5 Impact assessment of aquifer recharge

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5.1 Introduction

5.1.1 A changing context

Environmental development plans, policies and programmes can result in outcomes that may affect the health of present and future generations. There is a growing consensus that a systematic assessment of health effects is needed in such cases. This consensus has been expressed in numerous international laws and legally binding agreements, which now include provisions for the integration of health impact assessments in policy development (e.g. the Amsterdam Treaty of the European Union, Art.152; Declaration of the Third Ministerial Conference on Environment and Health).

The World Health Organization (WHO) stated that:

“Environmental health comprises those aspects of human health, including quality of life, that are determined by physical, chemical, biological, social and psychosocial factors in the environment. It also refers to the theory and practice of assessing, correcting, controlling, and preventing those factors in the environment that can potentially affect adversely the health of present and future generations”.

This definition clearly illustrates the need to integrate the results of health environmental impact assessments, because this is the only way to incorporate health protection and promotion in development policy. Incorporation of health promotion strategies in national and local development policy is now widely supported by health professionals involved in the formulation of national health policies.

The Ottawa Charter for Health Promotion (1998) states that:

“... Health promotion is the process of enabling people to increase control over, and to improve, their health. To reach a state of complete physical, mental and social, well-being, an individual or group must be able to identify and to realise aspirations, to satisfy needs, and to change or cope with the environment. Health is, therefore, seen as a resource for everyday life, not the objective of living. Health is a positive concept emphasizing social and personal resources, as well as physical capacities. Therefore, health promotion is not just the responsibility of the health sector, but goes beyond healthy life-styles to well-being...”.

The Director of the Pan American Health Organization stated that:

“...It is not enough to look at the health outcomes. One must look at those social conditions that determine health outcomes – the determinants of health ... we must look at the disparities of these determinants of health and determine to what extent they are distributed so unequally as to produce health disparities. It is of fundamental importance that in discussions on equity, we understand the difference between disparities in health status and disparities in the determinants of health that cause these health inequalities or inequities” (Alleyne, 2000).

There is evidently general international agreement on the concept of integrating health impact assessments in development planning. However, institutional mechanisms are lacking, especially at the local level, to include such assessments in development efforts outside the health sector proper, let alone take the result of such studies into account in the final policy formulation.
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The omission of health impact assessment and the adoption of a nonintegrated, sectoral approach is likely to result in a serious underestimate of the overall cost of an adopted policy, particularly in the cost–benefit assessment, if this is based on a narrow preliminary impact assessment. This concern is particularly relevant in the area of water resource management, as will be demonstrated in this chapter.

5.1.2 Role of the health community

Health impact assessment can be described as the estimation of the effects of any specific action (plans, policies or programmes) in any given environment, on the health of a defined population. As such, a health impact assessment is an integral component of:

- strategic environment assessment for large-scale planning procedures;
- environmental impact assessment for specific projects;
- environmental assessment.

These three procedures share several key stages and follow-up measures. Implementing an appropriate assessment procedure during a limited preliminary assessment of policy options can achieve many goals at low costs and great benefit to the community. Yet, even in their basic form, assessment procedures can be dauntingly complex.

The use of groundwater for the production of drinking-water and the cultivation of a variety of food products, some of which are consumed raw, make it imperative to assess the health risks associated with any recharge option. An integrated approach to groundwater management in general, and a health impact assessment of management options in particular, is strongly recommended, especially where territorial limitations for water use and safe water are interconnected with social, economic and environmental issues.

The chemical and microbial quality of groundwater is inextricably linked to events occurring above the aquifer. Examples of some of the many factors that can impact on the quality of the groundwater are air deposition of small particles, contaminated rainfall, untreated stormwater, polluted agricultural runoff, untreated or partially treated wastewater discharged from municipal and industrial sources, accidental spills and illegal waste dumping. Chemical pollution can originate at a site far removed from the aquifer, but may still contaminate groundwater. Furthermore, some types of chemical pollution are irreversible, precluding the intended use of the aquifer and is considered to be virtually irreversible. Finally, there is a history of institutional inattention to groundwater management compared to surface water management. This has hampered the collection of adequate environmental data, and the compilation of information on health impact assessment experiences, especially for new technological options. The lack of consolidated experience has caused further uncertainties in guidance on policy formulation and implementation.

The complexity of carrying out impact assessments makes it necessary for health professionals to extend their skills into new areas. For example, assessing the potential health effects of planned or accidental contamination of groundwater resources requires health professionals to acquire new knowledge on toxicology, and to become familiar with modern laboratory and data interpretation techniques.

This chapter addresses the challenges posed by health impact assessment related to aquifer recharge by means of recycled water. In particular, it:

- reviews the social, economic and environmental issues that act as health determinants;
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- explores the role of preliminary environmental health assessment in defining policy options;
- describes the basic principles of environmental health impact assessment as applied to aquifer recharge.

