1 Introduction

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1.1 Background

1.1.1 The need for aquifer recharge

Increasing demand for water, particularly in arid and semi-arid regions of the world, has shown that the extended groundwater reservoirs formed by aquifers are invaluable for water supply and storage. Natural replenishment of this vast supply of groundwater is very slow. Therefore, exploiting groundwater at a rate greater than it can be replenished causes groundwater tables to decline and, if not corrected, eventually leads to mining of groundwater. Artificial recharge as a means to boost the natural supply of groundwater aquifers is becoming increasingly important in groundwater management.

Groundwater can have a wide range of beneficial uses. For example, it can be used for irrigation of parks or agricultural land, industrial application, or to provide a potable water supply (i.e. one that is suitable for drinking).

1.1.2 Types of recharge

Artificial recharge involves augmenting the natural movement of surface water into underground formations. The recharge can be either direct or indirect. In direct recharge, water is introduced into an aquifer via injection wells. The injected water is treated to ensure that it does not clog the area around the injection well. Indirect recharge involves spreading surface water on land so that the water infiltrates through the vadose zone (the unsaturated layer above the water table) down to the aquifer. Methods for spreading water include over-irrigation, creating basins using construction methods, or making artificial changes to natural conditions (e.g. modifying a stream channel) (Asano, 1998). An advantage of indirect recharge is that the vadose zone acts as a filter, treating, and therefore improving the quality of, the water percolating through the soil. This process is referred to as soil aquifer treatment.

Recharge can be intentional or unintentional. Injection of treated wastewater would be an example of direct intentional recharge; whereas, infiltration of water used for agricultural irrigation would generally be an example of unintentional indirect recharge. Unplanned indirect reuse for potable water supplies is increasing, due to municipal water intakes located downstream from wastewater discharges or increasingly polluted rivers and reservoirs.

1.1.2 Wastewater as a resource for recharge

Various sources of water are available for groundwater recharge but, in recent years, the use of nonconventional water resources such as recycled municipal wastewater, has received increasing attention. The primary reasons for considering use of recycled water in groundwater recharge are that recycled wastewater is available for reuse at a relatively low cost and that it provides a dependable source of water even in drought years.

As artificial recharge has increased in popularity, managers have begun to search for additional sources of recharged water. A critical question is whether waters of impaired quality should be used for this purpose, and whether the water recovered from such systems is suitable for potable uses as
well as nonpotable ones. Obviously, water of impaired quality could only be used with appropriate pre and post-treatment, and treatment gained from soil and aquifer processes.

1.1.3 Challenges to using wastewater for recharge

Using recycled municipal wastewater for artificial recharge of groundwater presents a wide spectrum of technical and health challenges. A major consideration is the possible presence of chemical and microbiological agents in the source water that could be hazardous to human health and to the environment. Concerns about hazardous agents in the water apply particularly to potable reuse. Although nonpotable uses such as irrigation can result in human exposure to hazardous agents, there is less potential for exposure and the risks are therefore significantly lower (NRC, 1994).

Two possible constraints that may limit the use of recycled municipal wastewater for groundwater recharge are concerns over the impacts of emerging contaminants on long-term human health, and public perception on potable reuse. Minimizing the health risks caused by water that people drink is of great importance worldwide.

A further concern is how risk resulting from aquifer recharge will be defined accurately in terms of environmental and health issues (e.g. preventing the degradation or impairment of water quality in groundwater basins that are, or could be, used for domestic water supplies). Detailed information on the processes governing the fate of pathogens and chemicals is required in order to develop appropriate models for determining risk assessment.

Four water quality factors are significant in groundwater recharge with recycled water:

- human pathogens
- mineral content
- heavy metals
- trace organic compounds.

Human pathogens and trace organic compounds are of particular concern when groundwater recharge involves aquifers supplying domestic water (Tsuchihashi, Asano & Sakaji, 2002).

The need for definitive information on the extent of contaminant removal by the soil and underlying geological formations, and on the fate of pollutants during groundwater recharge, has been recognized and is being studied extensively. Much of the research on groundwater recharge and potable water reuse is becoming as relevant as research on unplanned indirect reuse for potable supplies. Tapping 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 wastewater recycling and reuse for potable purposes.

