Sanitary completion of protection works around groundwater sources

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The proper sanitary completion of groundwater sources is of particular relevance to the microbial quality of water. It is essential to prevent the direct contamination of groundwater at the point of abstraction or resulting from rapid recharge pathways close to the source. Where contamination is allowed to directly enter the groundwater source or reach groundwater close to the point of abstraction, the travel time may be too limited to ensure adequate die-off and the processes of attenuation may not be effective in reducing the numbers of pathogens (Robertson and Edberg, 1997).

Sanitary completion is also important in preventing direct chemical contamination, but often does not provide the same degree of protection. The subsurface leaching and transport of mobile and persistent chemical contaminants means that land use controls will be required to limit risks. This is illustrated, for instance, by studies in a small town in Uganda that showed little contamination by microbial contaminants, but significant increases in nitrate derived from faecal sources (Barrett et al., 2000a). Large-scale protection measures, such as designation of groundwater protection zones, are discussed in Chapter 17.

Sanitary completion refers to the protection works at the abstraction point and the immediate surrounding areas. It is sometimes also referred to as wellhead protection, although this would usually cover a wider area around the well than covered in this
chapter. In this chapter, sanitary completion includes the underground and above ground construction of the abstraction facility as well as the immediate area surrounding the abstraction point.

**NOTE**

This chapter introduces options for controlling risks through sanitary completion. The information presented supports defining control measures in the development of a Water Safety Plan (Chapter 16).

### 18.1 SANITARY COMPLETION AND HEALTH

The direct contamination of groundwater sources resulting from poor sanitary completion has been linked to both endemic disease and outbreaks. Such contamination is present in both developed and developing countries. For instance, Olson *et al.* (2002) describe an outbreak of *E. coli* O157:H7 in Alpine, Wyoming, including cases of haemolytic uraemic syndrome, which was related to consumption of water from a poorly protected spring which sanitary surveys had identified as being at risk from contamination by surface water. Poor sanitary completion measures also appear to have played a role in the Walkerton outbreak in Canada (O’Connor, 2002). In developing countries, the use of poorly protected groundwater sources has been linked to acute diarrhoeal disease (Trivedi *et al*., 1971; Nasinyama *et al*., 2000). Good sanitary completion measures have been shown to be necessary to maintain the quality of water and protect public health (US EPA, 1993; Pedley and Howard, 1997; Robertson and Edberg, 1997).

The effectiveness of sanitary completion in reducing risks of pathogens is profound as it provides a barrier to direct contamination of the source (Robertson and Edberg, 1997). The degree to which risks will be reduced, however, varies between pathogen types and aquifer types and there is a need for multiple interventions to act as barriers to most pathogen types.

For many aquifers, good sanitary completion measures will control the majority of risks posed by protozoa. Sanitary completion will greatly reduce the risks from bacteria in alluvial aquifers, but significant risks will remain in fracture flow aquifers where the enforcement of protection zones and, possibly, disinfection will be required. Sanitary completion measures will in general provide much less protection against risks posed by viruses, with protection zones and disinfection being required to reduce risks.

Most sanitary completion measures do not significantly add costs onto good standard design practice. There are cost implications, however, in ensuring that effective maintenance is performed to prevent basic protection measures from deteriorating and becoming ineffective. In some cases, cost considerations may be important with regard to selecting whether improvement of sanitary completion measures or alternative interventions will be the preferred option. For instance, where an aquifer is subjected to
low-level or intermittent microbial contamination, it may be more cost effective to chlorinate the water prior to distribution than to try to deepen the borehole.

18.2 THE NEEDS FOR EFFECTIVE CONTROL MEASURES IN SANITARY COMPLETION

Sanitary completion typically includes a number of essential control measures to prevent the contamination of groundwater. Failures in such control measures have been reported from a variety of situations in both developed and developing countries (Lewis and Chilton, 1984; Lloyd and Helmer, 1991; Platenberg and Zaki, 1993; Daly and Woods, 1995; Gelinas et al., 1996; Howard et al., 2003). In addition to the immediate protection works at the abstraction point, the appropriate sealing of abandoned wells is also noted as essential to protect functioning groundwater sources (Rojas et al., 1995; Robertson and Edberg, 1997).

Failures in sanitary completion measures may result from poor construction and in particular lack of adherence to basic quality standards. For example poor jointing on casings of boreholes, incorrect selection and placement of grouting, poor selection and installation of gravel packs, poorly mixed concrete used for linings and aprons may all result in seepage of contaminated water into groundwater sources (Howsam, 1990; US EPA, 1993).

Some drilling techniques lead to increased risks because they do not allow for grouting around the casing to be used (ARGOSS, 2001). Failure to consider the pH of the groundwater may lead to corrosion and rapid deterioration of rising mains, resulting in loss of water and abandonment of the supply (Leake and Kamal, 1990). In addition, methods of water lifting can present a direct route of contamination such as through the priming of handpumps with contaminated water (MacDonald et al., 1999).

Failures in sanitary completion may also result from poor maintenance (Lloyd and Bartram, 1991; Lloyd and Helmer, 1991; Platenberg and Zaki, 1993; US EPA, 1993; Daly and Woods, 1995; Howard et al., 2003). In many cases specific measures constructed to protect a groundwater source fail because other measures, such as fences and diversion ditches, have not been maintained. The failure to maintain ditches and fences can result in increased access to the groundwater source, increased stress and erosion on the other protection measures and increased likelihood of inundation by surface water.

Control measures as part of sanitary completion should be identified and implemented in the planning, design, construction, operation and maintenance of an abstraction facility. As the risks to groundwater sources can be described using the source-pathway-receptor model (see Table 8.8 in Chapter 8.5.2), control measures can be categorised as: controlling the source of hazards, e.g. faecal material from a pit latrine overlying an aquifer and close to an abstraction point, and controlling pathways to avoid direct or very rapid ingress of contaminated water, e.g. through cracks in the casing of boreholes, improperly sealed apron surrounding the headwall of a dug well or borehole, eroded backfilled area of a protected spring, abandoned dug wells and borrow pits. Control measures both for sources and for pathways include indirect measures to decrease the likelihood of a hazard or pathway developing, such as a fence around the
water source to prevent access of animals or humans which could be a source of hazard (through defecation) or cause a pathway (through causing damage to the source or the immediate surrounding area).