5.2 Social, economic and environmental issues as determinants in groundwater management

5.2.1 Importance of a groundwater policy

Groundwater serves a variety of needs:

- **Agriculture** is by far the most intensive user of groundwater resources, especially through irrigation. It is estimated that 90% of all groundwater abstractions serve an agricultural need.
- **Industry** is the second largest consumer of groundwater, often using drinking-water for free, or at a heavily subsidized rate.
- **Household needs** for drinking, hygiene and food preparation are a third need to be met by groundwater resources.
- **Natural environment** relies on groundwater as the main source for the base flow of shallow aquifers and wetlands, representing an effective buffer against droughts.

Groundwater may also serve a variety of community water needs, such as watering of common areas and supply of water to community services (e.g. public buildings and fire brigades). Such applications are at present not considered as a strict health policy issue, but this view may well be revised in future.

Water resource management is an area undergoing rapid change. Policy development will need to take into account future evolution in the sector, which may include a number of issues that are discussed below.

*Effect of global forces*

The availability of water resources, their use and management will be shaped by a range of global forces. Such forces include rapidly changing demographic conditions, wider geographical distribution of human settlements, increased local demand for water and wider availability of technologically advanced options, such as desalination and water reuse.

*Private sector involvement*

An increased interest by the private sector in the management of groundwater resources can be expected as a result of advances in demand management. This, in turn, will affect water pricing. As the price of water increases, the demand for exploiting groundwater will grow, as will research into new technologies for abstraction and aquifer recharge.

*Deteriorating water quality*

Aquifer water quality can be expected to deteriorate as a result of several factors. However, this problem is currently receiving inadequate attention, because facilities and expertise for aquifer water quality assessment are lacking, as are databases dedicated to the gathering of relevant information. Inadequate investment hampers assessment of the impact of diffuse sources of pollution, and prevents a better understanding of the interaction between sources of pollution and groundwater quality. Pollution affecting groundwater can originate from the air or the surface, as discussed in Section 5.1.2. Excessive use of groundwater in many key crop-producing areas is pushing the watertable downward, while changes in groundwater flow carry pollutants into
noncontaminated areas. Furthermore, the increasing use of bottled water (much of which is spring water, and thus comes from aquifers) is a trend that is extending into poorer countries or regions, setting a new exposure scenario that requires appropriate environmental health assessment and surveillance.

Financial aspects
Aquifer recharge with recycled water may require major investments to pretreat wastewater before is used for recharge purposes. This might, in turn, require the construction of new wastewater treatment plants, modernization of old plants, maintenance to more exacting standards or other substantial investments. The total financial requirements might make other forms of water resource management, such as desalination, financially competitive in certain areas.

Financial aspects such as access to funding and investment will be key to addressing the water crisis. The current trend of privatisation of water services may lead to an access to water determined by market-driven economical strategies, rather than by the recognition of any universal right of access to water. It is therefore crucial to implement a regulatory framework on water resource management and water use.

Legislation
Legislation concerning groundwater has often been neglected in comparison to the attention given to surface water. Regulatory frameworks are variable, and are often split into self-contained sets of regulations dealing with water, industry and agriculture — a situation that is not particularly helpful to local policy-makers.

New technologies
Artificial recharge will require the application of advanced technologies to avoid adverse health effects, especially where the end goal is the production of drinking-water. Preliminary assessment of all technical options for aquifer recharge needs to be part of any water management plan; for example, enhanced natural recharge could be an alternative option achievable at significantly lower cost than recharge with wastewater, but would require carefully planned land use.

5.2.2 Health aspects of a groundwater policy
The health impacts caused by scarcity or impaired quality of groundwater can be organized into three main categories:

- environment-related physical health:
  - communicable (microbiological contamination) and noncommunicable (chemical contamination) diseases;
  - poor hygiene caused by water scarcity;
  - unsafe drinking-water;
  - unsafe food crops due to contaminated irrigation water;
  - contamination-related diseases with effects on future generations (e.g. endocrine disrupting chemicals causing sterility and impaired juvenile development);

- health care services:
  - incremental health care needs,
  - displacement of traditional care services, surveillance, laboratory and expertise costs;
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- social well-being:
  - effects on income, socioeconomic status and employment (industrial and agribusiness based on groundwater resource);
  - effects on migration and resettlement (migration related to water scarcity, increased water demand in highly urbanized areas);
  - continued investment needed for groundwater management (development, implementation and maintenance of aquifer recharge and water treatment plants), which can be a significant burden for local policy-makers.

A wise investment in groundwater management is therefore an investment in public health. Table 5.1 summarizes the benefits of investing in groundwater management, and the potential problems that arise from the lack of such investment.