1.2 Aim and structure of this report

1.2.1 Aim

The aim of this report is to contribute to improving practices in intentional groundwater recharge, and to introduce a precautionary approach in other practices (e.g. agricultural irrigation with raw wastewater and land disposal of wastewater), which result in unintentional recharge, to reduce the risks to acceptable social, economic and environmental levels. The report is a first step on the path
to developing simple, flexible and practical health-related guidelines that will help to improve practices in both direct and indirect groundwater recharge.

This report is written for civil and sanitary engineers, agricultural engineers, hydrologists, environmental scientists and research scientists. It will also be a useful reference for public works officials, consulting engineers, agriculturists, industrialists, academics and students.

Water is precious. Managing water is a global challenge that affects the environmental, social, economic and political cornerstones of our existence on Earth. Artificial recharge provides an opportunity for sustainable management of water resources, conservation and improvement of quality, to face future water demands. Recharge concepts are simple but practitioners know that we have much to learn about issues relevant to sustainability of managed recharge of groundwater, especially with regard to public health and environmental aspects.

1.2.2 Structure

The remaining chapters of this report look at various aspects of the health and environmental risks of aquifer recharge using reclaimed water.

Chapter 2 is an overview of aquifer recharge. It presents an approach to recharge that takes into account the intended use of the groundwater; it also considers existing guidelines. Issues such as differentiation between potable and nonpotable aquifers, and direct and indirect reuse are critical when implementing aquifer recharge projects. The water withdrawn from the recharged aquifer should not require supplementary to meet existing quality standards for its intended use. Moreover, the treatment that applied wastewater effluent undergoes in the vadose zone should not be taken into consideration. Although the effect of such treatment is well documented, it should be considered only as an additional barrier in case of failure of the basic treatment. In contrast, percolation of recycled water through the unsaturated zone can be considered as an additional treatment.

Chapter 3 reviews recharge of groundwater in both developing and developed countries. In the case of developed countries, social acceptance is the main limitation on indirect intentional reuse. Consequently, intense communication campaigns are needed, aimed at persuading society to accept the concept of intentional reuse, especially with regard to public health and environmental protection issues. In addition, economic aspects (levels of initial investments and operation and maintenance costs) should be considered in such campaigns. This chapter also suggests that developed countries undertake epidemiological studies to substantiate their arguments for artificial recharge of groundwater.

In developing countries, especially those in arid or semi-arid regions, artificial recharge of groundwater is particularly important. A shortage of water in these countries has forced a situation in which water of a less than desirable quality is being used. Chapter 3 takes into account both this situation, and the fact that relatively cheap improvements in indirect intentional reuse practices could significantly reduce health risks, especially those concerning gastrointestinal diseases. The guidelines provided in Chapter 3 will be useful in the design and implementation of such improvements, in systematizing epidemiological studies and in undertaking toxicological studies to guard against the effects of toxic pollutants. The guidelines cover cases where disposal of wastewater in soils results in incidental recharge.

Chapter 3 also gives extensive consideration to pathogens present in waters and in wastewater, waterborne diseases and microbiological indicators, and describes treatment processes in both the developing and developed world. This chapter reviews various types of aquifer storage recovery systems and considers regulatory issues, emphasizing aspects relevant to setting regulations for recycled water intended for human consumption via aquifer recharge. Important regulatory concerns include treatment practices and technologies, evaluation and use of the “best” indicator
organism, selection monitoring parameters, definition of sampling (taking into account epidemiological studies and toxicological tests) and use of a risk evaluation model. Finally, Chapter 3 describes examples of legislation and proposes guidelines to be applied to indirect potable reuse of aquifers recharged by spreading and by injection.

Chapter 4 looks at legislation concerning drinking-water production and considers the main contaminants of concern for aquifer recharge. It considers two approaches to health risk assessment of artificial recharge of groundwater. The first method, known as the parameter approach, involves estimating the health risk using as a reference either drinking-water standards or (in a quantitative risk assessment) toxicological data, and data on infectious doses and acceptable risk (chemical and biological). The alternative approach is to study the effect of recharge on test organisms or on the population, and estimate or calculate the risk posed by chemicals and pathogens. The chapter reviews several biotests (e.g. bioassays, genotoxicity tests and effect-specific tests) that are used to understand and assess the effect of specific contaminants, such as endocrine disrupting compounds.

