions may occur that are outside the span between ambient groundwater and injected water. These may be particularly effective in permanently degrading substances that are strongly sorbed to organic carbon. An example of this is given for chloroform and other trihalomethanes by Pavelic *et al.* (2006) at ASR sites.

Where aerobic aquifers are the target storage zone, aerobic degradation of trace organics may occur. Ying *et al.* (2003, 2004) have illustrated degradation of estradiol and nonylphenol, two known endocrine disrupting compounds

(EDCs), under aerobic conditions without co-metabolites, and recent work has shown that a wider range of EDCs can be degraded under aerobic conditions in the presence of biodegradable organic carbon. Also, Greskiowak *et al.* (2006) reported degradation of phenazone (a pharmaceutically active compound) to occur exclusively under aerobic conditions for a pond infiltration site near Berlin (Germany).

A recent research project on bank filtration in Berlin conducted by the Berlin Water Competence Centre (and briefly described by Massmann *et al.* 2005a) found that the cyanobacterial toxin, microcystin degraded readily within the aquifer in the presence of a substantial biofilm (Grützmacher *et al.* 2005). Laboratory studies in South Australia (Dillon *et al.* 2002) in the absence of biofilm also found degradation of microsystin at a marginally slower rate. This suggests that biologically active zones on the banks of bank filtration zones and in close proximity to injection wells support higher rates of biodegradation. Recent studies by Reed (2007) suggest that microbial communities in ASR well biofilms are capable of inactivating bacterial pathogens at a faster rate than in the formation where labile nutrient fluxes are significantly reduced.

Skjemstad *et al.* (2002) and Grünheid & Jekel (2005) also showed substantial attenuation of labile organic carbon in an anaerobic aquifer during ASR and in columns representing bank filtration. In general, the larger molecular weight molecules having functional groups susceptible to attack were found to be the most readily biodegraded organic components. A large class of organic constituents however were recalcitrant after 50 m of travel through the aquifer from a reclaimed water ASR well. Their nuclear magnetic resonance spectra were indistinguishable from old waters in aquifers (>10,000 years by C-14 dating) and in samples of deep ocean water (Skjemstad *et al.* 2002). The persistence of this unreactive fraction, even though the source water had a sewage origin, was not considered problematic as it is was also correlated with composition of the original drinking water supply and is unlikely to be metabolised within humans and animals, including aquatic organisms resident in the aquifer. An indicative summary of degradation rates in aquifers for some species is given in Table 1.

In order for aquifer treatment to be effective, a number of criteria need to be met for the quality of recharge water:

- Turbidity is constrained so that physical clogging is manageable (*i.e.* not irreversible);
- Labile organic matter is constrained so that biological clogging is manageable;

Table 1 | Observed rates of microbial pathogen inactivation and contaminant biodegradation in managed aquifer recharge systems and laboratory columns. T90 is the time to attenuate 90% of selected constituents in stormwater or recycled water within the observed aquifer. Temperatures and abundance of co-metabolites vary between and within sites

Species	Aerobic aquifer (days)	Anaerobic aquifer*(days)
Microcystin (cyanobacterial toxin)	3–5	5
Thermotolerant coliforms	<1–10	2–12
Cryptosporidium oosysts	na	21
Enteroviruses (e.g. Coxsackievirus)	1–30	8– > 100
Brominated trihalomethanes (DBP)	>260	>33
Chloroform (DBP)	>260	>60
Estradiol (human hormone)	6	>365
4-n-Nonylphenol (surfactant)	25	>365
4-t-Octylphenol (surfactant)	>365	⩾365
Bisphenol A (plasticizer constituent)	>365	⩾365
Ethynyl-estradiol (synthetic hormone)	>365	⩾365
Phenazone (pharmaceutical)	~50	>365
Atrazine (herbicide)	200	>365

*assuming nitrate reducing conditions.

- Dissolution of aquifer material is not excessive so that the aquitard and well integrity is not compromised and aquifer-derived solids in recovered water are at acceptable concentrations;
- Redox conditions are not adversely affected in such a way as to mobilise metals (e.g. arsenic) which may be resident in the aquifer;
- Beyond an attenuation zone, existing beneficial uses of the aquifer, including ecosystem support are not compromised; and
- No beneficial uses of the aquifer within the attenuation zone would be compromised if in future the recharge operation is to cease.

