2 Groundwater recharge with recycled municipal wastewater: criteria for health related guidelines

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2.1 Introduction

The quality of the water of a recharged aquifer is a function of:

- the quality of the recharge water;
- the recharge method used;
- the physical characteristics of the vadose zone and the aquifer layers;
- the water residence time;
- the amount of blending with other sources;
- the history of the recharge.

It is important to determine at which point water should be submitted to regulations and guidelines: at point of use, at the point of withdrawal from the aquifer or before recharge?

The aim of this chapter is to highlight some principles related to aquifer recharge with recycled water, and to propose a simple approach to health related guidelines that takes into account existing water regulations and guidelines, but avoids overlapping with them.

2.2 Features of aquifers

Aquifers have some specific features that may influence guidelines on aquifer recharge with recycled municipal wastewater.

When pollutants are introduced into an aquifer with the recharge water, they will either move with the water, as nitrates do, or be retained on the solid matrix, as generally happens to cations and organic matter. If pollutants that are retained do not break down, they will accumulate within the aquifer. Pollutant removal is regarded as a positive impact. However, despite promising findings (for example, the work of Fox et al., 2001, which provided evidence of organic compound removal in SAT), uncertainties remain about the fate of most contaminants. Questions raised about retained pollutants include the following:

- Is there a risk that the pollutants may appear in the abstracted water due to changes in the physical and chemical conditions prevailing in the aquifer or due to limited adsorption capacities?
- How long can microorganisms survive?
- To what extent are toxic pollutants degraded?

The most attractive aquifers for recharge projects are large aquifers that allow long-term storage and a long water retention time. Long retention time is an advantage, because it favours contaminant removal, but also a disadvantage, because contamination of the water can have a long-term impact, particularly for pollutants that are not efficiently removed. Reclaiming an aquifer that has been polluted is a difficult, long and expensive process; therefore, a prerequisite of artificial recharge is that it should not risk jeopardizing the groundwater resource.
Aquifers are exploited through pumping wells (private and public), which serve a range of different purposes, such as potable water supply, irrigation and industrial uses. The water quality required depends on the use, giving two main options for recharge. The first option is to plan and operate the recharge so that the quality of the water in the aquifer either meets the most stringent requirements or is not degraded. The second option, which is more sophisticated, is to use sector-based management — pumping water of different quality from different areas for different purposes. However, because an aquifer is a continuum, sector-based management requires in-depth knowledge of the aquifer and close monitoring of water quality. This type of management also requires stakeholders’ agreement and a control of the withdrawals; for example, to ensure that farmers do not pump water that is fit only for irrigation for a potable water supply. The extension of the plume of injected water should be monitored, which can be achieved through the measure of the content of wastewater tracers such as chloride (in freshwater aquifers), sulfate, boron and gadolinium anomaly. Furthermore, as retention times in aquifers are long, an exploitation policy, once adopted, cannot easily be changed in the short term.

Aquifers are complicated heterogeneous, multilayered systems, often with poorly defined boundaries. Reliable predictions of groundwater flow are possible only if the aquifer system is well known, which means that sufficient data need to be available to work out well-calibrated hydrodynamic numerical models. Flow patterns are relatively easy to predict and control in granular media aquifers; however, due to their discontinuous and anisotropic porosity, the situation is quite different in fractured rocks and karst formations, where, despite recent improvements, modelling solute transfer is, and will long remain, difficult to achieve.

2.2.1 Considerations for regulating water quality

In most countries, the quality of water intended for human consumption is regulated through standards set at the regional, national or international level. Examples of such standards are the European Drinking Water Directive 98/83/EEC (Commission of the European Communities, 1998), the United States Environmental Protection Agency Drinking Water Standards (US EPA, 1993) and the World Health Organization Guidelines for Drinking-water Quality (WHO, 2003). In most countries, other water uses, such as agricultural and landscape irrigation, urban and industrial uses, are not submitted to regulations. However, there are regulations and guidelines covering water for nonpotable uses that is known to have originated in wastewater (e.g. WHO 1989; US EPA 1992). Several Mediterranean countries have national regulations and guidelines; for example, France (Conseil Supérieur d’Hygiène Publique de France, 1991), Israel (Halperin, 1999), Italy (Ministero dell’Ambiente e della Tutela del Territorio, 2003), Spain (Salgot & Pascual, 1996) and Tunisia (Government of Tunisia, 1989).

