Management priorities for protecting groundwater will vary widely between settings. Once the pollution potential has been assessed for a given catchment (as discussed in Chapter 14), the priorities for management will depend on the public health burden this pollution is expected to cause currently and in the future. This will determine the urgency with which preventative or rehabilitating management responses are needed.

Management responses will also vary widely, as the feasibility of technically appropriate interventions will depend on the social and economic context in each setting. Also, choices can often be made among a range of responses to a problem, and participatory approaches are likely to lead to different decisions by different communities.

Situation analysis and management decisions for a groundwater catchment need to be based on sound information and on a clear, well-documented decision-making process. Uncertainties and gaps in the information base need to be transparent. This chapter discusses criteria for determining management interventions in relation to their urgency for protecting public health, and in relation to their feasibility for a given catchment.
15.1 ENSURING THE SUITABILITY OF INFORMATION

Establishing a well-documented inventory of all of the available information for a proposed groundwater management area is usually the first step in assessing the pollution risks if groundwater is used as a source of drinking-water. Such an inventory forms the basis of decisions about how potential water quality health risks will be managed. Chapter 6 and the checklists at the ends of Chapters 7-13 provide guidance on what type of information might be included in such a catchment inventory.

Decisions about managing risks to human health usually require the following factors to be addressed to be effective and sustainable (adapted from US Congress Commission, 1997).

- **The decision making process is iterative** – in general, health-risk management decisions need to be periodically reviewed as further information becomes available. An iterative approach helps ensure that management strategies remain up to date with new scientific findings, technological developments, and with national or international best practices.
- **Decision making is participatory** – broad participation with a range of interested or affected parties improves the quality and diversity of opinions that inform the decision-making process. Participation also increases the likelihood that risk management decisions will be accepted and implemented by the relevant parties.
- **Decision making is well-informed** – risk management decisions generally need to be based on information from a variety of sources and on different types of information. Information used may include scientific data, anecdotal records, information about regulatory requirements and socioeconomic information for the region.
- **Decision making is contextual** – management decisions must be appropriate to the social and economic realities of the specific region. Simply adopting practices developed in other parts of the world where there are differences in the level of expertise or available resources to implement management decisions generally does not work. Management practices developed locally are more likely to be sustainable.
- **Decision making is holistic** – focusing management decisions on only one issue may not lead to better health outcomes for communities in the longer term. In general, protecting and managing drinking-water quality should be seen in the context of being one item in a package of measures to protect the health of communities.

Ensuring that information gathered addresses the above factors generally helps prevent many of the pitfalls that often affect decisions made about how drinking-water supplies are managed, particularly the following two:

- crucial information gaps lead to poorly informed decisions which cause resources to be wasted on ineffective measures or even lead to health problems as illustrated in Box 15.1;
- decisions on measures urgently needed to improve public health are sometimes not taken or are unduly postponed because information gaps are used as an excuse for not allocating resources to the measures.
Establishing groundwater management priorities

Box 15.1 Cholera Epidemic in Peru in 1991

Andersen (1991) reports that during the 1980s a decision by local water officials to stop chlorinating water pumped from many of the wells in Lima, Peru contributed to more than 300,000 cases of cholera and over 3500 fatalities. The reason given for the decision against disinfection was the perception of a cancer threat from chlorination by-products.

Studies indicating a small statistical lifetime risk of cancer from trihalomethanes and other chlorination by-products were interpreted as demonstrating a more significant health risk than the threat from waterborne pathogens. It is possible that the scale of the epidemic could have been greatly reduced had all of the information about the respective health risks of waterborne pathogens and chlorination by-products been available and understood by the relevant decision makers, and had the relative risk been assessed.

In general, there will always be gaps in the information gathered, and management decisions will often have to be made based on some degree of uncertainty. However, if there are potentially significant risks to human health, the lack of information should not be used as an excuse to delay reasonable and cost effective measures to protect health. If concerns are substantial although the risk level is uncertain, consideration should be given to short-term measures that can be implemented to protect health. This may involve temporary provision of an alternative drinking-water source until the information gaps have been sufficiently closed and the supply demonstrated to be safe, or appropriate control measures have been implemented. In some cases both risks and potential management measures may be self-evident. These generally relate to elements of good environmental practice which can be implemented without the requirement for a detailed pollution potential assessment.