The need for and type(s) of pre-treatment of recharge water from any given source are specific to the aquifer, and depend on aquifer mineralogy, grain size, hydraulic conductivity, degree of macro-porosity/fracturing and confinement and on the ambient groundwater quality.

ENGINEERED TREATMENT PROCESSES

Engineered treatment processes are normally designed to attenuate specific species or constituents with particular attributes within a defined range of source water flow rates and water quality characteristics. No single treatment is capable of efficiently delivering a desired water quality with a highly variable source water quality. Therefore, a series of treatments is usually required. For example roughing filtration is generally used as a pre-treatment for biofiltration in order to reduce turbidity to a level that enables the biofilter (or slow sand filter) to operate for sufficiently long run times to be economic (Page *et al.* 2006). Similarly, micro-filtration frequently precedes reverse osmosis for the same reason. Table 2 lists pre-treatments that have been used for aquifer recharge projects or research projects with a view to achieving the water quality requirements for effective aquifer treatment (Figure 1b). Other treatments such as pH adjustment and dissolved oxygen removal have also been used to address metal leaching problems (Ibison *et al.* 1995). More rigorous assessments of various treatment processes and combinations in water reuse have been undertaken elsewhere (e.g. Khan *et al.* 2005).

Engineered post-treatments for aquifer storage have included use of activated carbon to remove a musty taste and odour in stormwater recovered for drinking water from an anaerobic aquifer at the site described by Rinck-Pfeiffer *et al.* (2005). Although pathogen removal is expected to be complete, it is likely in warmer climates that recovered

Table 2 | Pre-treatments for managed aquifer recharge with reclaimed water and stormwater and showing the relative effectiveness of each treatment for removal of suspended solids and labile organics

Treatment	Reclaimed water	Stormwater	Suspended solids removal	Labile organics removal
Roughing filter		Y	*	
Rapid sand filtration		Y	*	
Biofiltration		Y	* * *	* *
Activated carbon filtration	Y	Y	*	* * *
Chemical coagulation and filtration		Y	* *	*
Dissolved air flotation and filtration	Y		* * *	*
Membrane bioreactor	Y		* * *	*
Microfiltration		Y	* * *	
Reverse osmosis		Y	* * *	* * *
Activated sludge digestion	Y		*	* *
Settling/aeration ponds	Y	Y	*	*
Wetland ponds		Y	* *	*
Reedbeds		Y	* *	*

Y = treatment has been widely applied for this type of source water. Treatment effectiveness: blank = ineffective. * = only partially effective. * * = moderately effective. * * * = very effective.

water will be chlorinated to inhibit biofilm growth in distribution systems, and therefore avoid inadvertent production of off-flavours and odours. Further research is planned to assess the blending in distribution systems of chlorinated water containing organics from conventional sources with unchlorinated water that is naturally disinfected and depleted in organics following aquifer storage. Where disinfection byproducts are problematic, aquifer storage prior to chlorination has been shown to cause a significant reduction in precursors for trihalomethanes and haloacetic acids (Dillon & Toze 2005).

URBAN STORMWATER TO DRINKING WATER PROJECT

A specific project to recharge wetland-treated urban stormwater into a confined brackish anaerobic aquifer is discussed to present information on an example of a combined passive treatment system intended for production of water fit for drinking water quality. The project, at Parafield Gardens, South Australia, is reported in more detail by Rinck-Pfeiffer *et al.* (2005). Stormwater from a 1600 ha catchment in the City of Salisbury discharges *via* a trapezoidal concrete channel through an urban area. A 47 × $10^3\,m^3$ pond was excavated below channel level (the 'in-stream pond') to divert and capture all flow between dry weather flows and very high flows. This water is lifted by a high capacity pump into a holding pond of 48 × $10^3\,m^3$ capacity from which the water discharges under gravity to a 2 Ha reed bed for further treatment with a residence time of about 10 days. From there the treated water goes to either; a wool scouring factory, council park irrigation, two ASR wells, a mixing tank to supply the new subdivision of Mawson Lakes with a blend of brackish reclaimed water and recovered stormwater, or to the ASTR site where four injection wells and two central recovery wells have been established and the aquifer is in the process of being flushed.