Table 5.1 Effects of investing or failing to invest in groundwater management

<table>
<thead>
<tr>
<th>Potential benefits of investing in groundwater management</th>
</tr>
</thead>
<tbody>
<tr>
<td>• increased prosperity because a healthy population is a major contributor to a vibrant economy;</td>
</tr>
<tr>
<td>• reduced expenditures on health and social issues;</td>
</tr>
<tr>
<td>• overall social stability and well-being.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Potential consequences of failing to invest in groundwater management</th>
</tr>
</thead>
<tbody>
<tr>
<td>• lack of health impact assessment of policies, programmes and projects;</td>
</tr>
<tr>
<td>• greater-than-necessary adverse health impact of development policies.;</td>
</tr>
<tr>
<td>• the tendency of vertical disease control programmes to ignore environment and development links;</td>
</tr>
<tr>
<td>• lack of funding for research into health impacts.</td>
</tr>
</tbody>
</table>

It is important to remember that the concept of health has evolved to include not simply the absence of disease, but also the promotion of good health. The implementation of this expanded concept requires an assessment of the impact of any development on all aspects of human well-being. Decision-makers therefore need to be aware of the following basic principles when defining a policy for water resources management:

- health determinants can be defined as the range of personal, social, economic and environmental factors that determine the health status of an individual or a defined population;
- coordination of actions to improve health across various sectors implies multidisciplinary cooperation as well as in-depth knowledge of the individual sectors and their specific rules and regulations;
- the protection of human health reduces the socioeconomic burden of ill-health;
- policy and planning efforts need to include the potential reduction of costs in the health-care sector if policies with negative health consequences are abandoned;
- improved health results in improved productivity throughout life;
- WHO recommends that greater equity in health be achieved;
- health and well-being are key components of sustainable development;
- public awareness of health impact of environmental activities is increasing;
health policy planning requires the experience of a multidisciplinary team based on the principle that “no one is essential but everyone is needed”;

environmental health impact assessment is an essential element of any cost–benefit investigation;

changes in environmental and social determinants of health will provide an incentive for the health sector to review the delivery of its services and improve performance and efficiency.

5.3 Preliminary environmental health impact assessment

In the case of aquifer recharge by means of recycled water, a cost–benefit analysis is particularly important because of the high costs involved in implementing recharge schemes, maintaining equipment and monitoring treatment facilities. Performing these operations without a proper environmental health impact assessment could create a considerable financial burden, without any guarantee of ultimate success.

A preliminary environmental health impact assessment is recommended as the first step during the initial evaluation of a new water option for water resource management. The goal is to assess all realistic policy options (e.g., natural recharge, artificial recharge, recharge by means of recycled water and desalination). The assessment must consider the potential health benefits as well as the health risks, to maximize benefits and reduce costs (especially those related to surveillance). Historical data can be particularly useful in this endeavour; examples of such data are incidence of water-related diseases in areas that use untreated water, or prejudice suffered in agricultural areas in times of water scarcity. An environmental health impact assessment should be approached from both a technical and an economical viewpoint, with a health impact assessment integrated as just one component in a broader appraisal.

The preliminary assessment should follow a staged approach, in line with the standard procedures for cost–benefit analysis (Pearce, 1983; Layard & Glaister, 1994; Layard & Misham, 1988) as shown in Figure 5.1.

Only the first two stages of the approach outlined in Figure 5.1 are discussed in detail here, because the aim of this chapter is limited to outlining basic principles of environmental health assessment, rather than detailed discussion of particular policy options.
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5.3.1 Outline policy goals

National and international regulations related to groundwater management have been formulated in a variety of forums, and have generally been well received by the international community. Often, however, the true front-line managers dealing with water resource management are municipalities, communities, farmers and manufacturers, in short, the hands-on users. The adequacy of groundwater management policies and procedures thus depends on these stakeholders, who are often also responsible for land-use planning and wastewater management.

Actual or future problems related to water resource management need to be defined when policy goals are outlined, taking into account scarcity or deterioration of quality of water destined for drinking, agriculture, industrial use or community purposes. Demand management is a common component of any policy dealing with water resources, but in setting policy, it is important to identify different options for management (e.g. artificial or natural recharge) before deciding on the final selection.

Groundwater resources supporting drinking-water production will be of primary concern in the definition of any water resource policy. This is particularly so if a potential threat of contamination by persistent pollutants exists, because such contamination could be effectively irreversible. In this case, a more complex environmental health assessment is required, and a higher financial risk must be taken.

Groundwater resources used to meet needs other than drinking-water production (such as industrial, irrigation or community uses) may have contamination levels that are deemed “acceptable” for the intended purpose. Quality standards for such uses have to be set by local authorities based on international guidelines. Monitoring of sites where pollution originates and of quality of the applied groundwater, should be instituted and maintained.

Potential causes of water stress or water quality deterioration are summarized in Table 5.2.

