

6 Groundwater recharge with recycled municipal wastewater: health and regulatory considerations

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6.1 Introduction

The lack of specific criteria and guidelines governing the artificial recharge of groundwater with recycled municipal wastewater is currently hampering the implementation of large-scale groundwater recharge operations. Thus, policies and guidance for planning and implementing new groundwater recharge projects are needed, and would serve as the basis on which future and current groundwater projects would be designed and evaluated.

This chapter discusses some of the challenges for groundwater recharge. It presents three case histories of wastewater recycling for nonpotable reuse, with less stringent water quality goals than would be required if potable reuse was being considered. It also discusses risk assessment for drinking-water contaminants and presents the proposed State of California criteria for groundwater recharge as an illustration of a conservative approach to groundwater recharge.

6.2 Challenges for groundwater recharge

Groundwater recharge with recycled wastewater presents a wide spectrum of technical and health challenges that must be carefully evaluated. Some basic questions that need to be addressed include (Asano and Wassermann, 1980; Roberts, 1980; NRC, 1994):

- What treatment processes are available for producing water suitable for groundwater recharge?
- How do these processes perform in practice at specific sites?
- How does water quality change during infiltration–percolation and in the groundwater zone?
- What do infiltration–percolation and groundwater passage contribute to the overall treatment system performance and reliability?
- What are the important health issues to be resolved?
- How do these issues influence groundwater recharge regulations at the points of recharge and extraction?
- What benefits, problems and successes have been experienced in practice?

Pretreatment requirements for groundwater recharge vary considerably depending upon the purpose of groundwater recharge, sources of recycled wastewater, recharge methods and location. Although the surface spreading method of groundwater recharge is in itself an effective form of wastewater treatment, a certain degree of pretreatment must be provided to municipal wastewater before it can be used for groundwater recharge.

6.3 Case studies of groundwater recharge with soil aquifer treatment

This section describes two case histories that illustrate the use of soil aquifer treatment for groundwater recharge. The first case history looks at a variation of the treatment process in Ben Sergao, a suburb of Agadir, in Morocco. The pilot study is of interest not only for the Greater Agadir, where water resources are limited, but also for a number of cities in Morocco where reuse of treated wastewater constitutes an essential option for wastewater treatment and disposal. The second case history looks at infiltration–percolation as a tertiary treatment to meet the WHO's microbiological standards applying to unrestricted agricultural reuse (WHO, 1989).

6.3.1 Case history 1 — wastewater treatment at Greater Agadir, Morocco

With a population of over 350,000, the rapidly growing Greater Agadir faces an increasing need for wastewater treatment and an increasing demand for water supplies. The two main discharges of raw sewage — one into the port area, the other into the bed of the Souss wadi within a few kilometres of its mouth — are incompatible with a valuable tourist attraction.

In a cooperative project between Morocco and France, pilot wastewater treatment through dune sand infiltration–percolation is underway at Ben Sergao, a suburb of Agadir (Bennani et al., 1992). The initial chemical oxygen demand (COD) of raw sewage is 1190 mg/l, and the first treatment is by anaerobic stabilization pond. The pilot plant to treat wastewater by infiltration–percolation treats 1000 m³/day of highly concentrated effluents in five infiltration basins of 1500 m² each, consisting of 2 m thick eolian sand. The anaerobic stabilization pond (1500 m³ for a theoretical residence time of 2 days; depth of 3–4 m) is used to reduce suspended solids (40–50 %) and organic matter (50–60 %), increasing the rate of infiltration and reducing the surface area necessary for the infiltration basin. The basin is submerged for 8 hours and remains dry for 16 hours.

The wastewater is infiltrated at the rate of 1 m/day. Nearly 100% of suspended solids and 95% of COD are removed; 85% of nitrogen is in oxidized form and 56% is removed. Microbiological quality of raw sewage, pond effluent and percolated water are shown in Table 6.1. The percolated water will be used in growing tomatoes (a vegetable extensively cultivated in the Agadir region), public gardens and future golf courses.