As the global population increases, water pumped for potable supply from rivers, lakes and even aquifers is increasingly polluted with wastewater. Due to advances in research and analytical techniques, new threats to public health from microorganisms and chemicals are constantly being discovered, and many of them are conveyed by wastewater. Potable water regulations must be adapted to integrate new knowledge, but must not impose too great a cost burden on less wealthy countries. Whatever the source of potable water, its quality should comply with the same regulations; however, monitoring of water quality should take into account the source and any harmful substances that have been identified.

Given that the different uses of water abstracted from aquifers recharged with recycled municipal water are subject to regulations and guidelines, is it necessary to impose more requirements on aquifer recharge? This issue has been indirectly addressed by the establishment of a framework for European Community action in the field of water policy (Commission of the European Communities, 2000). The directive states that member states shall:
implement the measures necessary to prevent or limit the input of pollutants into groundwater and to prevent the deterioration of the status of all bodies of groundwater, …

protect, enhance and restore all bodies of groundwater, ensure a balance between abstraction and recharge of groundwater, …

implement the measures necessary to reverse any significant and sustained upward trend in the concentration of any pollutant resulting from the impact of human activity in order progressively to reduce pollution of groundwater;

ensure the necessary protection for the bodies of water identified with the aim of avoiding deterioration in their quality in order to reduce the level of purification treatment required in the production of drinking-water.

The main aim of these statements is to avoid and reverse any significant and sustained degradation of either the quality or quantity of aquifer water. Though these measures are primarily intended to address diffuse pollution resulting from agricultural activity, they can be applied to artificial recharge. Artificial recharge must not lead to a supplementary treatment of the groundwater pumped for drinking-water supply. Such goals are targeted by the State of California criteria for groundwater recharge (State of California, 1992). Recharge projects must be designed in such a way that they do not jeopardize the public water supply systems, including use of groundwater for potable water supply (Asano, 1992).

A similar approach could be taken for aquifers in which the water quality is too degraded for the supply of potable water, either now or in the future. The most widespread examples of such aquifers are the overexploited coastal aquifers invaded by seawater. Aquifers can be artificially recharged with recycled water to serve several water needs (e.g. agricultural and landscape irrigation, urban and industrial uses) that do not require potable water quality. The recharge should be implemented in a way such that the groundwater quality is improved and meets, on a long-term basis, the most stringent standards related to the intended water applications. Thus, recharge can improve the status of an aquifer and provide groundwater that can be useful for a range of purposes.

Australia, in its Water Quality Guidelines for Fresh and Marine Waters (NWQMS, 1992), has accepted a differential protection policy. In these guidelines, the level of protection offered at sites where recycled water is injected will depend on the potential environmental values of ambient groundwater and, therefore, on its current water quality (Dillon et al., 2001).

There is general agreement that recharge should not create a need for supplementary treatments after withdrawal for the water to meet the standards related to its intended application. Meeting the standards at the point of use is not enough; qualitative requirements have to be satisfied within the aquifer.

The status of the aquifer may not be the same throughout its whole extension. For example, large coastal aquifers contain saline water near the shoreline and high-quality fresh water inland; in which case, different policies could be adopted near the coastline and further inland. Areas invaded by seawater can be recharged by lower quality water in order to accumulate water fit for irrigation; whereas, further inland, potable water can be extracted and high quality water should therefore be maintained. However, such sector-based management is only possible if the expansion of low-quality water can be, and is, controlled.
2.3 Aquifer recharge requirements

2.3.1 Recharge for indirect potable reuse

Artificial recharge for indirect potable reuse is an attractive option that has been considered for years and has already been implemented in several countries. Most if not all well-documented cases of reclaimed water recharge for indirect potable reuse are in the United States of America (USA) (e.g. West Basin and Orange County, CA; Mesa and Tucson in AZ). The recharge should not degrade the quality of the groundwater nor impose any additional treatment after pumping. Apart from those in Australia (NWQMS, 1995), regulations concerning aquifer recharge do not rely on the capability of the aquifer to remove pollutants to meet the water quality required within the aquifer. In practice, the recharge water reaching the saturated zone of the aquifer should have previously acquired the quality acceptable for drinking-water.

If the recharge is direct, then the injected water should be potable and should, as a minimum requirement, meet the standards enforced in the country or contained in the WHO Guidelines for Drinking-water Quality (WHO, 1996). Moreover, the injected water should be treated to prevent clogging around the injection wells, long-term health risks linked to mineral and organic trace elements, and the degradation of the aquifer. The capacity of the aquifer to remove pollutants provides an additional barrier protecting the abstracted water quality.