In many cases, a combination of control measures addressing hazard sources and contamination pathways is necessary. Sanitary completion provides one barrier to contamination from such sources, but should be integrated with proper pollution containment practices and other environment engineering interventions (such as improved drainage) to be effective.

### 18.3 CONTROL MEASURES IN SANITARY COMPLETION: PLANNING AND DESIGN

The initial design of a groundwater abstraction facility is crucial in determining how protected the source will be. Some background information and a number of basic considerations should be taken into account at this stage.

**Planning site and design in relation to the hydrogeological environment**

The first step in sanitary completion is to understand the nature of the hydrogeological environment – where and how many aquifers exist, what type of aquifers exist, expected yields, depth and nature of the overburden and the degree of interconnection between different aquifers (Chapter 8). It is also important to assess how the water will be abstracted – are there springs or must the groundwater be abstracted through sinking a well or borehole into the ground? This information can then be used to make basic decisions such as the type of technology to be used, the depth of abstraction and additional protection measures required.

Where aquifers are deep or multiple aquifers are found, setting the intake deeper is likely to improve the microbial quality of water. In many aquifers, in particular relatively fine-grained aquifers, there is far less vertical movement of water (and therefore pathogens) than horizontal movement. The increase in travel times for relatively small increases in depth may be many tens or hundreds of days (ARGOSS, 2001). This increases the potential for die-off of pathogens and potentially greater dispersion; although in the latter case sophisticated models may be required to predict this. It may also increase the potential for attenuation, although this cannot be relied upon.

Sinking tubewells into deeper (usually older) aquifers may also be an important way of avoiding chemical contamination in shallow groundwater, as is the case in relation to arsenic contamination in Bangladesh (Ahmed et al., 2002). Where tubewells are deepened it is important that shallower layers are cased off to prevent ingress. Often the incremental cost of deepening a well is relatively low in comparison to the overall capital investment and thus yields a significant cost-benefit. Deepening tubewells requires ascertaining whether there is no or very limited hydraulic connection between contaminated shallow and uncontaminated deeper aquifers. Hydraulic connection between aquifers is relatively common in aquifers found in weathered basement rocks and may also occur in alluvial aquifer sequences with no defined aquitard or aquiclude. Where hydraulic connections exist, deepening a tubewell may limit the improvement of water quality, as induced leakage from shallow aquifers may still lead to contamination.
Planning control measures in designing abstraction may be hampered by lack of hydrogeological information. For example in fracture aquifers it may be difficult to determine the level of risk posed to a deep aquifer by a contaminated shallow aquifer. Geophysical investigation and detailed assessment may provide some, but possibly not all, the answers required during the design stage. In such cases, monitoring as part of validation of the design chosen is particularly important.

Planning site, design and operational control measures in relation to the outcome of hazard assessment

As discussed in Section II and Chapter 14 of this book, a critical step before embarking on the design of a groundwater source is to evaluate what hazards exist close to the proposed site and their potential to be attenuated or diluted. This includes determining whether particular aquifers are contaminated and therefore whether their use as a drinking-water supply is justified.

Where the situation assessment identifies existing contamination of a well or spring, or a high potential for pollution from activities and conditions too close to the abstraction facility, control measures can either be identified towards removing the cause of the hazard(s) (see also Section V), or towards changing the site or depth of the well. While removing hazards would be the preferable, in practice population density and/or severity of contamination may make relocation of wells more feasible.

Whilst an emphasis should be placed on ensuring microbial quality of water, attention should be paid to the chemical quality of different groundwaters. Assessing whether particular aquifers contain toxic levels of chemicals (e.g. arsenic) or whether the levels of chemicals will affect the acceptability of water to consumers (e.g. high iron or manganese levels) or cause unacceptable operational problems (e.g. very hard waters) is critical in the design process. The acceptability of water is a particular problem as this may lead households to reject the use of an otherwise safe source and use contaminated sources for drinking. This not only fails to meet basic health needs for low-risk drinking-water, but also represents a significant waste of resources.

In cases where the hazard only represents a risk under certain pumping conditions, the pumping regime could be defined as control measure in order to reduce the influence of the hazard. This is unlikely to be satisfactory, however, as there may be considerable uncertainty both in the abstraction model used as basis for decisions, and in operational monitoring and corrective action to ascertain that this pumping regime is always adhered to.

If the hazard cannot be removed and changes in design of the source are not possible, post-abstraction disinfection is likely to be an effective control measure. In some cases, it will be more effective to use a lower microbial quality of water and then apply treatment at household or community level and/or implement a health education programme dealing with steps available at the household level to reduce the risks. Also, a residual risk may have to be retained if contamination is relatively low, other routes of disease transmission are more significant than water and are therefore other interventions are a greater public health priority where resources are insufficient to simultaneously improve drinking-water quality.
18.3.1 Drainage and fencing

Control measures are important to protect abstraction facilities against the potential for inundation by contaminated surface water or damage by animals or overland flows caused by heavy rainfall by diverting surface water away from the headworks. For protected springs this diversion should be located above the protection works and should direct the water into a drainage ditch downstream and away from the spring. For dug wells and boreholes, diversion ditches should circle the headworks and drain the water away from the source. In designing the ditch, the topography and likely overland flows should be evaluated to ensure that the depth of the ditch is adequate to remove all stormwater.

Diversion ditches should be located some way from the groundwater source, but not so far that significant overland flow will be generated within the area between the ditch and the headworks. A general rule of thumb is a minimum of 6 m and preferably 10 m for boreholes and dug wells and up to 20 m for protected springs (Morgan, 1990).

Restricting access by both humans and animals to the headworks is also important to reduce risks of contamination and thus, where possible, water sources should be enclosed by a fence. However, this needs to be balanced against cultural norms, for instance fencing of community water sources in Bangladesh is often not practiced because this may be interpreted as restricting the use of the source.

The wellhead of boreholes serving a piped distribution system should be located within a locked building which only the operation staff of the water supplier should have access to. Where users must collect water directly at the borehole or dug well source, fencing is still required and access should be restricted to only one or two entrances. For springs, the whole backfilled area should be fenced and inaccessible as users will collect water from outlets on the spring box. Where the spring feeds a gravity piped water system, the whole spring protection works should be fenced off and access limited to the community operator. All valve and junctions boxes should have concrete lined sides and a lockable lid.