Detecting information gaps during the situation analysis is an iterative process which feeds back into improving the quality of the available information, and helps ensure the inventory is relevant to the local region and water supply. Although obtaining additional information generally requires more investment, it is important to recognize that this effort is usually fairly minor in relation to the resources that may be required to implement some engineered management measures. The additional information may also be important in determining the most cost-effective solution. It is often crucial to be able to convince those responsible for financing management decisions such as funding bodies, government, or donor agencies, to fund such investigations before beginning an activity. This may be facilitated through ongoing consultation with these bodies, and by ensuring that both the information inventory and the criteria used in assessing its value as a basis for selecting management options are well documented and supported by the water consumers.
15.2 PRIORITIZING POLLUTANTS IN GROUNDWATER WITH RESPECT TO URGENCY OF MANAGEMENT RESPONSES

In supply settings where polluted groundwater may affect drinking-water quality, adequate management responses for the protection of public health are required. The determination of their urgency involves a site specific prioritization of individual pollutants in relation to their sources (e.g. polluting activities) on the basis of the following two aspects:

- the extent of the existing groundwater pollution level (e.g. from monitoring data), or the current or predicted groundwater pollution potential of a contaminant in a given setting (as defined in Chapter 14);
- the public health burden, i.e. severity and extent of health consequences.

Management responses for contaminants with the greatest public health burden and the highest pollution level or potential should receive higher priority than those whose health impacts are mild or whose occurrence in groundwater is unlikely. This prioritization approach is conceptually depicted in Figure 15.1.

**Figure 15.1.** Urgency of management responses required to protect public health
The scheme in Figure 15.1 is similar to other risk ranking matrixes commonly used for relating the consequence (e.g. severity and extent) of impacts to the likelihood of an event occurring (WHO, 2004; SGWA, 1998; Deere et al., 2001; MOH NZ, 2001). However, it is different with respect to the role of events causing groundwater pollution: while in general reviewing the likelihood of hazardous events is of crucial importance for risk assessment, groundwater pollution tends to be a more continuous process, e.g. from leaky sewers, poorly sited or designed latrines, waste disposal sites or agricultural activities. Although a pollution event may suddenly occur on the soil surface (e.g. through a tank truck accident or a farmer applying manure), occurrence in the aquifer is often more continuous, and the time pattern with which the pollutant may appear in the aquifer depends on hydraulic loading (i.e. rainfall patterns) as well as on aquifer vulnerability. Nitrate is an example that highlights how discrete contamination events on the surface may lead to continuous contamination of the aquifer.

The pollution potential, as defined in Chapter 14, encompasses both aquifer vulnerability and pollutant loading (in terms of pollutant load and hydraulic load) and thus already includes an assessment of the probability that polluting events on the soil surface result in groundwater contamination. Therefore, for determining the urgency of rehabilitating or preventative management responses, the scale in Figure 15.1 is not event likelihood, but rather pollution potential in terms of the probability of groundwater pollution occurring.

Tables 15.1 and 15.2 give an example of a simple prioritization matrix which applies the general concept of Figure 15.1. The classification scales in Tables 15.1 and 15.2 are based on a qualitative ranking rather than having quantitative values. This reflects the uncertainty of estimating pollution potential and public health burden. Such a ranking scheme therefore has a relative nature: the aim is not a quantification of risk in absolute terms, but to identify the management responses that need to be most urgently addressed.

