Arsenic, Drinking-water and Health Risks Substitution in Arsenic Mitigation : a Discussion Paper

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Arsenic, Drinking-water and Health Risk Substitution in Arsenic Mitigation: a Discussion Paper

Author:
Guy Howard, Programme Manager WEDC
Loughborough University, Leicestershire, UK

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Executive Summary

Risk substitution

- There are water-related health risks associated with all forms of water supply. In reducing one water-related health risk another may be substituted, sometimes of greater magnitude. In Bangladesh, a consequence of reducing the risk from microbial contamination of drinking water was the inadvertent substitution of a risk from arsenic.

- In developing an emergency response to the arsenic crisis, the potential for risk substitution from other hazards must be considered. Water supply options should be selected within an overall risk management framework of Water Safety Plans. In selecting options, it is important that a consistent approach is adopted in evaluating all risks.

Substitute hazards

- The hazards that may substitute for arsenic include: microbial hazards (pathogens); toxins derived from cyanobacteria in surface water; and chemical contaminants from pollution. This report provides a qualitative risk comparison between arsenic and other hazards, but quantitative risk comparisons should be considered as a priority in the short term.

Risks and poverty

- Risks from both arsenic and microbial hazards are strongly related to poverty and nutrition, and for microbial hazards there is a synergistic relationship between under-nutrition and repeated infection by microbial hazards.

Nature of health effects

- Microbial hazards lead to acute health effects and attack rates commonly range from 20 to 70%. Effects range from self-limiting diarrhoea to mortality. Mortality is more common in particularly sensitive sub-groups (infant, children, immuno-compromised and pregnant women).

- Arsenicosis is a chronic disease with a significant latency period for non-cancer and cancer effects. The proportion of a population exposed to elevated arsenic that will develop arsenicosis is uncertain, but may be significant.

Treatment of health effects

- Medical treatment of infections by microbial hazards is generally well understood. In practice access may be limited to medical care, particularly among the poor.

- Medical treatments for arsenicosis are not fully developed. There is indication that switching to arsenic-safe water and anti-oxidants may reverse symptoms in early stages.

Comparing the risks

- Overall the risks posed by microbial hazards are greater than those posed by arsenic. This does not mean arsenic mitigation is not important but that emergency response measures must ensure that risks from microbial hazards do not increase.

- For all options considered in the emergency programme, hygiene education will be essential to promote safe water handling.

- In the short term it is unlikely that risks from cyanobacterial toxins will be greater than those posed by arsenic, but in the longer-term would need to be considered in defining appropriate water supply options.

Audits in emergency response

- During implementation of the emergency response, third-party audit of construction quality is essential and should apply to all agencies undertaking construction.

Effective control of risks

- Although designs can include effective control measures for microbial hazards, good operation and maintenance is essential to ongoing risk management, even within the short timeframe of an emergency response.

- Community operators require proper training in O&M, including action-oriented monitoring and must have access to the appropriate tools. In addition to training of operators, O&M should be supported through development of an ongoing surveillance programme.

Pond sand filters

- The performance of pond sand filters is often poor and there are concerns regarding both the ability to reduce risks from microbial hazards and cyanobacterial toxins. Consideration is being given to develop slow-sand filters as a more effective alternative to pond sand filters. The use of any technology for treating surface water must meet clear criteria regarding selection of ponds.

Dug wells

- There is some evidence emerging of arsenic contamination of dug wells. Dug wells are also vulnerable to microbial hazards. Although these can be reduced through good design it is difficult to assure water safety in the monsoon and chlorination may be needed. It may be more appropriate to consider renovation of dug wells rather than construction of new wells.

Deep hand tubewells

- Deep hand tubewells are an attractive option as microbial hazards are relatively easy to control. More recent data indicates that the deep aquifer is contaminated with arsenic in some areas. This needs urgent clarification.

- The USGS study will provide further useful information to base decisions regarding the use of deep hand tubewells outside of areas that have been shown to be arsenic-safe.

Rainwater

- The risks posed by rainwater harvesting are relatively easy to manage. Rainwater may not last the whole dry season and therefore promotion of rainwater will need to be combined with other solutions.

Arsenic removal

- Arsenic removal technologies were not included in the short-list of emergency options as none had been formally verified through the ETV. The disadvantages noted for risk substitution for arsenic removal technologies are shared by other alternatives and do not appear adequate to disbar consideration in an emergency response. Community-level technologies would be more attractive than household options at this stage.

Household water treatment

- Household treatment of water to remove microbial hazards could be considered as an option as there is evidence that these have a significant impact on diarrhoeal disease. Promotion of household treatment for microbial hazards could be considered in conjunction with other emergency interventions.

Surveillance

- A programme of water quality surveillance should be developed to support the emergency response and the longer-term mitigation strategy. This can build on pilot activities in urban areas undertaken by DPHE and WHO and the protocol for surveillance in rural areas developed recently for DPHE. The surveillance programme should include testing for *E.coli* or thermotolerant coliforms and a rolling programme of repeat testing of tubewells for arsenic.