Inasmuch as recharged groundwater may be an eventual source of potable water supply, groundwater recharge with recycled municipal wastewater may often involve treatment beyond the conventional secondary wastewater treatment level. In the past, several apparently successful groundwater recharge projects were developed and operated using primary and secondary effluents in spreading basins. However, because of the increasing concerns about protozoan cysts, enteric viruses, and trace organics in drinking-water, groundwater recharge with recycled wastewater in industrialized countries now generally entails further treatment after conventional secondary treatment. For example, surface spreading operations practiced in the USA to reclaim wastewater commonly include primary and secondary wastewater treatment, tertiary granular-medium filtration and, finally, chlorine disinfection.

Table 6.1 Microbiological quality of raw sewage, pond effluent, and percolated water

	Raw sewage	Pond effluent	Percolated water	Overall removal efficiency
Fecal coliforms (No./100 ml)	6×10^6	5×10^5	327	4.26 logs
Fecal streptococci (No./100 ml)	2×10^7	1.6×10^6	346	4.78 logs
Nematode ova (No./l)	139	32	0	~100%
Cestode ova (No./l)	75	18	0	~100%
Total helminths ova (No./l)	214	47	0	~100%

Source: Bennani et al. (1992)

6.3.2 Case history 2 — disinfection of secondary effluents via infiltration and percolation

This case study deals with infiltration–percolation as a tertiary treatment to meet the microbiological standards applying to unrestricted agricultural reuse (Brissaud et al., 1999).

Because of the potential for direct human exposure, effluents from conventional wastewater treatment must be disinfected if they are to be used for irrigation of public parks, sports fields, golf courses and edible crops, to comply with relevant regulations. When the object is to meet WHO's unrestricted irrigation criteria (WHO, 1989), the additional treatment can be achieved through infiltration–percolation. An infiltration–percolation pilot plant constructed in Vall-Llobrega, Catalonia, Spain was intermittently fed with secondary effluents which percolate through 1.5 to 2 m of unsaturated coarse sand and recovered by under drains. In 1997, a 0.82 m/d hydraulic load was applied for more than six months. The mean fecal coliform removal was about four log units.

Infiltration–percolation allows oxidation and disinfection of the wastewater to occur. This is why soil aquifer treatment is used in Spain and France as a tertiary treatment with the aim of removing pathogens from the effluents of conventional wastewater treatment plants. It is a low-technology method that can be used to prepare wastewater for unrestricted irrigation (Brissaud et al., 1999). However, the reported disinfection performance provided by infiltration–percolation is uneven and dependent on the hydraulic loading of the system. The average water quality of secondary effluents and the percolated water is shown in Table 6.2.

Table 6.2 Water quality of secondary effluent and percolated water

	Secondary effluent	Percolated water
Suspended solids (mg/l)	18	1.2
COD (mg/l)	97	51
NH ₃ -N (mg/l)	28	0.5
NO ₃ -N (mg/l)		47
Fecal coliform (CFU/100 ml)	$6.1 \times 10^5 \sim 7.3 \times 10^6$	Variable, in the range of 100–500 dependent on the hydraulic loading

COD = chemical oxygen demand, CFU = colony forming units.

Source: Brissaud et al. (1999)

6.4 Health and regulatory aspects of groundwater recharge with recycled wastewater

Groundwater recharge with reclaimed water and direct potable water reuse share many of the public health concerns encountered in drinking-water withdrawn from polluted rivers and reservoirs. Ongerth and Ongerth (1982) have argued that the issue that has arisen in regard to groundwater recharge relates to the so-called “single standard” – meaning that all domestic water sources (natural and recycled water) should be subject to the same set of standards. The implication in the use of this term regarding wastewater reuse is that more stringent requirements may have been applied to recycled water for potable applications than for surface water or groundwater sources now in use. Clearly, whatever the source of a given array of chemical contaminants, the same health effects will occur and be of equal health consequences if the exposure is the same. There is, however, an important difference in the circumstances. With existing water sources, chemical contaminants should be identified and their harmful effects understood and mitigated as promptly as resources and public policy will allow. On the other hand, proposals to develop optional projects for potable reuse of wastewater that may deliberately introduce residues of uncharacterized substances into community water supplies should be carefully considered case-by-case to assure that benefits are significantly greater than the potential unquantifiable risks.