The approach shown in Figure 15.1 as well as in Tables 15.1 and 15.2 can in principle be expanded to a quantitative or semi-quantitative assessment by reducing uncertainty through improving the knowledge base. For the pollution potential, this would require analyses of the range of contaminants in the groundwater on a regular basis as well as monitoring or modelling of peak concentrations during events and changes over extended time spans to identify trends in order to calculate the dose the population would receive from drinking-water. For the public health burden, the categories for the size of the population affected and the severity of the effect would be calculated and expressed by the concept of Disability Affected Life Years (DALY) as a common public health unit which summarizes all health outcomes caused by a certain disease agent (i.e. chemical or pathogen) and provides an estimate of the burden of disease of this agent (Havelaar and Melse, 2003; WHO, 2004).

For most settings, however, the management of groundwater resources will be substantially improved by a simple approach of setting priorities based on a relative ranking of the urgency of issues as discussed above. Guidance for estimating the pollution potential is provided in some detail in Chapter 14 and in Section II of this monograph. Specifically for chemicals, Thompson et al. (in prep.) also provide guidance on deriving priorities for management from the use of chemicals and the conditions in
the catchment. The following will briefly address some general aspects of ranking the public health burden of contaminants which frequently occur in groundwater.

Table 15.1. Simple prioritization scheme: consequence and probability scales (adapted from WHO, 2004; MOH NZ, 2001)

<table>
<thead>
<tr>
<th>Public health burden (consequence scale)</th>
<th>Description</th>
<th>Position on Y-axis in Figure 15.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insignificant</td>
<td>Insignificant</td>
<td>Low</td>
</tr>
<tr>
<td>Minor</td>
<td>Minor impact for a small population</td>
<td></td>
</tr>
<tr>
<td>Moderate</td>
<td>Minor impact for a big population</td>
<td></td>
</tr>
<tr>
<td>Major</td>
<td>Major impact (potentially lethal) for a small population</td>
<td></td>
</tr>
<tr>
<td>Catastrophic</td>
<td>Major impact (potentially lethal) for a big population</td>
<td>High</td>
</tr>
</tbody>
</table>

Scale for assessing the probability of groundwater pollution occurring

<table>
<thead>
<tr>
<th>Pollution potential (probability scale)</th>
<th>Description</th>
<th>Position on X-axis in Figure 15.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insignificant</td>
<td>Well protected aquifer and insignificant pollutant/hydraulic load</td>
<td>Low</td>
</tr>
<tr>
<td>Low</td>
<td>Low aquifer vulnerability and minor pollutant/hydraulic load</td>
<td></td>
</tr>
<tr>
<td>Moderate</td>
<td>Low aquifer vulnerability and significant pollutant/hydraulic load</td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>High aquifer vulnerability and significant pollutant/hydraulic load</td>
<td></td>
</tr>
<tr>
<td>Very high</td>
<td>High aquifer vulnerability and substantial pollutant/hydraulic load</td>
<td>High</td>
</tr>
</tbody>
</table>

Table 15.2. Simple prioritization scheme: ranking matrix for determining the urgency of management responses (adapted from WHO, 2004; MOH NZ, 2001)

<table>
<thead>
<tr>
<th>Pollution potential (probability)</th>
<th>Insignificant</th>
<th>Public health burden (consequence)</th>
<th>Major</th>
<th>Moderate</th>
<th>Minor</th>
<th>Catastrophic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very high</td>
<td>High</td>
<td>Extreme</td>
<td>Extreme</td>
<td>Extreme</td>
<td>Extreme</td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>Moderate</td>
<td>High</td>
<td>High</td>
<td>Extreme</td>
<td>Extreme</td>
<td></td>
</tr>
<tr>
<td>Moderate</td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
<td>Extreme</td>
<td>Extreme</td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
<td>Extreme</td>
<td></td>
</tr>
<tr>
<td>Insignificant</td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td></td>
</tr>
</tbody>
</table>
Ranking of contaminants according to their public health burden

Ranking microbial and chemical contaminants in groundwater in terms of their public health burden depends to a large extent on site-specific factors, and it is not possible to develop an absolute ranking scale that will fit all cases. However, as a general rule the importance of contaminants in groundwater can be ranked in the following decreasing order:

- waterborne pathogens (Chapter 3);
- naturally occurring groundwater constituents such as fluoride and arsenic (Chapter 4.1);
- nitrate (Chapter 4.2);
- industrial chemicals such as chlorinated or aromatic hydrocarbons (Chapter 4.3), pesticides (Chapter 4.4) or metals (Chapter 4.5);
- pharmaceuticals and endocrine disruptors (Chapter 4.6).