### Table 5.2 Potential causes of water stress and water quality deterioration

<table>
<thead>
<tr>
<th>Type of problem</th>
<th>Causes</th>
<th>Concerns</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anthropogenic pollution</td>
<td>Inadequate protection of vulnerable aquifers against human-made discharges and leachates from urban and/industrial activities and intensification of agricultural cultivation</td>
<td>Pathogens, NO₃, NH₄, Cl, SO₄, B, heavy metals, DOC aromatic and halogenated hydrocarbons</td>
</tr>
<tr>
<td>Excessive abstraction</td>
<td>Saline and/or polluted groundwater induced to flow into freshwater aquifer</td>
<td>Mainly Na and Cl but can also include persistent anthropogenic contaminants</td>
</tr>
<tr>
<td>Wellhead contamination</td>
<td>Inadequate well design and construction allowing direct ingress of polluted surface water or shallow groundwater</td>
<td>Mainly pathogens</td>
</tr>
<tr>
<td>Naturally occurring</td>
<td>Relate to pH–Eh evolution of groundwater and dissolution of minerals (aggravated by anthropogenic and/or excessive abstraction)</td>
<td>Mainly Fe and F, but sometimes As, Mn, Al, Mg, SO₄²⁻, Se and even NO₃⁻ from palaeorecharge</td>
</tr>
</tbody>
</table>

Even if water scarcity is not be a current problem, future demand, both in quantity and in quality, needs to be forecasted at this stage. Inclusion of data on population health is highly recommended, particularly data on mortality and morbidity suspected to be related to water scarcity, incidence of communicable disease caused by poor hygiene and contamination by pathogens. Information on
health determinants should also be included (e.g. industrial growth and evolution of markets for agricultural produce).

The most desirable data could conceivably result from a retrospective health impact assessment related to historical water scarcity and its impact on population health. Environment and health data collected at this stage will also be important in the next stages, particularly in cost–benefit evaluation. Basic environmental studies, including monitoring programmes, are necessary at this stage to assess the real water scarcity. Such studies should give special attention to the determination of the potential storage capacity and flow of aquifers.

More complex environmental studies may be required at a later stage to identify options, particularly regarding contamination of the resource. In extreme cases, contamination of an aquifer, especially by persistent pollutants, would preclude any recharge.

5.3.2 Identification of options

Site-specific environmental assessment of aquifers (including flow directions relevant to exposure assessment) is a prerequisite to evaluating options for recharge operations. In the case of extended aquifers, the environmental assessment should be regional. The assessment should preferably follow a basin approach as this will give a better understanding of the potential for sustainable implementation. Important aquifer characteristics to assess at this stage include:

- nature of aquifer storage;
- groundwater recharge processes and rates of recharge;
- vulnerability or impaired effectiveness of the subsoil in pollutant attenuation.

These characteristics are discussed in detail below.

**Nature of aquifer storage**

Characteristics of the aquifer to be considered in assessing the nature of aquifer storage include hydraulic properties such as permeability and storability, and reservoir volume properties such as effective thickness and geographical extent. This assessment will provide information about the aquifer’s capacity for autopurification or self-limitation of pollution. It will also help to verify whether aquifer recharge could be a useful part of groundwater demand management.

**Groundwater recharge processes and rates of recharge.**

Processes to be considered include direct recharge from land infiltration and indirect recharge from the beds of watercourses in the recharge area. This type of data is quite helpful for exploring links between recharge rates, land use and final water quality. Impaired recharge resulting from land use changes, anthropogenic contamination sources and other potential problems can be identified at this stage. Flow direction data are useful to identify pollution sources, and can be used in future exposure studies. Flow rates may form the basis for assessing the need for health surveillance on populations using water for agricultural irrigation or general community purposes. Information on groundwater recharge processes is also important for evaluating the possible advisability of actions aimed at improving natural recharge. Improving natural recharge can cost significantly less than implementing artificial recharge. Artificial recharge by injection will require extra energy for pumping, and the construction of new wells (unless the same well is used for recharge and abstraction). If the source of the recharge is recycled water and the final purpose is production of drinking-water, the cost of building, monitoring and managing facilities also needs to be taken into account.
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Vulnerability or impaired effectiveness of subsoil in pollutant attenuation

Assessing the vulnerability or impaired effectiveness of subsoil will require the assessment of subsoil profiles and the determination of hydrogeological characteristics. Subsoil attenuation for certain pollutants could help to reverse water contamination, thus allowing the aquifer to meet the requirements of the most prevalent water use. Aquifer recharge can only be attempted if natural defences are intact and appropriate land use zoning is implemented.

5.3.3 Integrating the results of the assessment

The environmental investigation outlined above is highly relevant for safeguarding population health. Toxicological studies undertaken at the start of the preliminary assessment will define the primary exposure pathway (e.g. drinking-water, agricultural produce or irrigation water). This information is particularly important in the case of chemical contamination, because it will allow a better definition and management of hazards to population health.

The integrated information resulting from this stage is also important in cases where recharge is considered in response to water scarcity. Preferred options should also be identified through this study. For example, if water scarcity is mainly due to climatic changes, improvement of natural aquifer recharge may be preferred over the construction of artificial basins in order to reduce loss by evapotranspiration at comparatively minimal cost. Alternatively, knowing that natural aquifer recharge can be quantitatively impaired by human land use such as construction of housing, deforestation and changes in river courses, environmental (including climatic) assessment will identify data and trends that are helpful for predicting potential benefits from new land use policies.