The current drinking-water standards and guidelines were not designed to deal with the mixtures and individual contaminants that may be unique to wastewater sources, so they alone cannot be used to completely evaluate the acceptability of a recycled water for potable reuse. However, it is within our capability to provide appropriate standards that may involve limits on both individual substances and aggregates, as well as treatment and source management specifications.

Tapping of polluted sources has potential effects that go beyond the increased cost of additional treatment. Incidental or “unplanned” indirect potable reuse of polluted water may expose people to health risks not associated with protected sources. The health concerns associated with drinking-water drawing upon polluted sources apply even more forcefully to treated wastewater reuse for portable purposes. In order to form a sound policy, the following questions should be considered: (a) is a water reuse option necessary as a water resource alternative; (b) what level of risk control is attained by a standard relative to the intended use; (c) how valid is the judgement of that level of risk, and, what is the acceptability of a given degree of risk? Risk analysis as applied to recycled water entails the same difficulties as that for other health hazards in the environment. Basically, the problem lies in quantifying the risks involved and agreeing upon what level of risk to accept (Ongerth and Ongerth, 1982).

6.4.1 Case history 3 — advanced wastewater treatment

Because of unspecified health concerns, several groundwater recharge projects in the USA are using microfiltration (MF) of secondary effluent followed by nanofiltration (NF) or reverse osmosis (RO) prior to subsurface injection into the aquifer. Drewes, Amy and Reinhard (2002) investigated advanced membrane treatment using NF and RO and found that membranes can efficiently reject high molecular weight organic matter. Approximately 40 to 50 per cent of the remaining TOC in permeates consisted of low molecular weight acids and neutrals representing a molecular weight range of ~500 Daltons and less. Based on carbon-13 NMR results and SEC-DOC analysis, NF and RO permeates still contained fulvic acid-related material that was not altered as compared to organic matter present in groundwater or surface water.

Emerging contaminants relevant to groundwater recharge will include: trace organics such as potential endocrine-disrupting compounds (EDCs), pharmaceutically active compounds (PhACs), and N-nitrosodimethylamine (NDMA); some trace inorganics; and microbes, for example nanobacteria ($\approx 0.1 \mu\text{m}$). Wastewater indicators, EDCs, and PhACs selected for study usually are not detected in either NF or RO permeates at pilot- and full-scale. These findings indicate that advanced

membrane treatment using NF or RO not only efficiently removes high molecular weight organic carbon compounds, but also selected organic wastewater indicators, such as EDCs and PhACs (Drewes et al., 2002).

6.5 Risk assessment in groundwater recharge

Risk avoidance or risk minimization should certainly be principal elements in the development of drinking-water standards and guidelines. However, technological and economic factors must also be taken into account. Aesthetic factors of taste, odour and appearance must be important considerations, even if they do not directly relate to the safety of the water, because consumer acceptance of, and confidence in, the quality and safety of drinking-water are essential. If water is esthetically unacceptable, consumers may switch to other, uncontrolled, waters that are actually less safe.