Chapter 4 also discusses analytical and probabilistic models for predicting economic, ecological and human health risk assessment for artificial recharge of groundwater.

Chapter 5 describes an integrated approach to assessing the impact of aquifer recharge, where territorial implementations for safe use are interconnected with social, economic and environmental issues. Where groundwater is the main water resource covering potable, washing and irrigation requirements, it is an important contributing factor to exposure risk for consumers or users. Initially, a preliminary environmental health assessment is required for defining policy options. Chapter 5 describes a procedure that includes the following stages:

- outline policy goals
- identify options
- assess the uncertainties of each option
- evaluate costs and benefits of each option
- identify the favored policy.

In a latter stage, the environmental health impact of aquifer recharge with recycled water must be assessed. This stage includes identifying chemicals and pathogens, and assessing risks and health impacts. Perspective data collection with the use of geographical information system (GIS) and environmental mapping for baseline definition and health surveillance is highly recommended.

Chapter 6 reviews health and regulatory aspects of groundwater recharge with recycled municipal wastewater, and provides practical recommendations to guide decision makers. At present, uncertainties about health risk considerations have limited the use of recycled municipal wastewater for groundwater recharge. Groundwater containing a large portion of recycled wastewater may affect the drinking-water supply. This chapter presents two case histories for soil aquifer treatment and nonpotable water recycling and reuse, with less stringent water quality goals than would be required if potable reuse was being considered. It also discusses the proposed State of California (USA) criteria for groundwater recharge as an illustration of a much more conservative approach.

Chapter 7 presents the basic principles of risk communication and sets out the main roles of communication in implementing policy options.

The report also contains four appendices. Appendix A describes the “Stockholm framework”, a harmonized framework for the development of guidelines and standards, in terms of water-related microbiological hazards (Bartram, Fewtrell & Stenström, 2001). Appendix B describes the Balearic Islands (Spain) as an example of regulation of wastewater reuse. Appendix C describes the process used to develop the WHO guidelines covering chemical aspects of drinking-water quality.
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Appendix D summarizes the proposed State of California criteria for groundwater recharge and reuse projects.

1.3 Conclusions

The main conclusions drawn from this report are the following:

- Development of guidelines to minimize the microbial health risks associated with groundwater recharge with wastewater should take into account other water-related exposures (i.e. through drinking-water, recreational/bathing water contact, and through the food-chain). The management of water-related disease needs a comprehensive approach such as that outlined in the “Stockholm framework” (see Appendix A).

- Various models (analytical and probabilistic) are used for predicting human health risk. Microbiological risk assessment tools will play a critical role in developing future criteria based on the epidemiological studies. However, alternative strategies for minimizing risks in four dimensions (technical, economic, environment and health) using multicriterion decision analyses should be practised.

- Appropriate preapplication treatment technologies and site characteristics (soil permeability, groundwater depth etc.) should be tested to eliminate the potential threats posed by chemicals and pathogens. Establishing these factors ensures that a reliable minimum degree of treatment can be set, that must be adhered to before the recycled water is used. However, the regulatory issue is whether permitting the discharge of chemicals not present in any measurable quantity in a groundwater basin would constitute degradation or impairment of groundwater basin.

- Biotests are biological tests in vitro or in vivo. They can be used to assess the health risk associated with the use of a certain type of water or to monitor the quality of the water produced. The major advantage of biotests is that the water is considered as a mixture. Biotests using endogenous estrogen equivalents should be evaluated, to help to develop a basis for tracing organics in recycled water.

- Future research should be directed toward defining the limits of physical, chemical and biological agents that should be used to establish safe and sustainable groundwater recharge practices. Some topics for future research are how to more precisely establish:
  - microbiological risks;
  - presence, concentration and health significance of pathogens and toxic substances in recycled water by region;
  - fate of micropollutants, including pathogens in the soil and underlying geological formations;
  - residence times (using models),
  - extraction distances and chlorination alternatives;
  - soil and aquifer attenuation.

1.4 References

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