18.3.2 Design of boreholes

Boreholes or tubewells may be shallow (5-45 m) or deep (up to several hundred metres). The choice of pump (hand, mechanized or electric submersible) to withdraw the water will depend on the hydraulic (or pumping) head in the pump, with handpumps being typically constrained to depths of 45 m or less. Where confined or semi-confined aquifers are used, the water table may rise considerably higher than the depth of the well and a handpump may still be used despite the well being physically relatively deep. Where mechanized or electric submersible pumps are used, they are typically linked to a distribution system. An example of a shallow borehole is shown in Figure 18.1. Selection of appropriate design such as the use of geotextile stockings, telescopic screen or external gravel packs can improve filtration and reduce potential sanitary risk (Driscoll, 1986).
Figure 18.1. Design of a shallow borehole with handpump

For all boreholes or tubewells ensuring proper sanitary completion of the above ground infrastructure is essential to prevent direct ingress of contaminated surface water. Key components are to provide a casing over the unsaturated zone and over the upper part of the aquifer which may be expected to dewater during pumping. It is important to provide a bentonite grout seal for at least the top 1-3 m, which should be continuous with a concrete apron surrounding the top of the borehole (Driscoll, 1986). The apron must be in good condition with cracks and faults repaired rapidly.

Sanitary completion of tubewells/boreholes will be dependent on the method of drilling. For instance, MacDonald et al. (1999) note that the use of the sludger method commonly employed in the alluvial aquifers in Bangladesh increases susceptibility to contamination via routes close to the tubewell because it precludes sealing the annulus between the casing and drilled tubewell. However, as the formation typically collapses around the casing, the susceptibility can be reduced (Ahmed et al., 2002).

Boreholes are usually fully developed prior to commissioning to ensure adequate flow using a variety of techniques. Well development is not typically designed to improve water quality, but care is needed when using some techniques (notably hydrofracturing and acidization) to avoid the creation of preferential flow paths in consolidated formations that could allow rapid transport of contaminants.

18.3.3 Design of dug wells

Most hand-dug wells are shallow (typically 20 m or less in depth) although wells as deep as 120 m have been constructed (Watt and Wood, 1977). They are often more vulnerable
to contamination than boreholes, thus while some shallow dug wells have mechanized pumping, the majority (particularly those in developing countries) have water abstraction through some form of handpump, windlass or rope and bucket system. A typical design is shown in Figure 18.2.

**Figure 18.2.** Design of a dug well with handpump

Hand-dug well designs usually have some form of lining over the unsaturated zone. In order to secure a year-round supply, caissons may be sunk below the water table to prevent drying. The design should include an apron surrounding the top of the well (usually of 1-3 m radius) with lining extended 30-50 cm above the top of the apron to provide protection against direct ingress of surface water. It is preferable that a cover is put on the well to prevent direct contamination of the water (Collins, 2000).

Studies by Lewis and Chilton (1984) note that the design, construction, operation and maintenance of the apron results in a direct reduction in levels of contamination. Dug wells can be backfilled with a sanitary seal of between 1-3 m, which increases travel time resulting in increased die off rates of pathogens. However, backfilling of wells is difficult if deepening of the well is required during drought periods. Alternative techniques such as curbing (attachment of section stabilizers) can be used to prevent movement of the shaft section of well and therefore not disturb the sanitary seal (Watt and Wood, 1977).

The means of abstraction should minimize the potential for introducing contamination from dirty containers. This may include using a handpump or other sanitary means of
withdrawing water from the well such as a rope and washer pump, which have been shown to be effective in reducing levels of contamination (Gorter et al., 1995). (See Section 18.5.1 for more detail about risks associated with pumps.) Where a windlass, rope and pulley system with a bucket is used, then only one bucket should enter the well and hygiene education should emphasize the need to keep the well bucket from coming into contact with the ground.

Hand dug wells often represent particular problems for sustaining good quality water, as it is difficult to ensure that very shallow water cannot enter the lining during wet periods. There are a number of different linings that may be used, including precast concrete, concrete cast in-situ and brick linings (Collins, 2000). Each of these methods gives varying degrees of sanitary protection.

Where water quality is difficult to maintain, additional improvements have been made to dug wells. These include the addition of a small sand filter set inside a box at the base of the well, a permeable base plate or ongoing chlorination of the water in the well (Lloyd and Helmer, 1991; WHO, 1997; Godfrey et al., 2003). Chlorination has proven to be effective in post-emergency situations where other technology alternatives are unavailable but its effectiveness in terms of sustainability is questionable (Rowe et al., 1998; Godfrey, 2003).

### 18.3.4 Design of protected springs

A spring is a natural groundwater source which is protected by providing a concrete headwall or spring box around the eye of the spring (where water emerges) that prevents direct contamination (WHO, 1997; Howard et al., 2001; Meuli and Wehrle, 2001). There are a number of designs for protected springs, all of which utilize some form of retaining wall or spring box with an excavated area backfilled with loose material to encourage spring flow towards the outlet. A protective cover usually overlies the excavated area and the area is fenced for some distance to prevent direct access by humans and animals. One design that has been used in periurban areas is shown in Figure 18.3.

![Figure 18.3. Cross-section of the backfill of a protected spring (Howard et al., 2001)](image-url)
Where protection is poor, contamination may occur at the point of emergence due to recharge by contaminated water in the immediate area. Thus the proper protection of the spring eye becomes vital. At most springs, the eye of the spring is excavated and the area backfilled with loose material. The filter media should be sufficiently fine to provide reasonable filtration of the groundwater entering from the spring eye and any surface water percolating through the immediate area: usually gravel although finer media may be required in more polluted areas.

It is important that this filter is overlain by an impermeable layer, commonly clay but can be a concrete cover, to reduce direct infiltration of surface water, and the whole area grassed (Howard et al., 2001; Meuli and Wehrle, 2001). The filter media should be placed in the backfill area from the base of the excavation up to the expected highest level of wet season water table rise (only applicable in gravity springs).

### 18.3.5 Design of infiltration galleries

Infiltration galleries come in a variety of forms – they may run alongside rivers or other surface water bodies or may tap a spring line. They can be used as a part of a treatment train or may provide water directly via a shallow well or from a gravity-fed piped water supply. Infiltration galleries have been used in many countries and often have long life spans, for instance an infiltration gallery has been in operation in Lima, Peru for over 100 years and still provides high quality water with limited maintenance (Rojas et al., 1995).