Risk assessment is fundamentally an attempt to quantify the possible health consequences of human exposure in particular circumstances. In the case of drinking-water, the conclusion would be expressed in terms of the probability (within specified levels of uncertainty) of cases of adverse effects, such as fatalities, in the reference population group. For example, an incremental upper limit risk of bladder cancer of one per million in a population typically consuming 2 litres of drinking-water per day for 70 years (see “Stockholm framework” discussion in Appendix A). The lower limit risk might well be zero, especially if one or more assumptions are invalid. All such computations and “conclusions” are limited in their reliability and credibility by the quality of the exposure and toxicological data, the mathematical expressions used, and the lack of scientific understanding of the mechanisms of carcinogenesis operating at low environmental doses in genetically diverse humans, compared to the high doses to which test animals are exposed. In addition, little is known of the effects of interactions of low doses of chemicals (Cotruvo, 1988).

In its simplest terms a risk assessment could be represented as follows:

$$\text{RA} = \frac{\text{concentration distribution} \times \text{persons exposed at each dose} \times \text{risk}}{\text{per dose} \times \text{time}}$$

The basic information required to perform a quantitative risk assessment includes quantitative information on: the occurrence, human exposure and toxicology of the substance. Although methodologies are available to attempt to quantify each of these factors, in practice, data limitations and analytic complexities usually lead to many simplifying assumptions.

Comprehensive quantitative data on the frequency and concentration range of the contaminants in public drinking-water supplies are needed to determine the potential for human exposure under a variety of conditions, and to predict the exposure consequences of any control options being considered. The same analyses should be done for other water-related exposures (see “Stockholm Framework” discussion in Appendix A); and air, occupational and other contributions to total human exposure. Typically, drinking-water data are the most feasible to obtain, given the finite nature of drinking-water sources and the availability of analytical methods of high sensitivity and reliability. Statistically based surveys can be designed to generate high-quality data on national distributions of drinking-water contaminants by source type, population, season or other variables.

Computing human exposure from occurrence data requires detailed information on water and food consumption patterns, and other lifestyle factors that often are very difficult to model. These factors will be dependent on age, size, season and location. Water consumption has been studied in several countries and reasonable distributional data are available. For example, the average drinking-water consumption estimated from eight studies was 1.63 l/day. A dietary study (Ershow & Cantor, 1989) concluded that the median daily water consumption in the USA was 1.2–1.4 l/day,

that 80–85% of people consumed less than 2 l/day and about 1% consumed more than 4 l/day. This included all tap water, including coffee, tea, and reconstituted juices, soups and food water (e.g. from rice). These estimates are probably low for very warm climates.

Dietary patterns are much more complex, and databases that can be extrapolated to populations are not very extensive. Localized ambient air inhalation data are available for a few substances. Indoor air quality data are potentially of greatest interest but are also limited. Water can contribute to indoor air exposure to volatile substances such as trihalomethanes or radon, or even *Legionella* organisms from growth in plumbing systems. This indirect exposure should be considered when projecting total exposure and the drinking-water contribution. For volatile organic compounds in drinking-water this inhalation dose can be equivalent to the amount from ingestion of water.

Toxicology assessments require highly qualified health scientists to analyse the complex data describing the toxicology of a substance, select the appropriate valid studies from the often conflicting or incomplete data, and arrive at a judgement on the relevance of the information to human health risks. The analyses should include all relevant toxicology, including whole animal acute, subchronic (90-day), and chronic (lifetime) studies, reproductive and developmental studies, neurotoxicology and other relevant animal data, in vitro studies of mutagenesis and cytogenetics, and also human epidemiology, if available.

The rough relationship between postulated levels of risk and the ability to identify cancer risk in the human population is illustrated in Figure 6.1. It is clear that the risks that are postulated for exposure levels typical to drinking-water are usually well beyond what epidemiological studies can measure. Since regulatory policy generally strives to limit risks below 1/100,000 for life threatening diseases like cancer, these lower risks are estimated by making inferences about the shape of the dose–response curve and extrapolations from effects to humans at higher doses or animal testing. Imperfect though this system is, it attempts to incorporate all of the available information and creating usable (albeit unverifiable) low dose risk hypotheses that can be helpful for decision making.