The study will also revisit current land-use policy. Implementation of appropriate zoning laws can result in the protection of the quality of the natural recharge, particularly against contamination by pathogens originating in, for example, cattle herding in the recharge zone.

5.4 Environmental health impact assessment

Environmental health impact assessment can be performed as a:

- prospective assessment of the proposed new policy to identify its likely impact;
- retrospective assessment of effects following policy implementation;
- concurrent assessment, where the policy is assessed at the same time as it is implemented, to identify the true nature of the impact in circumstances where the impacts have been anticipated but not characterized.

While a preliminary assessment needs to consider all determinants of health, once a project has been chosen, the focus will change to physical health, in particular:

- the potential health impact on the surrounding population — this will require hazard and exposure assessments;
- an assessment of the need, and a definition of the methodology, of epidemiological studies, to determine whether a link exists between health outcomes and water contamination;
- an assessment of the necessity to monitor environmental and health data (e.g. health surveillance to investigate any significant deviation from the baseline status leading to a risk factor identification).

Health professionals will contribute to the implementation of risk communication to stakeholders, and to the determination of (potential or actual) health costs that are supposed to be an integral part of the overall cost–benefit evaluation.
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5.4.1 Epidemiological studies

Environmental health impact assessments require also epidemiological studies. These are mostly observational studies, carried out along any of the following approaches:

**Cohort studies**

Cohort studies respond to the question: “What are the health effects of a given exposure?” The cohort study is an observational approach, which most closely resembles an experimental study. Exposed and unexposed populations or identified groups (e.g. vulnerable groups such as children or elderly persons) identified at one point in time are then followed to assess differences in health outcomes among them. In this study, the investigator controls neither the exposure conditions nor the attribution of exposures to the study object. As a result, risk factors to the health outcome are more likely to be unevenly distributed between the exposed and the unexposed groups, leading to differences in baseline risk. To moderate this comparability problem (characteristic of all observational studies), the investigator can only control unexposed groups. The technique may be used retrospectively when subjects have been identified and followed-up in the past, or may be used prospectively, in which case, a long-term and hence costly follow-up may be required.

The measure of the effect is described by:

- the risk ratio or relative risk (the proportion of exposed cohort developing the disease of interest, relative to the unexposed group); and
- incidence of mortality rate ratio (incidence rate of the outcome in the exposed group relative to the unexposed group).

**Case–control studies**

Case–control studies are used when there is a need to assess the contribution of environmental causes to a given disease. Also known as case–referent studies, they are the most commonly used environmental health investigation. Case–control studies differ substantially from cohort studies: investigators identify and select cases (i.e. subjects affected by the disease of interest), and controls (i.e subjects without the disease of interest). These groups are then followed backward to assess whether their respective past patterns of exposure differed before the cases actually developed the disease. A case–control study is not suitable for direct measurement of risk, because the sample of cases and controls is not proportional to the underlying population.

**Cross-sectional studies**

In a cross-sectional study, the prevalence of a particular disease, set of symptoms or other indication of ill-health is investigated at a single time-point (or over a relatively narrow period of time). Comparisons can then be made between the frequency of ill-health; for example, between workers exposed to a particular hazard and those not exposed. Alternatively, the study can compare workers suffering different degrees of exposure. A cross-sectional study can determine the prevalence rate, defined as the number of existing cases divided by the population at a given time point.

5.4.2 Health hazard and risk: assessing the potential health impact on the surrounding population through exposure assessment

A hazard is defined as the potential to cause harm, while a risk is defined as the likelihood that harm will indeed occur.

Aquifer recharge by recycled water may pose health hazards due to contaminants present in the treated wastewater, or in the water pumped from the recharged aquifer. Assessment of the health
hazards in water pumped from the aquifer against quality criteria for intended use (e.g. irrigation or drinking-water) could disclose health risks that may otherwise be hard to assess.

The quality of the recharged groundwater is not always strictly correlated to the quality of the recycled water being infiltrated or pumped into the aquifer. Results from the mixing of recycled water and water already present in the aquifer can be further modified by several physical, chemical and biological interactions between water and the subsoil; such interactions are often unpredictable.

The presence of contaminants in groundwater does not necessarily imply that recycled water used for recharge is contaminated. As stated earlier, groundwater can be contaminated from sources that are geographically far removed from the point of recharge or abstraction. This spatial problem is further compounded by the very slow and variable flow rates (from tens to hundred of years) characteristic of many aquifers, so that unequivocal identification of a pollution source affecting a given aquifer is difficult. The presence of a source of pollution outside the aquifer or the recycled water can easily be verified by simultaneously investigating the quality of both waters. If the presence of an external source of pollution is confirmed, it is wise to investigate recharge areas first, followed by other potential sources of groundwater contamination (e.g. waste dumping, irrigation practices, industrial discharge and uncontrolled animal husbandry).