Arsenic, Drinking-water and health risk substitution in arsenic mitigation: a discussion paper

1.0 Introduction

A key policy lesson for public health protection that emerges from the arsenic crisis in Bangladesh is that in improving water supply services, consideration must be given of the degree of public health risk substitution that may result. In the case of Bangladesh, the provision of tubewells tapping the shallow aquifer substituted one public health risk (diarrhoeal disease) by another from arsenic. This risk substitution was not predicted at the time and the evidence of the potential for such a substitution was certainly not adequate for an evaluation of the probability and nature of potential substitutes.

In developing the arsenic emergency programme it is essential the potential for risk substitution is properly evaluated and that the selection of water supply options is undertaken within an overall risk management framework. Increasing scientific knowledge of the nature of different risks and how these may be controlled, makes such evaluation both practical and urgent in the arsenic emergency response.

This paper discusses some of the key issues that arise in relation to potential risk substitution from alternative water supply options, taking into account the varying nature of risks and the potential for their management. Within this framework, the efficacy and ease of medical treatment is considered as well as the management actions that can be taken to reduce exposures to hazards in drinking water. The paper draws on the developing paradigm of water safety plans, the approach that forms the basis of the revised 3rd edition of the WHO Guidelines for Drinking-Water Quality (GDWQ).

The key tool within the revised GDWQ is the development and implementation of Water Safety Plans (WSPs) related to health-based targets for water safety. The development of this approach has particular relevance to microbial hazards. WSPs are comprehensive management plans from catchment to consumer that when put in place will assure water safety and outline the necessary means of monitoring and verifying that such risks have been managed at a level determined as tolerable in the context of overall disease burden. Documents supporting this report contain examples of WSPs for small systems.

2.0 Nature of hazards that may substitute for arsenic

There are three principal types of hazard that could be expected to potentially substitute for arsenic from water supply provided during an emergency response. These are:

- Toxins derived from cyanobacteria that may lead to adverse health effects including liver cancer; and,
- Microbial hazards: pathogens derived from human and animal faeces that cause diarrhoea, as well as a range of other diseases, some with significant chronic sequelae;
- Chemical contaminants in source water introduced from pollution.

2.1 Comparing risks from microbial hazards and arsenic

Microbial hazards represent an overall greater threat than chemical hazards and in developing countries account for a significant proportion of the burden of disease. Diseases due to microbial hazards from poor water, sanitation and hygiene are responsible for 5.7% of the total global burden of disease. For microbial hazards, as for carcinogenic risk from arsenic, it is assumed that no safe threshold exists and that any exposure has the potential to initiate an adverse health effect.

When comparing the risks associated with arsenic and microbial hazards, several important points emerge. Both are strongly influenced by poverty and nutrition. Risks of infection by microbial hazards (pathogens) increases markedly with increasing poverty. The overall health burden from pathogens is significantly greater in poorer communities. Arsenicosis also appears to be related to poverty and has a greater incidence among poorer households exposed to elevated concentrations of arsenic. For both pathogens and arsenic, poor nutrition is likely to contribute to greater susceptibility. In the case of microbial hazards, repeated infection also significantly contributes to under-nutrition.

The degree of uncertainty regarding the epidemiology of arsenic-related health effects and the progression of arsenicosis makes quantitative risk comparisons with health effects from microbial hazards difficult. Equally, there is significant uncertainty regarding the role of drinking-water in infectious disease transmission in Bangladesh, primarily because of the limited water quality data and the limitations of data solely expressed in term of index organisms. Undertaking quantitative risk assessment is certainly possible, but would require collection of further data on target pathogens in drinking water and this should be considered as a priority in the short-term. However, although quantitative risk comparison may be difficult, qualitative comparisons are possible and are outlined below.

2.2 Nature of health effects

The nature of health effects between microbial hazards and arsenic are very different. Arsenicosis is essentially a chronic disease and there is a significant latency period before symptoms are developed. There appears to be discrepancy in the literature regarding latency, with some reports of 2 years being the minimum for hyperpigmentation and keratosis. Researchers in Bangladesh suggest that 5 years is the minimum latency, whilst some other estimates suggest that this is 9 years. Latency for cancers is also unknown, but it is estimated to be of the order of 20 years.

Microbial hazards typically lead to acute health effects with (in all but a few cases) incubation periods of typically hours to days. Most episodes of infection lead to self-limiting diarrhoea provided fluid replacement is practised. However, all pathogens can lead to mortality and this may be significant in sensitive sub-populations, notably infants and children (all pathogens), immune compromised (often to specific opportunistic pathogens) and pregnant women (specifically in relation to hepatitis E virus). Furthermore, although many episodes of diarrhoea are in themselves self-limiting, there is a synergistic relationship with under-nutrition from repeated episodes.

The proportion of a population exposed to elevated arsenic from drinking-water that will go on to develop arsenicosis is unknown. WHO have modelled the progression of arsenicosis using data from Samta, Bangladesh. The range of those affected over 30 years was 15.75% in the lowest estimate scenario to 29.25% in the highest estimate scenario. Variation in the estimates of mortality from cancers was between 5.0 and 6.5%. This implies a significant overall health burden for those affected.