Setting requirements for indirect recharge is not an easy task. The quality of infiltrated water may be dramatically improved when percolating through the vadose zone, thanks to retention and oxidation processes. These processes affect organic matter, nutrients, microorganisms, heavy metals and trace organic pollutants. However, though much is known about these processes (Bouwer, 1996; Drewes & Jekel, 1996), forecasting the efficiency of the treatment provided by infiltration through the vadose zone and lateral transfer in the saturated zone is hardly feasible. Performances depend on a number of factors such as depth of the unsaturated zone, physical and mineralogical characteristics of the soil layers, heterogeneity, hydraulic load, infiltration schedule and infiltrated water quality.

Therefore, when transfer through the vadose zone is part of the treatment intended to bring injected water up to potable water quality, a case-by-case approach is highly recommended. For each project, pollutant removal tests should be performed, at the laboratory and onsite. Every category of pollutants of concern should be considered. The example of the Dan Project in Israel shows that submitting secondary effluents to a soil aquifer treatment system in a dune sand aquifer can result in the production of a nearly potable water (Sack, Icekson-Tal & Cikurel, 2001). However, recharging potable water aquifer with secondary effluents through such treatment would not be recommended; further treatment, including microbial decontamination, would be needed to reliably obtain potable quality in the aquifer. Furthermore, relying on water transfer in the unsaturated zone to meet potable water quality would not be recommended in heterogeneous soils.

2.3.2 Recharge for nonpotable reuse

The quality of the water extracted from the aquifer should meet the most stringent standards related to the intended water use. In health-related standards applying to wastewater reuse, microorganisms are the main concern. For irrigation, limits can be set for other parameters such as organic matter and heavy metals. Trace organic elements are not likely to present a major harmful impact. As with potable aquifer recharge, relying on the saturated zone of aquifers to improve the recharged water quality is not recommended, even if there is no doubt that filtration effects exist. The saturated zone should only be considered as an additional barrier.
When recharge is direct, the recycled water should have been upgraded to meet the standards and limits required for the intended applications. Also, suspended solids and organic matter should have been drastically reduced to avoid clogging around the injection wells.

Indirect recharge requires a less treated injectant and is easier to implement. Soil aquifer treatment is an appropriate treatment to meet the required water quality, provided it is properly designed and managed. Prediction of the quality of the percolating water when it reaches the saturated zone is generally difficult, mainly because of the high heterogeneity of soil layers. Therefore, a detailed investigation of the hydraulic characteristics of the soil layers below the infiltration site is useful. Onsite performance tests are necessary, except in the case of dune sand layers, which are often homogeneous. When highly permeable or heterogeneous onsite soils are not able to provide the required treatment, infiltration percolation through calibrated sand beds filling pits excavated at the soil surface can be used as a treatment before infiltration through onsite soil layers (Brissaud et al., 1999).

The quality required of the recycled water applied in infiltration facilities should depend on the site, the hydraulic load, the infiltration schedule and the quality to be reached in the aquifer. A secondary treatment is a minimum. Each project must be tailored according to the local context and the water quality to be reached.

2.4 Conclusion

This chapter proposes a simple approach to health related guidelines, which takes into account existing water regulations.

Introduction of pollutants into aquifers may have long-term impacts; therefore, avoiding jeopardizing groundwater should be a prerequisite of any aquifer recharge project. Also, recharge should not create the need for supplementary treatments after withdrawal to meet the standards related to the intended water uses.

Distinction between potable and nonpotable aquifers is essential and will allow development of aquifer recharge and saving of water resources. Distinction is also essential between indirect recharge, using surface spreading and direct recharge through injection wells.

Several approaches, with the important exception of that used in Australia, assume that although the saturated zone can improve water quality, this factor should not be taken into account when setting regulations. The conservative approach is to consider transfer into the aquifer as an additional barrier. Therefore, when direct recharge is performed, the quality of the injected water should meet the quality required from the water that will be subsequently withdrawn from the aquifer. The implication of this is that only potable water should be injected into potable aquifers; and that when aquifer water is to be pumped for unrestricted irrigation, the injected water should meet the standards established for the reuse of wastewater for unrestricted irrigation.

In contrast to the situation with direct recharge, water quality improvement due to percolation through the unsaturated zone is taken into account for indirect recharge. However, because this improvement varies with a number of factors, the recharge design should be tailored case-by-case, after in-depth investigations and preliminary in situ tests.

Sector-based management of aquifers is appropriate in some situations, but must be accompanied by the implementation of consistent monitoring programmes.

The regulations developed by the Balearic Islands provide an example of a Mediterranean attempt to address health-related issues; they should not be regarded as a model.
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2.5 References