This ranking is indicative only but is typical of both the observed occurrence of contaminants in groundwater and the severity of the health burden that they cause. It can be used as a preliminary ranking if no other site-specific information is available.

Waterborne pathogens pose a much greater immediate threat to public health than chemical contaminants and are generally considered to have the highest priority for a management response before chemical contamination issues are considered. In situations where the pollution potential for pathogens is also considered to be high, the implementation of management measures is considered to be extremely urgent (Figure 15.1). Conversely, in situations where the pollution potential is considered to be low (for instance, due to the fact that groundwater is being pumped from a well-constructed deep tubewell in a porous medium aquifer), a management response will be considered to be much less urgent, and addressing other contaminants, such as some accumulating chemical contaminants, might have a higher priority.

As discussed in Chapter 4, fluoride and arsenic in groundwater supplies may have significant effects on public health. These contaminants are generally of natural origin, and in many situations their concentration is low in groundwater. Their presence in health-relevant concentrations in a given groundwater supply depends on local geological factors and on specific hydrochemical conditions (Chapter 8) being present in the aquifer to allow these chemicals to be mobilized from sediments or bedrock into groundwater. Therefore it is essential to specifically address the possible presence of natural groundwater constituents in the catchment-specific situation analysis. This should include undertaking specific sampling and chemical analysis for these constituents, and obtaining information about the local geological conditions to determine whether there is a risk of land use or groundwater pumping increasing the concentrations of fluoride or arsenic in groundwater. This information will help determine where these chemical constituents should plot on the matrix in Figure 15.1.

In some situations, nitrate is of concern to public health because of potential health effects on bottle-fed infants (i.e. methHb, particularly in the presence of simultaneous microbial contamination; see Chapter 4.3), the large inputs of this chemical to groundwater in areas with intensive agriculture and/or on-site wastewater disposal, and its tendency to accumulate in aquifers. The potential health consequences of nitrate contamination will vary depending on the size of the population exposed (which in turn
strongly depends on social factors, i.e. prevalence of breast feeding and parental knowledge) and this will affect where this contaminant will plot on the scheme in Figure 15.1.

With the exception of localized major point sources of contamination, exposure to chemical contaminants such as heavy metals, organic pollutants (e.g. chlorinated or aromatic hydrocarbons), and pesticides through drinking-water is usually a less immediate threat to public health. One aspect is that the major exposure pathways to these substances are usually air pollution and food rather than drinking-water (WHO, 2004). For protecting public health, management of these greater sources of contamination might be more urgent than addressing their occurrence in water. Although implementing management measures to deal with these contaminants is usually less urgent for most groundwater supplies, there may be circumstances in which a situation assessment may indicate the probable presence of very high concentrations in groundwater due to local contamination, raising the management priority of one or more of these chemicals.

Pharmaceuticals, endocrine disruptors and most pesticides rarely occur in groundwater in concentrations that have been shown to be hazardous to human health. In most cases the ranking following Figure 15.1 will therefore result in a rather low urgency for management response. However, in many societies there is increasing concern over traces of pharmaceuticals and pesticides found in groundwater used as drinking-water sources. Such issues may be addressed in the priority setting matrix by including other criteria, such as public perception and value judgements, in addition to public health burden. Where public concern over pharmaceuticals or pesticides makes the headlines, management measures may indeed be ranked as urgent. However, scientifically substantiated assessment of the public health impact will always need to be the most important criterion for setting priorities and for defining the urgency of management responses in order that resources are not diverted from more pressing public health problems.