When using an infiltration gallery it is important to ensure that the collector pipe is laid at an adequate depth to ensure a year-round supply. The collector pipe should be surrounded by a gravel pack designed to reduce the velocity of water entering the drain to ensure that suspended sediments are removed. It is preferable that the intake holes be on the underside of the collector pipe to increase the flow path length. However, it is recognized that in most cases inlet holes will be required on the full pipe for hydraulic reasons and that the gravel pack must be laid properly. The interior of infiltration galleries will be self-cleaning if the velocity is at least 1 m per second.

### 18.4 CONTROL MEASURES IN SANITARY COMPLETION: CONSTRUCTION AND MATERIALS

The construction process and materials used are critical in ensuring that proper sanitary completion is achieved. Substandard work should be rejected. Poor construction quality allows faults to develop at the abstraction point. It is essential that technicians undertaking water source construction are properly trained and that guidelines for construction (for instance concrete mixes, rising main materials, etc.) are provided and followed.

The materials used can be critical to prevent water quality deterioration. Cement should be of good quality and within the recommended date of use. Sand and gravel should be clean and mixed in the proportions specified in the design. Reinforcing materials should be free of rust and dirt to ensure that a firm bond is formed with the concrete and care should be taken in selecting the gauge of reinforcing materials.
An important part of the construction process is quality control. This requires periodic checking and auditing of field practices to ensure that they are consistent with stated quality goals and objectives that the construction agency has set itself. Such quality control is necessary in all situations, whether construction is undertaken by the public or private sector. In all cases, but particularly where work is contracted to a third party, it is essential that there is evidence that the quality of construction is adequate. This may take the form of inspection and signing off a contract prior to full payment, or unannounced site visits.

18.4.1 Pumps and rising mains

For dug wells and tubewells, the selection of the rising main material is important. Galvanized iron rising mains should be avoided where water is relatively acid water because they are likely to corrode and lead to abandonment of the use of the handpump or the source. Where suction pumps are used, it is important that pumps are selected which have a non-return foot valve and do not require priming water to be added. As priming water is often taken from surface water or other stored household water, it may be contaminated (ARGOSS, 2001). Where priming water must be used, then it is important that only water collected from the well and stored in a covered container is used.

18.4.2 Cleaning of facilities prior to commissioning

For boreholes and dug-wells, good hygiene should be practiced by the team during construction. However, as some contamination will almost always remain, the wells should be thoroughly cleaned and disinfected prior to use and after maintenance tasks within the well.

For dug wells, the lining and caisson walls should be scrubbed with a chlorine solution prior to commissioning; after this washing down with chlorinated water should be sufficient. Where a handpump is installed on a dug well, the rising main should be filled with a chlorine solution and left to stand for at least one hour and preferably overnight.

Disinfection of boreholes requires filling the casing with a chlorine solution and leaving it to stand for at least one hour and preferably overnight. In both cases, the chlorinated water should be pumped to waste before use.

18.5 CONTROL MEASURES IN SANITARY COMPLETION: OPERATION AND MAINTENANCE

Whilst good design and construction will do much to ensure that wellhead protection is adequate, ensuring that it remains in good condition through ongoing preventative maintenance and repair is essential. This applies equally to springs and wells of large utilities and to small community or household supplies. The inspection routine should be defined in a management plan and include the recording of any deterioration detected and the action to be taken by whom and when.
For example, where pumps are used (whether handpump or mechanized), a stock of tools and spares should be kept by the operator so that repairs can be carried out quickly. Inherent to this is developing an effective supply chain for spares. In South Asia this has been successful as the small-scale private sector has been able to meet demand. In Africa, developing adequate supply chains has been more problematic, leading to relatively large numbers of boreholes being non-functional. In more developed countries, operators would normally have a store of the requisite tools and spares or would be able to source these quickly.

Proper training of operators of a supply is of critical importance for them to have and have the skills and knowledge to undertake at least basic preventative maintenance and perform minor repairs. More than one operator per source should be trained to ensure that maintenance and repairs can still be undertaken even if an operator moves away from the area or cannot undertake work at a particular time. For utility supplies, a number of operators may be identified who work at the supply on a rotational basis. Operators should have access to guidance and information about maintenance and repairs – e.g. specifying frequencies for replacement or worn parts and giving detailed information of repair procedures.

Where possible, the operators of water supplies should receive ongoing support from technical or professional support staff. Very often, even limited support in terms of regular visits to a supply to undertake an inspection and to meet with the operators of the supply can be very effective in sustaining good operation. This is particularly important for sustaining good quality small water supplies in both developed and developing countries and in rural and urban areas (Bartram, 1999; Holden, 1999).

In addition to basic maintenance and repairs of equipment, it is important that basic cleaning tasks are routinely undertaken. This involves cleaning and repairing diversion ditches, ensuring that wastewater ditches from springs do not become blocked and allowed to flood the source and ensuring the fence remains in good condition. Such tasks are best defined in management plans and usually are not onerous if done regularly. They can make a crucial difference in water quality control. Such activities should be supported by inspections of the site by the operator.

Experience shows that in order to sustain operation and maintenance some form of contribution from the users for the upkeep of the water source is very effective. In rural areas of low-income countries this may involve the contribution of labour. Other communities, particularly those in wealthier countries and those in urban areas of developing countries, may rely on payment by the users for the water services supplied. Most communities are willing to pay for water services providing the charges are realistic and the service meets the demands of the users. Routine payment is often preferred, as systems that operate solely on the collection of fees once a breakdown has occurred will mean that faults take longer to repair, although the latter approach has been found to work in some communities, for example in Eastern Uganda.

In both cases, community organization is often key to ensuring that maintenance procedures are supported. This may take the form of a committee that oversees the operation of the water supply. In many low-income countries, such a committee may be specific to the water source and it is preferable to ensure that the members are representative of the different interest groups in the community and in particular that
women’s concerns are adequately addressed. In higher-income countries such a committee may be a subcommittee from a local council or government at the local level. For instance in Chile user committees have been set up for all water supplies constructed by the regional water supply company using subsidies from the Government. These committees are supported by training programmes provided by the regional water supply companies who provide training to managers and operators of the supplies.