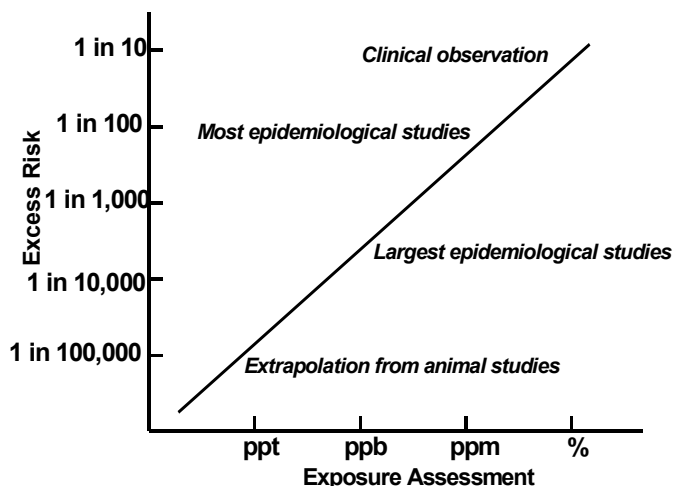


Figure 6.1 Sensitivity of epidemiology in detecting risks of regulatory concern (NRC, 1993).

Thus, WHO *Guidelines for Drinking-water Quality* (WHO, 1996) together with detection and evaluation methodologies aimed at source-specific contaminants, and site and technology-specific factors should be applied on a case-by-case basis. Such guidelines and techniques should be extended significantly to determine the design and operation of each specific project, to assure the suitability of the product water for its end use. They should also be expanded to include reuse and recharge applications. Indeed, the recommendations and methodologies described in the WHO *Guidelines for Drinking-water Quality* provide for appropriate authorities to make suitable water quality and safety determinations based upon the societal, economic and feasibility factors that bear

upon the cost–risk–benefit balance that must be struck to assure access to water of both adequate quantity and quality.

A brief description of the type of process used by WHO and national regulatory agencies to determine acceptable concentrations of contaminants in drinking-water is provided in Appendix C (Cotruvo, 1999). The methodology is evolving and variations are commonly applied, but this appendix describes the basic thought processes that are involved.

6.6 Proposed State of California planned groundwater recharge and reuse criteria

The proposed California criteria for groundwater recharge with recycled municipal wastewater rightly reflect a cautious attitude toward short and long-term health concerns. The criteria rely on a combination of controls intended to maintain a microbiologically and chemically safe groundwater recharge operation. No single method of control would be effective in controlling the transmission and transport of contaminants of concern into and through the environment. Therefore, the criteria specify source control, wastewater treatment processes, water quality, recharge methods, recharge area, dilution, extraction well proximity, and monitoring wells. An illustration of this conservative approach for regulating planned reuse projects is given in Appendix C. The approach may need to be modified to deal with particular circumstances of water quantity, water quality, economic considerations and risk–benefit environments. However, the example given highlights the potential of this approach for a comprehensive and protective regulatory program.

These proposed groundwater recharge criteria have undergone several iterations since the early 1990s (Hultquist et al., 1991), and, while several refinements have been made to improve the criteria, many of the requirements specified in earlier drafts remain unchanged (see Table 6.1). More recent revisions emphasized dilution and monitoring of unregulated organics and groundwater.

6.7 Summary and conclusions

Groundwater recharge with recycled wastewater presents a wide range of technical and health challenges. Case histories of groundwater recharge with soil aquifer treatment in Morocco and Spain illustrate the degree of removal of contaminants that can be achieved by this type of treatment.

Risk assessment is important to quantify the possible health consequences of human exposure. However, the data needed to assess the exposure that might result from contaminants in recycled water are often lacking, and assessment of the risk is complex. The proposed California criteria for groundwater recharge with recycled municipal wastewater reflect a cautious attitude to health concerns. These criteria, which continue to be revised, illustrate the potential of this approach for a comprehensive and protective regulatory program.

6.8 References

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