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Hartog, Niels; Stuyfzand, Pieter J.

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Editorial

Water Quality Considerations on the Rise as the Use of Managed Aquifer Recharge Systems Widens

Niels Hartog [1,2,*] and **Pieter J. Stuyfzand** [1,3]

[1] KWR Watercycle Research Institute, P.O. Box 1072, 3430 BB Nieuwegein, The Netherlands; pieter.stuyfzand@kwrwater.nl
[2] Faculty of Geosciences, Utrecht University, 3508 TA Utrecht, The Netherlands
[3] Faculty of Civil Engineering and Geosciences, Delft University of Technology, 2628 CN Delft, The Netherlands
* Correspondence: niels.hartog@kwrwater.nl; Tel.: +31-6-53436286

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Abstract: Managed Aquifer Recharge (MAR) is a promising method of increasing water availability in water stressed areas by subsurface infiltration and storage, to overcome periods of drought, and to stabilize or even reverse salinization of coastal aquifers. Moreover, MAR could be a key technique in making alternative water resources available, such as reuse of communal effluents for agriculture, industry and even indirect potable reuse. As exemplified by the papers in this Special Issue, consideration of water quality plays a major role in developing the full potential for MAR application, ranging from the improvement of water quality to operational issues (e.g., well clogging) or sustainability concerns (e.g., infiltration of treated waste water). With the application of MAR expanding into a wider range of conditions, from deserts to urban and coastal areas, and purposes, from large scale strategic storage of desalinated water and the reuse of waste water, the importance of these considerations are on the rise. Addressing these appropriately will contribute to a greater understanding, operational reliability and acceptance of MAR applications, and lead to a range of engineered MAR systems that help increase their effectiveness to help secure the availability of water at the desired quality for the future.

Keywords: Managed Aquifer Recharge (MAR); Aquifer Storage and Recovery (ASR); hydrochemistry; source water quality; groundwater quality; water sources; water re-use; pre-treatment; clogging; large-scale MAR; emerging compounds; brackish/saline host aquifers; recovered water quality requirements

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1. Introduction

Throughout human history, the balance between water demand and supply, i.e., water availability, has varied both spatially and temporally. In this balance, the (perceived) quality of the water present with respect to the requirements for its intended use is of critical importance. Due to increasing weather variability caused by climate change, growing population and increasing urbanization which concentrates agricultural, industrial and drinking water demands, the world is increasingly challenged to provide a sustainable long term supply of fresh water (e.g., [1]). This challenge is particularly pronounced in geographic areas where fresh water is naturally scarce, such as deserts (e.g., [2–4]) and coastal areas (e.g., [5,6]) that may further suffer from sea water intrusion by sea level rise, land subsidence and a decrease in seasonal discharge by major rivers (e.g., [7–9]). As a consequence, problems such as seasonal water shortage, overexploitation of groundwater resources, saltwater intrusion, and disappearance of wetlands are already commonly occurring phenomena. Considering that economic growth, population increase, and climate change will further aggravate water availability, water crises were identified as a major global risk [10].

As managed aquifer recharge (MAR) techniques involve the intentional subsurface recharge and storage of water into an aquifer for subsequent recovery or for environmental benefits, they have the potential to alleviate or even prevent water crises. Important advantages of these techniques are the support of higher water demands [11,12], overcoming the temporal mismatch between water supply and demand [13,14], water quality improvements, and the protection of water against evaporation losses, algae blooms, and atmospheric fallout of pollutants during subterranean storage [13,14]. Although the application of MAR techniques has a history that goes back to pre-modern times (e.g., [7]), these benefits together with today's worldwide challenge for the sustainable management of water resources have caused MAR to be increasingly considered as a sustainable, water resource-efficient technique to meet both current and future water demands (e.g., [15–17]).

To fulfill the promise of MAR, however, to become globally significant in securing fresh water availability for the future [7], MAR techniques need to be applied in much larger numbers. Moreover, they also require application at much larger scales, and for a wider range of conditions and purposes. This maturation of MAR systems requires technological and scientific advances in addition to policy and economic innovations [3]. The water made available by MAR systems aims to be fit-for-purpose, meaning that depending on the intended use (e.g., counteracting salinization, irrigation or drinking water), different requirements may have to be met (e.g., [18]). Therefore, consideration of water quality is central in developing the full potential for MAR application. This ranges from the improvement or deterioration of water quality during soil passage to operational issues (e.g., well clogging) or sustainability concerns (e.g., the re-use of treated WWTP effluent and stormwater). To date, the rise of anthropogenic contamination and environmental awareness, and analytical developments have led to ever-increasing attention for water quality aspects. With the application of MAR expanding into a wider range of conditions, from deserts to urban and coastal areas, and purposes, from large scale strategic storage of desalinated water to the reuse of waste water, the importance of these considerations are only expected to rise further.

Various water quality issues that contribute to this development, are addressed by the 18 papers in this Special Issue "Water Quality Considerations for Managed Aquifer Recharge Systems" and were presented in part at the 9th International Symposium on Managed Aquifer Recharge (ISMAR-9) in Mexico City, 20–24 June 2016.