Water quality analyses have been recorded in the two ponds and the reed bed outfall. The raw stormwater contains pathogens, turbidity, and various anthropogenic organics that exceed drinking water guidelines. After passage through the reed bed, only pathogens exceed drinking water guidelines in the samples analysed. Passive adsorption samplers have been used to detect trace organics in the water as concentrations are low and conventional sampling approaches yield mostly non-detectable concentrations. Removal efficiencies have been difficult to record accurately to date owing to large variability in source water concentrations in relation to sampling frequency and low frequency of detections in the reedbed outfall. However, literature values for removal efficiencies in wetlands and basins for selected species (from Page *et al.* 2008), summarised within Table 3 are considered to be representative of this site.

The Tertiary limestone aquifer at this site is encountered at depths of between 160 and 220 m below ground surface and is comprised of distinct facies, based on stratigraphic logs and hydraulic conductivity profiles obtained by downhole electromagnetic flow metering. The zone targeted for

Table 3 | Summary of typical removal efficiencies for various constituents in stormwater and wastewater within wetlands and basins (after Page *et al.* 2008), and data for aquifer treatment at nearby sites

Constituent	**Wetland and basin removal efficiency (%)**	**Andrews Farm stormwater detention in nitrate reducing aquifer at 23°C for 542 days (min) removal efficiency (%)**	**Bolivar reclaimed water detention in nitrate reducing aquifer at 23°C for 419 days (min) removal efficiency (%)**
Suspended solids	60–94 (mean 77)		
Total organic carbon	32–80 (mean 42)	34	12
Biological oxygen demand	30–80 (mean 66)		
Total Kjeldahl Nitrogen	38–91 (mean 46)	47	32
NOx – N	15–95 (mean 64)	74	63
Pb tot	78–99 (mean 87)	74	
Thermotolerant coliforms	98–99 (mean 98)	100	100

Table 4 | T90 removal times (days) for selected micro-organisms at the Andrews Farm and Bolivar sites

Parameter	Andrews farm	Bolivar
Giardia	30	–
Poliovirus	17	–
E. coli	12	11
Streptococcus faecalis	5	–
Salmonella typhimurium	5	–
MS2 (bacteriophage)	–	4

storage is the upper 20 m thick sequence that excludes unconsolidated sand layers that are present deeper in the aquifer. The aquifer contains ambient groundwater with a salinity of around 2000 mg/L and is in a nitrate-reducing redox state and at a ambient temperature at this depth of 23°C. Transmissivity of this target zone is $\sim 50\,m^2/d$ with an effective hydraulic conductivity of 2.5 m/d. From geophysical logs and down-hole electromagnetic flow metering the largest hydraulic conductivity for any sub-layer was only three times the average hydraulic conductivity of the target zone.

Table 5 | Attributes of RECLAIM WATER project sites expected to influence type and rate of aquifer treatment

Site	Recharge Water	Aquifer Type	Redox Status and Aquifer Temperature	Minimum residence time before recovery (days)	Hydraulic conductivity (m/d)
Parafield Gardens ASTR South Australia	urban stormwater	Limestone, confined, non-karstic	Nitrate-reducing 23°C	>200	2.5
Torreele Dune Infiltration, Flanders/Belgium	Reclaimed water after UF/RO process	Dune sand, unconfined	Nitrate reducing 11–12°C	>35 mean 57	12–14
Nardo', South Italy	Reclaimed water (secondary effluent)	Fractured aquifer	Nitrate reducing 15°C pE (166–224 mV); pH 7.5–7.8;	>40 mean 60	664
Sabadell river bed infiltration, Catalonia/Spain	River water plus secondary effluent	Alluvial aquifer	Marginally aerobic mean: 15°C. 10°C in winter to 20°C in summer	To be determined	150 from prior studies, to be confirmed
Shafdan SAT, Dan Region, Israel	Reclaimed water (secondary effluent), UF permeate in pilot testing	Quaternary alternating units: sand, loamy sand, clay and calcareous sandstones (Kurkar).	Anaerobic, Manganese-reducing. 25°C	>150 days for the classical SAT and >40 days for the pilot UF-SAT	400 to 4000
Mezquital valley	Untreated wastewater from Mexico City	There are three aquifers: (1) shallow unconfined system of variable depth, (2) basaltic with some volcanic ash & lava intervals. (3) Cretaceous limestone that may be unconfined	Considered to be nitrate –reducing. To be confirmed. 22°C	Varies from several hours to a few days	Transmissivities (m^2/d) are: (1) 10–100 (2) 1000 + (3) unknown
Atlantis Recharge Site, South Africa	Reclaimed water (domestic secondary effluent) and urban stormwater runoff	Calcareous dune sand overlying shallow marine/fluvial sand deposits; peat lenses	Shallow: aerobic to anoxic, i.e. nitrate reducing; deeper layers sulphate-reducing; 18.4°C ∗ [*]	Basin 7: >210 days Basin 12: >150 days	2.1[*†]
Gaobedian Bejing/China	Reclaimed water (tertiary effluent)	sand and round gravels	Nitrate reducing 13°C	>30	12–17

[*] Groundwater temperature in the wellfield area determined by down-the-hole logging.