In summary, the simple ranking scheme presented in Figure 15.1 and in Tables 15.1 and 15.2 is based on the relative likely health burden caused by a number of contaminants, and not their absolute magnitude, and thus simply indicates management priorities. Waterborne pathogens may cause immediate illness and their presence in water requires an urgent management response either in the catchment or at the water supplier’s operational level (i.e. treatment). Chemical contaminants usually require long-term exposure to cause health effects. Consequently, management measures for chemicals are of less urgency in most circumstances and measures may be delayed until management responses for the control of pathogen contamination have been implemented.

Assessment of persistent contaminants
Unlike waterborne pathogens, which survive in groundwater for a limited period of time (Chapter 3), some chemical contaminants may persist in groundwater over a long period of time, with little or no attenuation. In situations where there is a continuing source of chemical contamination and the loading rate at which the chemical is leached into groundwater is greater than the rate at which the contaminant is removed by physical,
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chemical or biological processes in the aquifer, concentrations of the contaminant in groundwater may progressively accumulate with time.

The most common example of this behaviour is nitrate contamination in groundwater in regions where intensive agriculture is poorly managed. Nitrate concentrations in groundwater in these regions often continue to increase over many decades if appropriate land use management practices are not implemented. Accumulation has also been observed for various industrial chemicals (e.g. chlorinated solvents) and some pesticides (e.g. atrazine).

For such contaminants rehabilitation of groundwater quality is typically difficult and costly, and interventions may be needed before concentrations reach health-relevant levels. The process of prioritizing management responses therefore needs to address the issue of contaminant accumulation by estimating trends or using a prediction of the contaminant concentration in groundwater at some future time if no management action is taken to stop or reduce the polluting activity or practice. An outcome of such an assessment would be to indicate whether the contaminant could become an urgent management priority unless the source of contamination were to be removed or the loading rate greatly reduced. Such an assessment could be used to help set priorities for progressively changing land use within a catchment area to protect groundwater quality in the longer term or to introduce changes such as appropriate chemical handling practices in small or large industries.

Specific advice on predicting long-term nitrate concentrations in groundwater in urban and periurban environments where there is limited information can be found in Lerner (2000) and ARGOSS (2001).

15.3 SELECTION OF MANAGEMENT OPTIONS

The last step in the situation analysis for a groundwater supply is to select possible management options that are appropriate for the magnitude of the health risk posed by a specific contaminant. The range of possible measures for protecting groundwater from becoming polluted through human activities is discussed in some detail in Sections IV and V of this monograph.

Once the urgency of an intervention to protect public health has been determined, apart from the technical adequacy of the measure, selecting effective management options also needs to consider the following aspects:

- delayed response time between management interventions (i.e. removing the contaminant source) and measurable reduction of aquifer pollution;
- barriers in place in addition to groundwater protection (e.g. treatment);
- socioeconomic feasibility of management responses.

Aquifer response time

Aquifers tend to respond only slowly to changes in contaminant loading due to retention processes such as adsorption and desorption to soil particles (see Chapter 4). Moreover, due to slow flow rates and long retention times of water in many aquifers, elevated contaminant concentrations may remain present for many years. This effect has particularly been shown for contamination with chemicals such as nitrate or some...
pesticides (e.g. atrazine). For example, the response time between successfully implemented measures targeting the reduction of nitrogen loading from agriculture in the catchment area and measurable reduction of nitrate concentration in groundwater can range between a few years and several decades (Behrendt et al., 2000).

In situations where groundwater used for drinking-water supply is contaminated and where the implementation of management measures is assessed as urgent for protecting public health, the delay in response needs to be taken into consideration. As discussed below, measures in addition to those protecting or rehabilitating the aquifer from polluting activities might be needed (e.g. water treatment, change of source) in order to provide safe drinking-water.

The delay in response is an inherent property of the groundwater system that cannot be changed by any management measure. It is therefore important to recognize that control measures for reducing chemical contamination (e.g. nitrate, pesticides) in groundwater are likely to show results in the long term only and that short-term ‘success stories’ are rarely achievable. When planning and implementing management actions, this issue needs to be adequately communicated both to communities using the resource for drinking-water supply and to funding agencies and politicians in order to avoid misplaced expectations and disappointment that may impair the political or financial support.