18.6 ASSESSMENT OF SANITARY COMPLETION AND ESTABLISHING PRIORITY RISK FACTORS

The state of sanitary completion can be assessed using inspection methodologies, as described further below. These are particularly important in the context of system assessment to determine risks and priorities for upgrading abstraction facilities as well as for defining control measures in the context of developing a Water Safety Plan (WSP). Sanitary inspections may also be used in verification via a surveillance programme using standardised approaches (Howard, 2002; WHO, 1997). Examples of such forms are commonly available, for instance in Volume 3 of the Guidelines for Drinking-water Quality (1997). In both cases, water quality data would also typically be collected to allow combined analysis of the effectiveness of the control measures.

Sanitary inspection methods may also be used in the routine operational monitoring of the water source as part of a WSP. Sanitary inspection approaches for routine monitoring in developed countries are likely to be the same as those used in assessment. In developing countries, other tools such as simple pictorial monitoring tools may be more effective. Routine monitoring may include some analysis of basic water quality parameters, particularly if chlorination is practiced, but this is dependent on the skill of the operators and funds for supporting such analysis.

18.6.1 Sanitary inspection

Sanitary inspection provides an easy but effective means of both assessing and monitoring sanitary completion, particularly when this employs a standardized and quantifiable approach (Lloyd and Bartram, 1991; Lloyd and Helmer, 1991; WHO, 1997). Unless a standardized approach is adopted, problems are commonly found in comparing the findings between different inspectors (WHO, 1997; Howard, 2002). This leads to inaccurate and unreliable results and limits the potential for subsequent analysis of the data. A quantified approach allows an overall risk score to be calculated in order to assess the state of supply systems and to identify priorities for action. It also permits comparisons between different source types once the data is converted into a percentage risk.

Sanitary inspections should be undertaken frequently, at least as often as samples are analysed for verifying water quality and in some cases more often. Risks are not static, they change over time as new development occurs in the area and are sometimes due to poor maintenance practices. Certain risks may also be important only seasonally, for instance the collection of surface water uphill of a groundwater source may only occur during wet periods. Therefore inspections may be required in both wet and dry seasons.
Most sanitary inspections involve a series of simple questions with Yes/No answers. As the questions are usually framed in such a way that a positive answer indicates the presence of a risk, typically a score is allocated for a positive answer and no score for a negative answer. Adding up the positive answers provides an overall sanitary risk score. An example of a sanitary inspection form is given in Box 18.1 below. Other examples are available from volume 3 of the *Guidelines for Drinking-water Quality* (WHO, 1997).

In the form in Box 18.1, questions 7, 8 and 10 refer to potential sources of faeces in the environment; questions 1, 2 and 3 refer to direct pathway factors; and, questions 4, 5, 6 and 9 refer to indirect factors. The analysis of these factors in relation to water quality provides useful information regarding which remedial and preventative actions are required for the specific water source. Data collected this way can further be aggregated and evaluated across a range of abstraction facilities of a given region in order to identify key risk factors.

**Box 18.1. Example of a sanitary inspection form (based on Howard, 2002)**

**I. Type of Facility: PROTECTED SPRING**

1. General Information: Division: Parish:
2. Code Number:
3. Date of Visit:
4. Water sample taken? Sample No.:
   Faecal Coliform/100 ml:

**II. Specific Diagnostic Information for Assessment**

<table>
<thead>
<tr>
<th>Risk</th>
<th>1. Is the spring unprotected?</th>
<th>Y/N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2. Is the masonry protecting the spring faulty?</td>
<td>Y/N</td>
</tr>
<tr>
<td></td>
<td>3. Is the backfill area behind the retaining wall eroded?</td>
<td>Y/N</td>
</tr>
<tr>
<td></td>
<td>4. Does split water flood the collection area?</td>
<td>Y/N</td>
</tr>
<tr>
<td></td>
<td>5. Is the fence absent or faulty?</td>
<td>Y/N</td>
</tr>
<tr>
<td></td>
<td>6. Can animals have access within 10 m of the spring?</td>
<td>Y/N</td>
</tr>
<tr>
<td></td>
<td>7. Is there a latrine uphill and/or within 30 m of the spring?</td>
<td>Y/N</td>
</tr>
<tr>
<td></td>
<td>8. Does surface water collect uphill of the spring?</td>
<td>Y/N</td>
</tr>
<tr>
<td></td>
<td>9. Is the diversion ditch above the spring absent or non-functional?</td>
<td>Y/N</td>
</tr>
<tr>
<td></td>
<td>10. Are there any other sources of pollution uphill of the spring (e.g. solid waste)?</td>
<td>Y/N</td>
</tr>
</tbody>
</table>

*Total Score of Risks:* /10 (Risk score 0-3=low; 3-5=medium; 6-8=high; 9-10=very high)

**III. Results and Recommendations**

The following important points of risk were noted (list nos. 1-10):

Comments:

Signature of Health Inspector/Assistant:
18.6.2 System assessment through sanitary inspection as a management tool

Sanitary inspections provide a useful management tool for communities, water supply agencies and surveillance bodies. The value of the sanitary inspection is that it provides a longer-term perspective on the risks of contamination, gives an overview assessment of how effective operation and maintenance has been and which system upgrade is needed. Such information can help in directing resources for improvement of the infrastructure and for improved training of water supply operators. Sanitary inspections also provide an additional means of assessing the differences in water quality from different types of water sources thus helping overall national and regional planning and policy-making (Bartram, 1999; Howard, 2002). This type of analysis is likely to be undertaken by a utility or surveillance body rather than an operator of a supply.

In a number of countries, the combined analysis of sanitary risk scores and level of contamination has proved to be an effective way of prioritizing which water supplies receive investment (Lloyd and Helmer, 1991; WHO, 2004). In many cases there is a broad relationship between the overall sanitary risk score and level of contamination (Lloyd and Bartram, 1991; Lloyd and Helmer, 1991). However, such approaches do not necessarily identify which are the most important specific factors to address as the system of sanitary inspection provides each risk factor with equal weighting, despite awareness that this is unlikely to be the case.