Potential hazards to health may occasionally derive from naturally occurring chemical substances or biological pathogens, but more usually originates from an anthropogenic source. A list of significant pathogens that relate to contaminated water is suggested in Table 5.2.
### Table 5.3 Oral transmitted waterborne pathogens and their significance in water supplies

<table>
<thead>
<tr>
<th>Pathogen</th>
<th>Health significance</th>
<th>Persistence in water supplies</th>
<th>Resistance to chlorine</th>
<th>Relative infective dose</th>
<th>Important animal reservoir</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bacteria</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Campylobacter jejuni, E. coli</td>
<td>High</td>
<td>Moderate</td>
<td>Low</td>
<td>Moderate</td>
<td>Yes</td>
</tr>
<tr>
<td>Pathogenic E. coli</td>
<td>High</td>
<td>Moderate</td>
<td>Low</td>
<td>High</td>
<td>Yes</td>
</tr>
<tr>
<td>Salmonella typhi</td>
<td>High</td>
<td>Moderate</td>
<td>Low</td>
<td>High</td>
<td>No</td>
</tr>
<tr>
<td>Other Salmonella species</td>
<td>High</td>
<td>Long</td>
<td>Low</td>
<td>High</td>
<td>No</td>
</tr>
<tr>
<td>Shigella species</td>
<td>High</td>
<td>Short</td>
<td>Low</td>
<td>Moderate</td>
<td>No</td>
</tr>
<tr>
<td>Vibrio cholerae</td>
<td>High</td>
<td>Short</td>
<td>Low</td>
<td>High</td>
<td>No</td>
</tr>
<tr>
<td>Yersinia enterocolitica</td>
<td>High</td>
<td>Long</td>
<td>Low</td>
<td>High (?)</td>
<td>No</td>
</tr>
<tr>
<td>Pseudomonas aeruginosa*</td>
<td>Moderate</td>
<td>May multiply</td>
<td>Moderate</td>
<td>High (?)</td>
<td>No</td>
</tr>
<tr>
<td>Aeromonas species</td>
<td>Moderate</td>
<td>May multiply</td>
<td>Low</td>
<td>High (?)</td>
<td>No</td>
</tr>
<tr>
<td><strong>Viruses</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adenoviruses</td>
<td>High</td>
<td>?</td>
<td>Moderate</td>
<td>Low</td>
<td>No</td>
</tr>
<tr>
<td>Enteroviruses</td>
<td>High</td>
<td>Long</td>
<td>Moderate</td>
<td>Low</td>
<td>No</td>
</tr>
<tr>
<td>Hepatitis A</td>
<td>High</td>
<td>?</td>
<td>Moderate</td>
<td>Low</td>
<td>No</td>
</tr>
<tr>
<td>Enterically transmitted non-A, non-B, hepatitis E</td>
<td>High</td>
<td>?</td>
<td>?</td>
<td>Low</td>
<td>No</td>
</tr>
<tr>
<td>Norwalk virus</td>
<td>High</td>
<td>?</td>
<td>?</td>
<td>Low</td>
<td>No</td>
</tr>
<tr>
<td>Rotavirus</td>
<td>High</td>
<td>?</td>
<td>?</td>
<td>Moderate</td>
<td>No (?)</td>
</tr>
<tr>
<td>Small round viruses</td>
<td>Moderate</td>
<td>?</td>
<td>?</td>
<td>Low (?)</td>
<td>No</td>
</tr>
<tr>
<td><strong>Protozoa</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Entamoeba histolytica</td>
<td>High</td>
<td>Moderate</td>
<td>High</td>
<td>Low</td>
<td>No</td>
</tr>
<tr>
<td>Giardia intestinalis</td>
<td>High</td>
<td>Moderate</td>
<td>High</td>
<td>Low</td>
<td>Yes</td>
</tr>
<tr>
<td>Cryptosporidium parvum</td>
<td>High</td>
<td>Long</td>
<td>High</td>
<td>Low</td>
<td>Yes</td>
</tr>
<tr>
<td>Dracunculus medinensis</td>
<td>High</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Low</td>
<td>Yes</td>
</tr>
</tbody>
</table>

? — not known or uncertain

* Detection period for infective stage in water at 20°C: short = up to 1 week; moderate = 1 week to 1 month; long = over 1 month.

* When the infective stage is freely suspended in water treated at conventional doses and contact times. Resistance moderate implies that the agent may not be completely destroyed.

* Dose required to cause infection in 50% of health adult volunteers; may be as little as one infective unit for some viruses.