Multiple barriers
Wherever possible during the process of selecting management options, it is important not to select just one measure and rely on it for the long-term protection of public health. In particular, relying on water treatment alone to prevent health problems from contaminated groundwater may be a high-risk management strategy for some contaminants, particularly microbial contaminants. This could have significant public health consequences if the treatment system fails or mistakes are made by the operators of the system and water treatment is ineffective (O’Connor, 2002).

As depicted in Figure 15.2, risks to public health can generally be minimized when a group of complementary management measures are implemented together to ensure that there are several barriers in place between a potential source of contamination and a water consumer, particularly when the contaminant can have a major impact on health. The presence of several barriers means that the overall water supply is protected from a system failure or human error at any one point in the system because there are backup protection measures, and thus the water supply becomes a fail-safe system. This multi-barrier principle is one of the basic principles of drinking-water hygiene (WHO, 2004).

Typical barriers in groundwater supplies include:

- management practices in the catchment area to reduce contaminant inputs from human activities into groundwater (see Chapters 21-25);
- source-water protection through control of land use in protection zones (see Chapter 17);
- adequate design, construction and maintenance of water supply wells (see Chapter 18);
- treatment of pumped groundwater (LeChevalier and Au, 2004);
- ensuring adequate disinfection residual in the water distribution system;
- protection and maintenance of the distribution system (Ainsworth, 2004).
Figure 15.2. Reducing health risks by using multiple barriers to protect a water supply (adapted from Hrudey, 2001)

The extent to which these barriers are needed will depend on an assessment of the possible health outcomes of contaminants, the size of the population relying on the water supply, the resources available for management, and an assessment of the costs of implementing management practices against the possible benefits in the specific situation.

Many low-income countries lack the resources or expertise to implement a broad range of groundwater protection measures, and in some countries it can be difficult to convince key political decision makers of the importance of groundwater protection for long-term water safety. In such situations water treatment or the provision of another source of water are important immediate health protection measures.

**Socioeconomic feasibility**

Groundwater protection measures do not have to be expensive, and small incremental changes over a period of time can greatly improve the quality of groundwater or avoid degradation of quality. Even simple inexpensive measures such as ensuring that defecation is not carried out within 10 m of a water supply well and ensuring that surface run-off is diverted away from the well will significantly reduce public health risks from such a water supply (ARGOSS, 2001; Howard *et al.*, 2003). Other groundwater
Protection measures will require investments, e.g. constructing latrines, improving seals on wellheads or improving drainage of roads. Funding for these may or may not be available. Designating protection zones in the immediate vicinity of a wellhead or extended further into the aquifer’s catchment may be inexpensive to the authority doing so, but – as discussed in Chapter 5 – can disrupt the livelihoods of inhabitants of the land above the aquifer or can have substantial economic consequences for them. In some settings, though interventions may appear appropriate in theory, institutional capacity is too weak to implement them.

Unless a catchment is largely uninhabited and unused by humans, the aquifer protection measures introduced in Sections IV and V of this monograph will often intervene in the way people are currently doing things, and will work only if the stakeholders in the catchment are willing to make changes. This pertains to land use in general, but also to practices, e.g. in agriculture, sanitation or handling and storing hazardous chemicals. Therefore, while for a given setting the urgency of mitigating or preventing groundwater contamination is determined from an assessment of pollution potential and public health burden (Section 15.2), selecting appropriate management measures requires a further step, i.e. assessing their feasibility in the specific setting. Feasibility depends on a variety of factors, such as cultural values, public perception, education, land tenure rights, socioeconomic status, legal requirements and institutional capacities (see Chapters 5 and 20). These factors need to be evaluated in relation to the management responses envisaged. The result of such an evaluation may be that socioeconomic measures are a crucial part of the management package, equally or even more important than the actual technical measures to protect the aquifer.