[†] In Witzand wellfield.

∗ Notes

At the time of writing injection into the two central recovery wells was underway to flush the brackish ambient groundwater from the storage zone (Regel *et al.* 2007). Only partial breakthrough to observation wells has been recorded to date so it is not yet possible to give a site-specific account of aquifer treatment. However the same aquifer has been used for stormwater storage and treatment at Andrews Farm, 20 km north (Herczeg *et al.* 2004; Pavelic *et al.* 2006), and for reclaimed water ASR at Bolivar, 10 km to the north west (Dillon *et al.* 2007). These data are reported in Tables 3 and 4, as indicative of treatment effectiveness anticipated at this site. Neither the reedbed nor the aquifer are effective in completely removing nutrients, however in combination they can eliminate pathogens, and the surface treatment provides approximately an additional 2-log removal barrier.

In Australia guidelines for recycling *via* managed aquifer recharge are under development. Some of the concepts are outlined in Dillon *et al.* (2007) and Dillon & English (2007). A Hazard Analysis and Critical Control Points (HACCP) planning process was undertaken at the ASTR project and is described in (Swierc *et al.* 2005; Page *et al.* 2008).

In May 2007, a sample of the Parafield ASR recovered water was taken more than 12 months after the last injection of reedbed-treated stormwater into that well. After extensive testing to show that the water met drinking water standards, a bulk sample was taken for bottling and distributed to the Australian Prime Minister's Science Engineering and Innovation Council in June 2007 as bottled drinking water. The sample best represents the quality of water intended to be recovered on an ongoing basis from the ASTR project when the aquifer has been flushed. This project is part of the RECLAIM WATER European Community project and introduces stormwater as the water to be recovered and an ASTR system as the means of storing and recovering water in the aquifer. Table 5 shows the wide range of aquifer characteristics that may give rise to different types and rates of aquifer treatment at the RECLAIM WATER project partners' sites.

CONCLUSIONS

From this cursory discussion some basic principles emerge which may assist in the selection of treatment combinations compatible with passive treatment in aquifers. Firstly, aquifer pre-treatments have value for all processes in which turbidity and labile organic matter in source water should be low, or where the temperature and geochemistry need to be stable. It can also help to protect the integrity and longevity of subsequent treatments by preventing shock loadings of contaminants such as pesticides on biological treatment processes or industrial solvents on reverse osmosis membranes.

Where aquifers form part of post-treatment their primary benefit is in providing time for attenuation of pathogens, reducing labile organic matter and thereby reducing precursors for disinfection by products, and giving buffering storage and mixing so that intermittent failure in the initial treatment processes is compensated in the aquifer and the resultant recovered blend meets the required water quality criteria 100% of the time.

Specific combinations of treatment methods to accompany aquifer treatment will depend on source water quality, the required quality of water for consumers (including drinking supplies, industrial, irrigation, aesthetic and ecosystem support needs), and the nature of the aquifer. It appears to have a useful role as a pre-treatment for membrane processes or as a polishing step prior to activated carbon filtration.

Passive systems involving settling ponds, reed beds followed by 12 months of aquifer storage have proven to be highly effective in producing safe drinking water supplies from urban stormwater in a semi-industrial catchment in the City of Salisbury, South Australia. Similarly, water from Lake Tegel, containing as much as 40% reclaimed sewage, following bank filtration has produced safe drinking water supplies for Berlin for many years without any additional treatment. These examples suggest that passive treatment systems involving aquifers could be suited to accelerating progress in developing countries towards achieving the UN Millennium Development Goal for safe water supplies. This 'low technology' is based on robust natural treatment processes that can withstand power failures, has low capital and operating costs and low energy demands. In collaboration with Reclaim Water project partners, a sound scientific base is developing that will increase the understanding of risks associated with technical, economic and environmental aspects in securing new water supplies from otherwise wasted waters *via* aquifers.

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