It is often useful to be able to determine the importance of different risk factors in order to direct investment and action on those improvements in the source that will yield the greatest improvements in water quality. Such an approach is often particularly useful in order to assess whether microbial contamination of groundwater derives from poorly sited and constructed sanitation facilities or from poor maintenance of sanitary completion measures. Leaching from on-site sanitation has been identified in some cases to be the major cause (Boonyakarnkul and Lloyd, 1994; Rahman, 1996; Massone et al., 1998; Melian et al., 1999). Other research from a number of countries indicates that poor sanitary completion was more important in microbial contamination than subsurface leaching from hazards such as pit latrines (Gelinas et al., 1996; Cronin et al., 2002; Howard et al., 2003) as described further in Section 18.6.3 below. This is particularly the case in situations where there are a number of sources of human faecal matter in the environment such as refuse pits and dumps, open defecation and widespread occurrence of animal faecal matter (Barrett et al., 2000b; Chidavaenzi et al., 2000). Furthermore, it is often important to determine the influence of other factors such as rainfall and population density, which may affect contamination risks (Wright, 1986; Gorter et al., 1995; Barrett et al., 2000a; Howard, 2002).

18.6.3 Establishing the importance of different risks due to poor sanitary completion

There are a number of approaches that have been used to investigate the relationships between individual risks identified through sanitary inspection and water quality outcomes using statistical methods to analyse the data. These approaches range from the
use of simple reporting of the frequency of risks in relation to specified water quality targets to the use of contingency tables and logistic regression. In order to undertake such analysis, it is important that water quality data and sanitary inspection data are available and can be paired.

In undertaking analysis of the relationship between sanitary risk factors and water quality outcomes, it is useful to compare risks in relation to water quality targets, as the failure to meet specified targets would trigger action. Cronin et al. (2002) present the analysis of data from two sites in Kenya and Mozambique, where the frequency of reporting of individual risks identified in inspections of sanitary completion measures were compared against samples with results above and below the median concentration of thermotolerant coliforms. This is shown in Table 18.1 below. This analysis indicated that poor sanitary completion of wells was more important in leading to contamination than subsurface leaching from sources of faecal material.

Table 18.1. Risk factors relating to higher levels of microbial contamination in dug wells in Kisumu, Kenya (based on Cronin et al., 2002)

<table>
<thead>
<tr>
<th>Risk factor</th>
<th>Percent of samples &lt; median TTC/100 ml</th>
<th>Percent of samples &gt; median TTC/100 ml</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plinth &lt;1.5 m</td>
<td>83</td>
<td>100</td>
<td>+17</td>
</tr>
<tr>
<td>Well wall sealed</td>
<td>83</td>
<td>91</td>
<td>+8</td>
</tr>
<tr>
<td>Surface waste within 30 m</td>
<td>83</td>
<td>91</td>
<td>+8</td>
</tr>
<tr>
<td>Ponding on plinth</td>
<td>50</td>
<td>55</td>
<td>+5</td>
</tr>
<tr>
<td>Drainage channel inadequate</td>
<td>100</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>Well cover unsanitary</td>
<td>92</td>
<td>91</td>
<td>-1</td>
</tr>
<tr>
<td>Latrines within 10 m</td>
<td>55</td>
<td>58</td>
<td>-3</td>
</tr>
<tr>
<td>Open water within 20 m</td>
<td>64</td>
<td>67</td>
<td>-3</td>
</tr>
<tr>
<td>Ponding within 3 m</td>
<td>92</td>
<td>82</td>
<td>-10</td>
</tr>
</tbody>
</table>

Other analyses have used concentrations of indicator organisms in water to define a water quality target based on international guidelines or national standards. In this approach, for each risk factor the difference in frequency of reporting of each risk factor is compared between when the target is met and when it is exceeded with the difference providing an indication of whether there is a relationship and the strength of relationships found. Howard et al. (2003) describe such an analysis of water quality and sanitary risks in shallow protected springs in Kampala, Uganda shown in Table 18.2.

It is often useful to undertake further analysis of the data to assess the strength of the relationships between risk factors and water quality. In studies from Thailand, Boonyakarnkul and Lloyd (1994) developed a Sanitary Hazard Index (SHI), which related the intensity of faecal contamination associated with individual risk factors identified from sanitary inspection. These authors were able to identify which factors had the highest SHI and concluded that this should provide direction in relation to the priority accorded to reducing the presence of individual risk factors. The authors noted that there was a difference between those factors with the highest SHI and those that were most commonly reported.
Combined analysis of water quality and sanitary inspection data can also be undertaken using a range of non-parametric tests, which is common in the analysis of water resources data (Helsel and Hirsch, 1992). The use of dedicated software packages will assist in undertaking such analysis, but are not essential. Such analysis often incorporates other data such as rainfall and population density that are considered important in controlling quality.

**Table 18.2. Sanitary inspection and water quality data for protected springs in Uganda**

<table>
<thead>
<tr>
<th>Risk factor</th>
<th>Percent reported when &lt;1 cfu/100 ml</th>
<th>Percent report when ≥1 cfu/100 ml</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Masonry defective</td>
<td>8</td>
<td>17</td>
<td>+9</td>
</tr>
<tr>
<td>Backfill eroded</td>
<td>29</td>
<td>67</td>
<td>+38</td>
</tr>
<tr>
<td>Collection area flooded</td>
<td>79</td>
<td>83</td>
<td>+4</td>
</tr>
<tr>
<td>Fence faulty</td>
<td>83</td>
<td>100</td>
<td>+17</td>
</tr>
<tr>
<td>Animal access within 10 m</td>
<td>79</td>
<td>100</td>
<td>+21</td>
</tr>
<tr>
<td>Latrine less than 30 m uphill</td>
<td>4</td>
<td>0</td>
<td>-4</td>
</tr>
<tr>
<td>Surface water collects uphill</td>
<td>46</td>
<td>100</td>
<td>+54</td>
</tr>
<tr>
<td>Diversion ditch faulty</td>
<td>79</td>
<td>100</td>
<td>+21</td>
</tr>
<tr>
<td>Other pollution uphill</td>
<td>46</td>
<td>83</td>
<td>+37</td>
</tr>
</tbody>
</table>

One example of non-parametric statistical tests is a contingency table of odds ratios. To make this analysis, variables with continuous data (e.g. water quality, rainfall and population density) must be converted into binomial categorical data. In the case of water quality targets the resulting variable will be whether the target was complied with or was exceeded (often simply expressed as either Yes or No). For rainfall data, a new variable may be whether rain was recorded within a specified time period or whether a certain depth of rainfall occurred.