As discussed in some detail in Chapter 5, public communication and consultation is not only an important tool for assessing the potential of aquifer pollution and the feasibility of measures suggested by scientists and engineers. Beyond this, participation of the population affected by groundwater protection measures is key to developing approaches that will be supported locally and can therefore be implemented more readily. Where people’s livelihoods are positively affected by a protection measure, rather than the measure being perceived as only having a negative impact, particularly in the short term, interventions are more likely to be accepted and maintained. It is important to communicate that increasing costs arise not only from the protection of the resource, but also from its deterioration. In this context, there may be conflicting interests between different stakeholders in the catchment. For example, abandoning a resource and piping in water from a more distant one in order to be able to continue a polluting activity may be in the interest of some, but others who could not afford a more expensive supply would prefer protection. The planning of groundwater protection measures will need to consider how the needs of all stakeholders can best be incorporated into the policy, and how costs can be minimized while maximizing protection.

Figure 15.3 conceptually depicts that both urgency of an intervention and the feasibility in a given setting will determine which type of management action can be taken. Management responses to technically similar problems may be very different between settings, depending on what is locally feasible.
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Figure 15.3. Selection of management responses in relation to their urgency and feasibility

The upper right-hand corner of Figure 15.3 shows that where urgent groundwater protection measures are assessed to be feasible, the key management action is their rapid implementation. Additional short-term measures at the point of consumption (e.g. treatment) may be necessary until the groundwater quality shows a response to the protection measure (see example settings A and C in Table 15.3). Where interventions are urgent, but it is not feasible to improve groundwater in the medium term (bottom right-hand corner of Figure 15.3), the primary response to protect public health will be management actions other than groundwater protection, as safe groundwater is not likely to become available in the short term (see example setting B in Table 15.3). However, these tend to involve either use of a more distant source or treatment, both of which are costly. In settings in which an aquifer can still be rehabilitated, an extended process of community consultation and discussion may therefore lead to additional action for groundwater protection or remediation in the longer term. As discussed in Chapter 5, feasibility may be increased by socioeconomic measures such as compensation payments for restrictions on land use, but also by e.g. improving tenure rights to make protection attractive in the longer term.

A different group of situations are those in which management responses against contamination are assessed to be less urgent (see Chapter 15.1). If feasibility is also low (e.g. for protecting an aquifer from low levels of pesticides), no action would be taken other than improving risk communication to the public if there is a concern (bottom left-hand corner of Figure 15.3). However, where measures to prevent such pollution are feasible (upper left-hand corner of Figure 15.3; see example setting E in Table 15.3),
implementing such measures would be appropriate. Such a decision would follow the precautionary principle. Precautionary action is likely to be more feasible in settings in which the public perception values the resource and clean water is a widely accepted goal, and particularly where the overall public health and socioeconomic conditions enable such a priority to be set.

Table 15.3. Examples for the selection of management responses in relation to their urgency and feasibility

<table>
<thead>
<tr>
<th>Groundwater pollution problem</th>
<th>Urgency</th>
<th>Groundwater protection measure</th>
<th>Feasibility</th>
<th>Alternative and/or supplementary measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Example setting A with periodic detection of high <em>E. coli</em> counts in poorly constructed wells in a shallow vulnerable aquifer adjacent to an open defecation area</td>
<td>Extreme</td>
<td>Improve construction and maintenance of wells; Construct latrines downgradient from wells</td>
<td>High $\rightarrow$ upper right-hand corner of Figure 15.3</td>
<td>Additional short-term water treatment (e.g. boiling, disinfection)</td>
</tr>
<tr>
<td>Example setting B with periodic detection of high <em>E. coli</em> counts in poorly constructed wells in a shallow vulnerable aquifer adjacent to an open defecation area</td>
<td>Extreme</td>
<td>Improve construction and maintenance of wells; Construct latrines downgradient from wells</td>
<td>Low $\rightarrow$ bottom right-hand corner of Figure 15.3</td>
<td>Abandon wells and rebuild in uncontaminated area, or provide alternative water source (e.g. use of water tankers) Public consultation for increasing feasibility of aquifer protection</td>
</tr>
<tr>
<td>Example setting C with periodic detection of high <em>E. coli</em> counts from contaminated run-off in poorly constructed wells</td>
<td>High</td>
<td>Ensure setback distances to sources of pollution; Improve construction and maintenance of wells</td>
<td>High $\rightarrow$ upper right-hand corner of Figure 15.3</td>
<td>Public communication about wellhead protection</td>
</tr>
<tr>
<td>Example setting D with nitrate contamination from agriculture in properly constructed tubewells</td>
<td>Moderate</td>
<td>Implement control measures for stock density as well as for application of fertilizers and manure</td>
<td>Low $\rightarrow$ bottom right-hand corner of Figure 15.3</td>
<td>Provide appropriate bottled water for bottle-fed infants; and/or encourage breast feeding</td>
</tr>
<tr>
<td>Example setting E with pesticide contamination from agriculture in properly constructed tubewells</td>
<td>Low</td>
<td>Implement training programme for farmers on good practice in choice, application and disposal of pesticides</td>
<td>High $\rightarrow$ upper left-hand corner of Figure 15.3</td>
<td>Improve risk communication to the public</td>
</tr>
</tbody>
</table>
Management actions for the contaminants ranked as urgent may result in simultaneous remediation of those with a lower urgency ranking, e.g. where nitrate loading from human excreta occurs together with faecal indicators, measures reducing the latter are likely to also reduce the former. Such benefits need to be included in the case for measures that are being proposed.