* From experiments with human volunteers (see Section X)

* Main route of infections is by skin contact, but can infect immunosuppressed or cancer patients orally


Some chemicals of considerable chemical stability and hence long-lasting environmental persistence, which could be present in groundwater, are listed in Table 5.4.
5 Impact assessment of aquifer recharge

Table 5.4 Chemical contaminants of concern that could be present in groundwater

<table>
<thead>
<tr>
<th>Contaminants</th>
<th>Media</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asbestos</td>
<td>Soil, groundwater, air</td>
</tr>
<tr>
<td>Chlorinated hydrocarbons</td>
<td>Soil, groundwater, air</td>
</tr>
<tr>
<td>Dioxins</td>
<td>Soil, groundwater, air</td>
</tr>
<tr>
<td>Metals</td>
<td>Soil, groundwater, air</td>
</tr>
<tr>
<td>Pathogens</td>
<td>Soil, groundwater, air</td>
</tr>
<tr>
<td>Total petroleum hydrocarbons</td>
<td>Soil, groundwater, air</td>
</tr>
<tr>
<td>Pesticides</td>
<td>Soil, groundwater</td>
</tr>
<tr>
<td>Pharmaceuticals</td>
<td>Soil, groundwater</td>
</tr>
<tr>
<td>Polychlorinated biphenyls</td>
<td>Soil</td>
</tr>
</tbody>
</table>

Both microbial and chemical potential health hazards need to be reviewed to guide health surveillance and epidemiological studies. Pathogens generally offer a simple cause–effect relationship. The issue becomes more complex in the case of chemical contamination where the individual health outcome is the result of multifactorial effects, involving interplay of genetic, lifestyle, occupational and environmental factors. The long latency of many diseases further complicates the issue. Toxicological characteristics of potential hazards need to be investigated from recent scientific data; many international organizations currently make such information available online. Some health effects from persistent chemical contaminants are summarized in Table 5.5.

Table 5.5 Health effects from persistent chemical contaminants

<table>
<thead>
<tr>
<th>Health effect</th>
<th>Sensitive group</th>
<th>Some associated chemicals(^a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cancer</td>
<td>All</td>
<td>Asbestos, PAHs, benzene, dioxins, some metals, some pesticides, carcinogens, some solvents and natural toxins</td>
</tr>
<tr>
<td>Cardiovascular diseases</td>
<td>Especially elderly</td>
<td>Carbon monoxide arsenic, lead, cadmium, cobalt, calcium and magnesium</td>
</tr>
<tr>
<td>Respiratory diseases</td>
<td>Children, especially asthmatics</td>
<td>Inhalable particles, sulfur dioxide, nitrogen dioxide, ozone, hydrocarbons, some solvents, terpenes</td>
</tr>
<tr>
<td>Allergies and hypersensitivities</td>
<td>All, especially children</td>
<td>Particles, ozone, nickel, chromium</td>
</tr>
<tr>
<td>Reproduction</td>
<td>Adults of reproductive age</td>
<td>PCBs, DDT, phthalates</td>
</tr>
<tr>
<td>Developmental</td>
<td>Fetuses, children</td>
<td>Lead, mercury, other endocrine disruptors</td>
</tr>
<tr>
<td>Nervous system disorders</td>
<td>Fetuses, children</td>
<td>PCBs, methyl mercury, lead, manganese, aluminium, organic solvents</td>
</tr>
</tbody>
</table>

\(DDT = \text{dichlorodiphenyltrichloroethane}; \ PAHs = \text{polycyclic aromatic hydrocarbons}; \ PCBs = \text{polychlorinated biphenyls}\)

\(a\) Examples only:


Human exposure to hazardous substances requires a complete exposure pathway. Defining such a pathway requires the identification of the source, pathway, point of exposure, exposure routes and receptors.
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Source
The source is the origin of the contaminants. Sources can be either localized (point source) or spread over a wide geographical area (diffuse source).

Pathway
A pathway can be defined as an existing or potential physical link between sources and receptors. Such a link can be direct, when the source is in direct contact with the receptor, or indirect, when the contaminant is transported from the source to the receptor through environmental media. Surface water, air, soil, subsoil and sediments can all be considered as environmental media that can carry contaminants to aquifers and hence form part of a pathway.

Point of exposure
The point of exposure is the location of potential or actual human contact with contaminated environmental media. Typical examples include drinking-water, irrigating wells and food grown through irrigation using recharged groundwater, especially when the food is eaten raw. An often-overlooked aspect of exposure is the biological availability of potentially harmful chemicals through the food-chain. Hunting, fishing, foraging and farming activities may bring people into contact with such contaminants. When contamination of edible plants or animals is suspected, specific data obtained through sampling and biota studies are needed to evaluate any potential exposure pathway through the food-chain. Diffusion of contaminants to plants or animals can be evaluated referring to toxicological and ecotoxicological data. The latter will give information on the length of contamination (because biological organisms act as bioaccumulators of contaminants) and the capacity of the environment to react to contamination-induced stressors. An initial approach towards the investigation of water sources is shown in Table 5.6.