2. The Role of Water Quality Aspects in Developing the MAR Potential

2.1. Source Water Types for MAR

While surface water continues to be the main source water used in MAR (e.g., [7]), the use of other source water types such as desalinated seawater [2,19,20], treated waste water [20,21] and harvested rain water [5] and stormwater [22] is growing. Along with the variation of different source waters, the type and degree to which pretreatment is required to allow infiltration [22,23] are diverging as well. Pretreatment, e.g., by coagulation, sand filtration or soil aquifer treatment (SAT), is needed to remove suspended fines from the source water, in order to prevent infiltration well clogging (e.g., [24]) and to maximize the recharge capacity during surface infiltration [21,24,25]. In addition, to limit the clogging risk by microbial growth, disinfection of the source water, e.g., using UV [21] or chemical pretreatment, e.g., to remove high organic matter contents [23], can be considered. In addition to measures to minimize clogging risks, proper monitoring methods and interpretation tools are required to assess the impact on the development of MAR operations, e.g., during riverbed infiltration [26].

2.2. Effective and Reliable MAR Operation

For MAR systems to be effectively and reliably operated under a wide range of conditions, insight into and adequate monitoring of the factors and processes involved are required as determined by the objectives of a particular MAR application. For example, to be able to predict the need for post-treatment to remove iron or manganese mobilized during riverbank filtration, insight is required in what determines the development of iron and manganese concentrations during operation (e.g., [27–29]). Such insight can be supported by field monitoring, e.g., by using isotopes to assess the relative contribution of different water types to the recovered water in mixed source MAR systems [20], reveal the mobilization of chromium during infiltration of a desert dune sand aquifer [2], to assess retention times [30], or to study factors that affect clogging by, e.g., air bubbles [19]. Laboratory experiments allow one to focus on specific MAR aspects under well controlled conditions, e.g., to study the factors that affect the extent of removal of emerging compounds such as pharmaceuticals [31], or to assess the conditions that affect the risk of colloid-facilitated contaminant transport [32,33] or industrially produced nano-particles in the infiltrated source water. In addition, numerical modeling allows the assessment of water quantity and quality aspects for a wide range of MAR conditions, which can support the feasibility, design and optimization of MAR application [34].

2.3. Application of MAR at Larger Scales

To be able to alleviate water stress at regional levels, MAR needs to be applied at sufficiently large scales. As the analysis of surface water recharge in Orange Country, California indicated [25] there is also cost-effectiveness to be gained at these scales. Particularly in water-scarce areas of the world, there is long-term experience with large scale MAR systems (e.g., [20,24]). As illustrated by the world's largest storage of desalinated seawater in Abu Dhabi, MAR can provide strategic water security against periodic poor seawater quality, uncertain energy supply and fear of war or terrorism [2]. Large scale regional storage may also support economic interests of national importance that depend on the cost-effective availability of high quality water such as the greenhouse sector in the coastal area of The Netherlands [5]. Here, MAR may be used to counteract the ongoing salinization of groundwater caused by the massive abstraction of brackish groundwater for reverse osmosis treatment. Particularly for the application of MAR under unfavorable conditions that result in recovery decreases, such as the storage of fresh water in brackish/saline aquifers or the presence of high ambient groundwater flow, larger scale MAR systems suffer relatively less negative water quality effects due to mixing at the boundaries (e.g., [2]).

2.4. Enhancing the Performance of MAR

Several studies address the use of combined techniques to improve the performance of MAR. For example, riverbed filtration was used to remove suspended solids allowing higher recharge capacity during subsequent basin infiltration [25]. In addition to effective infiltration, an important aspect of the performance of MAR is the extent to which water quality improves or deteriorates during subsurface passage. The release of iron and manganese commonly occurs (e.g., [29]), resulting in post-treatment requirements and risks of abstraction well clogging. Therefore, the application of subsurface iron removal (SIR) is a promising technology to be combined with MAR [6,35]. In addition to iron mobilization due to the reduction of iron hydroxides, water quality deterioration due to pyrite oxidation upon the infiltration of oxic surface water is a frequently observed phenomenon (e.g., [36]). In relation to this, the pre-oxidation of the pyrite bearing aquifer sediments surrounding an ASR well was experimentally shown to hold potential to prevent arsenic and manganese mobilization in subsequent infiltration abstraction cycles [28]. However, besides controlling the extent to which water quality deterioration occurs, MAR is known to often result in water quality improvement ranging from the removal of viruses and bacteria (e.g., [37,38]), the removal of nitrate (e.g., [36]) or ammonium (e.g., [39]) to the degradation of pharmaceuticals and other "emerging compounds" (e.g., [37]). However, the extent to which these natural purification processes occur strongly depends on MAR specific conditions such as travel time distribution and redox conditions. An interesting new avenue is therefore the adaptation of particular redox conditions to favor the degradation of specific compounds, as illustrated by the use of different intermediate oxidation processes for the removal of various trace organic chemicals [40].

3. Conclusions

MAR techniques are increasingly considered for alleviating wide-spread, current and future water scarcity problems, as they provide robust, effective, sustainable, and cost-efficient freshwater management solutions. MAR is therefore expected to be increasingly applied in a wider range of conditions and settings, from drinking water production and ecological support to fulfilling industrial and agricultural water demands, as well as urban water demands for the creation of water resilient green cities. As illustrated by the papers in this Special Issue, these developments will lead to new water quality challenges and increasingly complex scientific questions. These relate to new source water types, the application of MAR in previously considered less favorable conditions such as brackish/saline groundwater environments, and the application at larger, regional scales as well as the development of simulation tools to optimize the design and operation of MAR facilities. Addressing these aspects appropriately will contribute to a greater understanding, operational reliability and acceptance of MAR applications, and lead to a range of successfully engineered MAR systems that help increase their effectiveness to help secure water availability for the future.

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