Generally, where socioeconomic conditions indicate that the availability of financial resources for advanced drinking-water treatment is low, maintaining groundwater quality as a cheap and safe resource not requiring treatment may be particularly important. Under these circumstances it is probable that the situation analysis would identify aquifer and/or wellhead protection as a high priority.

The important exception to the general scheme shown in Figure 15.3 is where groundwater contains toxic natural constituents such as fluoride or arsenic at concentrations that are of health concern. In these situations, groundwater protection measures will not reduce the concentrations of these constituents and water treatment or providing alternative sources of drinking-water are the only effective management options. This does not mean that groundwater protection measures are abandoned in these situations, as other possible contaminants derived from land use will still need to be managed to prevent contamination of the water supply even if it is being treated to remove the natural chemicals such as arsenic or fluoride.

### 15.4 DOCUMENTATION AND REPORTING

Comprehensive and easily understood documentation of the situation assessment is important as it enables both the decision-making process for a specific supply and the information on which the decisions were made to be clearly communicated to water consumers, regulatory and funding agencies and other stakeholders. In particular, documentation is important for the following reasons:

- **Documentation of the sources of information that were used to make management decisions enables the quality of the information to be assessed. This can help identify whether there are any major gaps in the information used which may affect both the assessment of groundwater pollution risks and the measures selected to manage groundwater quality.**

- **Potential water consumers and the general public have a right to know what potential contamination risks occur in an existing or proposed groundwater supply and about how these risks will be managed. Water consumers need assurance that their water supply will not pose a public health threat, and demand a high level of accountability from water suppliers and government regulatory agencies for decisions made about drinking-water safety (CELA, 2001).**

- **A report of the results of the groundwater source assessment is a powerful tool to initiate discussions with a wide range of stakeholders about the need to protect the quality of groundwater in a region.**

- **Good documentation allows decisions about water quality management to be easily evaluated and updated as new information becomes available.**
• Good documentation together with ongoing consultation with the community and key decision-makers helps secure funding and community support for implementing groundwater protection measures to ensure that drinking-water will not affect public health.

The whole process of the situation analysis should be documented formally in a report by the situation assessment team. As well as describing the results of the situation analysis and the criteria for decisions made in the assessments, the report should include the technical details such as key persons involved in conducting the situation analysis, when the information was collected, the sources of data (e.g. from site inspection, statistics, government bodies, universities, published/unpublished information), contact persons for information, and the location and format of storage of the information. A key component of this report will often be a series of maps of the catchment area showing the aquifers and groundwater conditions, vulnerability, groundwater supplies, land use and human activities which highlight the major potential sources of groundwater pollution. If possible, these should be in GIS format at a common scale so that they can be easily overlaid and updated.

15.5 REFERENCES