An example of a contingency table is given below in Table 18.3 taken from analysis performed by Howard et al. (2003), which combines analysis of sanitary risks and water quality objectives for faecal streptococci and thermotolerant coliforms in protected springs in Uganda.

In the example of Table 18.3, two water quality objectives have been selected to allow the data to be analysed: the absence of faecal streptococci and less than 10 cfu/100 ml thermotolerant coliforms, the latter being a more realistic target for non-chlorinated community-managed water supplies. Odds ratios exceeding 1 show a positive relationship between the risk factor and exceeding the water quality target.

For both water quality targets the analysis demonstrates that localised pathways combined to sources of pollution and rainfall lead to contamination. Furthermore, in this setting thermotolerant coliform contamination appears to result from a more complex set of factors than faecal streptococci but is still primarily linked to poor sanitary completion.

This data can be further analysed through logistical regression (Howard et al., 2003). Using the same data shown in Table 18.3, logistic regression models were developed and are shown in Table 18.4. The regression models included all co-variates where odds ratios showed relationships significant at least to the 95 per cent level. Although not
significant at least to the 95 per cent level for faecal streptococci, latrine proximity within 30 m was forced into the model as this was still deemed a plausible route of contamination.

Table 18.3. Contingency table for protected springs in Uganda (adapted from Howard et al., 2003)

<table>
<thead>
<tr>
<th>Variable</th>
<th>FS &gt;0 cfu/100 ml&lt;sup&gt;−1&lt;/sup&gt;</th>
<th>TTC &gt;10 cfu/100 ml&lt;sup&gt;−1&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Odds ratio p 95% CI</td>
<td>Odds ratio p 95% CI</td>
</tr>
<tr>
<td>Faulty masonry</td>
<td>1.216 0.475 2.42 1.506 0.075 1.4</td>
<td></td>
</tr>
<tr>
<td>Backfill area eroded</td>
<td>4.135 0.000 5.8 2.762 0.000 2.73</td>
<td></td>
</tr>
<tr>
<td>Collection area floods</td>
<td>0.619 0.085 0.71 0.603 0.035 0.53</td>
<td></td>
</tr>
<tr>
<td>Fence absent or faulty</td>
<td>9.492 0.008 48.26 3.496 0.138 17.64</td>
<td></td>
</tr>
<tr>
<td>Animal access &lt;10 m</td>
<td>3.627 0.202 25.73 1.366 0.756 9.64</td>
<td></td>
</tr>
<tr>
<td>Surface water uphill</td>
<td>2.203 0.014 2.95 3.933 0.000 4.36</td>
<td></td>
</tr>
<tr>
<td>Diversion ditch faulty</td>
<td>0.755 0.369 0.98 1.324 0.263 1.35</td>
<td></td>
</tr>
<tr>
<td>Other pollution uphill</td>
<td>3.75 0.041 12.3 5.728 0.029 26.23</td>
<td></td>
</tr>
<tr>
<td>Latrine &lt;30 m uphill of spring</td>
<td>1.938 0.057 2.85 1.759 0.036 1.94</td>
<td></td>
</tr>
<tr>
<td>Latrine &lt;50 m uphill of spring</td>
<td>0.838 0.531 0.98 0.738 0.198 0.17</td>
<td></td>
</tr>
<tr>
<td>High population density</td>
<td>4.49 0.000 5.43 4.708 0.000 4.75</td>
<td></td>
</tr>
<tr>
<td>Waste &lt;10 m uphill of spring</td>
<td>1.971 0.028 2.53 2.557 0.000 2.63</td>
<td></td>
</tr>
<tr>
<td>Waste &lt;20 m uphill of spring</td>
<td>2.437 0.001 2.78 3.085 0.000 3.03</td>
<td></td>
</tr>
<tr>
<td>Waste &lt;30 m uphill of spring</td>
<td>1.547 0.191 2.17 1.896 0.031 2.4</td>
<td></td>
</tr>
<tr>
<td>Rainfall within previous 2 days</td>
<td>4.966 0.000 6.29 3.827 0.000 3.75</td>
<td></td>
</tr>
</tbody>
</table>

Table 18.4. Logistic regressions for protected springs in Uganda (adapted from Howard et al., 2003)

<table>
<thead>
<tr>
<th>Model</th>
<th>Model log estimate</th>
<th>Variables</th>
<th>Log estimate</th>
<th>Standard error</th>
<th>df</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faecal streptococci &gt;0 cfu/100 ml</td>
<td>343.27</td>
<td>Constant</td>
<td>2.63</td>
<td>0.36</td>
<td>1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Eroded backfill</td>
<td>-0.8</td>
<td>0.29</td>
<td>1</td>
<td>0.006</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Faulty fence</td>
<td>-1.94</td>
<td>0.88</td>
<td>1</td>
<td>0.027</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Surface water uphill</td>
<td>-1.07</td>
<td>0.32</td>
<td>1</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rainfall within 2 days</td>
<td>-1.34</td>
<td>0.27</td>
<td>1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Thermotolerant coliforms &gt;10 cfu/100 ml</td>
<td>338.11</td>
<td>Constant</td>
<td>2.06</td>
<td>0.37</td>
<td>1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Eroded backfill</td>
<td>-0.72</td>
<td>0.34</td>
<td>1</td>
<td>0.034</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Collection area flooded</td>
<td>0.57</td>
<td>0.29</td>
<td>1</td>
<td>0.047</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Surface water uphill</td>
<td>-0.7</td>
<td>0.32</td>
<td>1</td>
<td>0.031</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High population density</td>
<td>-1.02</td>
<td>0.35</td>
<td>1</td>
<td>0.003</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rainfall within 2 days</td>
<td>-1.64</td>
<td>0.29</td>
<td>1</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Both regression models indicate contamination resulting from rapid recharge close to the springs and suggest that it is poor sanitary conditions at the spring itself that represent the greatest problems for the microbial quality of water. It is likely that this occurs through both direct inundation and very rapid recharge through preferential flow paths. In both cases, the principal sources appear to be waste dumps and surface water rather
Sanitary completion of protection works around groundwater sources

than latrines. This agrees with other studies that point to the importance of refuse dumps for the presence of indicator organisms (Chidavaenzi et al., 2000). In a study of wells in rural Mozambique, Godfrey et al., (2005) found that there was a pulse response of microbial contamination to rainfall events. Soil and engineering studies indicated that localised pathways were likely to be the primary cause of contamination rather than contamination due to aquifer pathways (Godfrey et al., 2005).