Table 5.6 Collecting samples and environmental data and information of concern for investigation of water sources

| Well survey: | well survey and inventory within the potential affected area, whichever is greater; |
| | an inventory of larger area downgradient of any known groundwater plumes, depending on site-specific hydrogeology and the extent of contamination; |
| | the well inventory should include the number, total depth, screen interval, use, yield, status, installation date, pump type and age, and location of all local wells and developed springs |
| Water sources: | monitoring wells; |
| | facilities water supply wells; |
| | municipal/utilities wells, springs and reservoirs; |
| | residential wells or springs or small. |
| Hydrogeology: | depth, thickness, extent, name and characteristics (including flow direction) of all groundwaters potentially affected by contaminations; |
| | depth, thickness, extent, name and characteristics (including flow direction) of all drinking-water aquifers; |
| | vertical and lateral extent of groundwater contamination. |

Adapted from ATSDR (1977).
Exposure routes

Although ingestion is the prevailing exposure route for drinking-water produced from recharged aquifers, dermal absorption and skin contact can also be considered. However, information on residence time is often lacking, which can compromise exposure assessment. In assessing exposure, the choice of the measurement methodology is very important. Duration, intensity and frequency of exposure all contribute to the calculation of the cumulative exposure. It may be important to evaluate intermittent or peak exposure as well as the mean exposure time. The period of exposure and the latency time must also be considered, depending on the particular health outcome of interest. Exposure is generally poorly characterized in past epidemiological studies. This makes it difficult to establish an unequivocal causal relationship between chemical contamination and health outcome.

Receptors

Receptors are organisms or environmental media that are exposed to the contamination. In the context of this chapter, the human population is the final receptor. Identification of receptors (e.g. workers, consumers and residents) is the last step in an exposure assessment. Population data must include vulnerable groups of interest such as children and elderly people). An exposure assessment needs to be undertaken on the smallest geographical distribution. This may help to determine whether health hazards affect predominantly certain groups or geographical areas.

5.4.3 Health impact assessment: suggested working procedures

Baseline data concerning population and health outcome may be collected from a variety of sources. In gathering population baseline data, care needs to be taken to avoid or correct the common problem of residence misclassification. The data obtained are generally useful not only for the initial study but also for future epidemiological work.

Health outcome databases will provide information on health conditions that may prevail in the area under investigation. Mortality rate databases address causes of death (e.g. cancer, infectious diseases and poisoning). Morbidity rates are of interest for health surveillance purposes for the identification of significant deviations from the baseline status. Unfortunately, health databases are often not recorded in a homogeneous way, and their usefulness is often limited to monitoring the frequency of events rather than estimating a disease rate. Therefore, in addition to baseline data on mortality and disease incidence rate, a cross-sectoral health survey of a random sample of the population may be useful to provide information on the prevalence and frequency of general health conditions and lifestyles.

Once baseline data are available, prospective studies can be performed to define any potential association between exposure and health outcome. A cohort study is not the first option for any health impact assessment because of the time and cost involved. Rather, health and environmental monitoring are recommended, followed (eventually) by case–control studies with detailed residential information.

Health surveillance is a routine system of capturing cases that have been recorded by existing health services. The analysis of the resulting data should indicate whether there has been a significant increase in the recorded number of cases of the health impact of interest.

Health services may be provided with specific tools for the purposes of the study. For example, in monitoring studies, databases referenced to a geographical information system (GIS) can be useful in integrating fragmented information from data sources; it also allows the detection of links between pollution sources and the location of particular health outcomes. Further integration of such information on a geographical map with other relevant data such as the geological characteristics, flow direction and extent of the aquifer can be helpful. Such data compilation will
be useful in the (quite difficult) investigation and interpretation of environmental factors and health outcome.

Timing of follow-up studies for health surveillance depends on the latency time of the health outcome of interest. In the case of chemical contaminants, scheduling should take into account cumulative impacts.

Case–control studies are used when a significant deviation from the baseline has been registered during the monitoring phase. The limits of this study design and its relevance for the topic at hand are described above (Section 5.4.1). Data collected during the initial phases of a health impact assessment, such as baseline assessment and monitoring of health surveillance, may speed up a case–control study; however, the long latency of certain impacts will require a long observation time. Uncertainties in the assessment of risk factors, especially in cases of multiple exposures, make results difficult to interpret unequivocally. Thus, case–control studies are best used only in particular cases; for example, when teratogenic contaminants or microbial pathogens are present.

Further epidemiological investigations are recommended only when characterization of environment and populations, exposure pathways, environmental monitoring or exposure estimations have indicated that a completed exposure pathway is likely to exist, and when a health impact assessment has revealed a real deviation from the baseline.

5.5 Conclusions

Health impact assessment of aquifer recharge by recycled water needs to be considered in the overall context of groundwater management. Health impact assessment is recommended both in the preliminary assessment (when different technical options for aquifer recharge are being evaluated) and in the characterization of exposure to potential pathogens. Prospective data collection, possibly using GIS, environmental mapping of the baseline situation and health surveillance are strongly recommended.

Health professionals face a new challenge in assessing risks and health impacts by persistent chemical contaminants, whose health outcome often encompasses a wide range of causative factors. Improving health professionals’ knowledge and creating mechanisms to enable daily cooperation with multidisciplinary teams will be neccessary in the future.

5.6 References


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WHO/IPCS (International Programme Chemical Safety) www.who.int/pcs/index.htm