The findings of Howard et al., (2003) and Godfrey et al., (2005) are in agreement with other studies into the causes of microbial contamination of shallow groundwater supplies, which have tended to emphasize direct ingress rather than subsurface leaching of contaminants in causing contamination (Rojas et al., 1995; Gelinas et al., 1996). These findings emphasise the importance of sanitary completion of groundwater sources.

The influence of sanitary completion on controlling quality may vary with different technologies and areas. For instance, studies in Thailand by Boonyakarnkul and Lloyd (1994) concluded that on-site sanitation factors led to the greatest Sanitary Hazard Index and were therefore priority risks to resolve. In Uganda, the major control on quality in tubewells appeared to be the proximity and location of on-site sanitation rather than wellhead completion (Howard et al., 2003). By contrast, studies in Bangladesh reported that wellhead completion was more important than subsurface leaching from on-site sanitation (MacDonald et al., 1999; Ahmed et al., 2002).

The results of these studies support the validation of control measures, an essential step within a WSP (see Chapter 16). The performance of a WSP may be assessed by repeating the above analysis after upgrading sanitary completion to address faults identified.

18.7 CONTROL MEASURES FOR SANITARY COMPLETION OF GROUNDWATER SOURCES

The design, construction, operation and maintenance requirements for groundwater sources can be translated into a series of control measures or points at the wellhead or spring protection works. Key control measures for different types of groundwater source are shown in Table 18.5 below. Planning measures to control the presence of hazards in the catchment area or immediate vicinity of a well or spring are discussed in more detail in Chapters 18-25.

NOTE

In water supplies developing a Water Safety Plan (Chapter 16), system assessment would identify which control measures exist, their effectiveness and which need to be upgraded or newly introduced. Management plans would document why specific control measures were chosen, how their performance is monitored and which corrective action should be taken both during normal operations and during incident conditions when monitoring indicates loss of control.
Table 18.5. Examples of control measures for sanitary completion and options for their monitoring and verification

<table>
<thead>
<tr>
<th>Process step</th>
<th>Examples of control measures for sanitary completion</th>
<th>Options for their monitoring and verification</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLANNING</td>
<td>Plan site and depth of abstraction to avoid presence of hazards and pathways for their ingress into the water source, e.g. prevent presence of faecal material within set-back distance</td>
<td>Review (applications for) permits for construction of new abstraction facilities or for reconstruction and upgrade of existing ones</td>
</tr>
<tr>
<td></td>
<td>Plan pumping regime to avoid leaching of contaminants into the aquifer by providing sufficient distance from sources of contaminants</td>
<td>Sanitary inspection of design and condition</td>
</tr>
<tr>
<td>DESIGN AND CONSTRUCTION</td>
<td>Ensure good drainage around wellhead or spring, e.g. • with ditches to divert runoff away from the wellhead or backfill area of a spring • for wells with an apron to direct spills away from the wellhead • for springs with good drainage of wastewater away from the spring area</td>
<td>Sanitary inspection of design and condition</td>
</tr>
<tr>
<td></td>
<td>Design wellhead or spring area protection to prevent direct contamination, e.g. with • Fencing to exclude animals from wellhead or spring backfill area • apron extending around the wellhead at least 1 – 1.5 m from casing • for boreholes ensure that join between apron and casing or lining is sound • for dug wells ensure wellhead is raised by at least 0.3 m and covered by slab • for springs ensure backfill area behind spring box or retaining wall is protected, e.g. with grass cover</td>
<td>Sanitary inspection of design and condition</td>
</tr>
<tr>
<td></td>
<td>Ensure sanitary completion of lining, e.g. • with lining extending at least 30 cm above the apron • with seal sufficiently extended below ground level: at least 1.5 m for boreholes with handpump and 5 m for mechanised boreholes • for boreholes with rising main in good condition • for dug wells by proper construction and use of mortar seal on lining, ensure lining stays in good condition (no weep holes during rainfall !)</td>
<td>Sanitary inspection of design and condition</td>
</tr>
<tr>
<td></td>
<td>Ensure adequate choice and good condition of structures, e.g. • for boreholes that pumps are firmly attached to the wellhead • for dug wells install handpump or other sanitary means of abstraction</td>
<td>Sanitary inspection of design and condition</td>
</tr>
<tr>
<td>OPERATION AND MAINTENANCE</td>
<td>For boreholes and wells, ensure pumping regime does not exceed amounts allowed for during planning For dug wells ensure hygienic use of handpump or other means of withdrawing water</td>
<td>Meter or estimate amount of water abstracted Regular inspection of condition and of use. Periodic analysis of microbial indicators.</td>
</tr>
<tr>
<td></td>
<td>Ensure regular maintenance and cleaning of well or spring environment, e.g. removal of debris blocking diversion ditches or those removing wastewater from the vicinity of springs; repair of fences; repair of structures such as aprons, covering flaps, handpumps</td>
<td>Review inspection reports for compliance to management plans. Periodic analysis of microbial indicators.</td>
</tr>
</tbody>
</table>
Table 18.5 focuses on control measures for the design and construction of wells and springs which are specific to sanitary completion. For the operation of abstraction facilities, maintenance and repairs are crucial control measures for keeping contaminants out, and management plans to define the scope and timescales of such activities are important to support that they are regularly carried out.

Regardless of whether or not any of these control measures are part of a WSP, their monitoring and verification is crucial to ensure that they are in place and are effective. Table 18.5 therefore includes options for surveillance and monitoring of the control measure examples given. As most of the control measures for sanitary completion involve issues of design and maintenance, many of them are most effectively monitored by regular inspections and through reviewing inspection and maintenance reports. The periodic analysis of microbiological indicator organisms is also crucial to the verification and validation of protection measures. In this context, management plans are an important tool to ascertain that inspection and maintenance activities are regularly carried out. This aspect of monitoring focuses on checking whether the controls are operating as intended, rather than on contaminant concentrations in groundwater.

**NOTE**

Options for monitoring suggested in Table 18.5 focus on the control measures rather than on groundwater quality.

Comprehensive groundwater quality monitoring programmes are a supplementary aspect of verification of the efficacy of sanitary completion.

### 18.8 REFERENCES


Sanitary completion of protection works around groundwater sources