Estimating the number of people that will develop symptoms of an infectious disease from exposure to pathogens is also uncertain, as this depends in part on the dose ingested and susceptibility of the host, but outbreak data suggest that this is in the range of 20% to 70%. The proportion of those who become infected who die varies, but is typically low among healthy adults with much higher rates for sensitive sub-populations.

Medical treatment for microbial hazards is generally well-understood, although in practice access to the required interventions may be limited, particularly among the poor. Some sequels (e.g. reactive arthritis) may be more problematic to treat.

Treatment of arsenicosis remains an area of uncertainty. Current evidence suggests that during early onset, switching to arsenic safe water reverses symptoms, although there is a lack of controlled trials in Bangladesh on which to validate this and to identify the stage at which this is no longer effective. It is not clear whether early removal of arsenic-contaminated water would reduce the onset of cancers, but it is assumed that it would have some impact because of the cumulative nature of the risk.

More recent work suggests that anti-oxidants within vitamins A, C and E and possibly compounds containing zinc and selenium also work to reverse symptoms. A recent controlled trial was performed in Bangladesh, but this remains to be published and may require further controlled clinical trials. However, this does indicate the necessity of combining both environmental and medical interventions for arsenicosis.

The nature of the acute health effect from microbial hazards, the particular impact on sensitive sub-populations, the typical attack rates and the synergistic relationship with under-nutrition show that the risk posed by microbial hazards is greater than for arsenic. This does not imply that arsenic mitigation is not important, but to emphasise the need for emergency response measures to ensure that risk from microbial hazards do not increase.

Experience shows that control of microbial hazards in the technologies considered for the emergency response is possible, but that in order to achieve this control actions are required in the short and long-term. The Section 3 of this paper will identify specific issues that need to be considered and suggest ways in which control can be maintained. Examples of water safety plans for most of the technologies are provided in the supporting documents.

It should also be recognised that if technologies are introduced that are not acceptable to the end users then not only will the risk from arsenic continue to threaten the health of some of the population, but risks from microbial hazard may also increase as water supplies deteriorate. Part of the acceptability will include the typically greater distance to the source that will result from most of the options considered in the emergency response. There will be a need for ongoing education and effective risk communication to prevent households from maintaining use of existing contaminated tubewells for water for drinking and cooking.

2.3 Comparing risks from other potential hazards

The risks associated with toxins derived from cyanobacteria include liver cancer. Other effects include acute poisoning from immersion in water where there is a bloom. Cyanobacterial blooms are found in surface waters with high nutrient loads and recent work in Bangladesh has identified that these blooms occur in some ponds in the country. Nutrient loads may be derived from general pollution and commercial fish-farming may further contribute to phosphate and nitrate input. In addition to direct adverse health effects, algal blooms often lead to significant taste and odour problems that may lead to the rejection of a source by users.

Although toxins from microcystis (particularly microcystin-LR) may lead to cancer end-points, the overall health impact of cyanobacterial toxins remains unclear. Within the short-time horizon of an emergency response it is unlikely to represent a greater risk than drinking arsenic contaminated water. Furthermore, as discussed below some removal of toxins may be possible through water treatment.

In the longer-term response to arsenic, however, the risks from cyanobacterial toxins may be more significant given the extended duration of consumption. This will therefore need to be addressed in defining water supply options. It would seem unwise at this stage to consider the use of a water source that is known to be affected by cyanobacterial blooms for any intervention likely to extend beyond a very short-time period and only then if no other options were available and there was strong preference for communities for use of pond water.

Other potential hazards include chemical derived from pollution, for instance nitrate and pesticides from agriculture and heavy metals from industry and air pollution. Although there is evidence of pollution of surface waters and from air pollution in urban areas, the overall risks associated with such pollution will be significantly lower than for microbial hazards and arsenic.

3.0 Technology options and controlling risks

A short list of technologies has been identified by the National Committee of Experts (NCE) as suitable for consideration in the emergency

response to arsenic (that is in villages where the proportion of arsenic contaminated tubewells exceeds 80%). These are:

- Pond-sand filters
- Dug wells (also referred to as ring wells)
- Deep hand tubewells
- Rainwater harvesting

It is envisaged that direct provision of the first three technologies by DPHE and partners in a supply-driven approach, but that Government would only engage in promotion of rainwater harvesting. The NCE excluded arsenic removal technologies from consideration in the emergency response. These are considered here, however, as the rationale for exclusion of these technologies appears to be inconsistent with approach used to accept the other technologies. Household treatment of water to remove microbial hazards is also briefly considered.

3.1 General issues regarding risk substitution

In discussing the potential for risk substitution and risk management for emergency response technologies, some general key points emerge. For all options used in the emergency response, hygiene education will be essential to promote safe handling of water to reduce re-contamination and increasing risk from microbial hazards. A WSP for water handling is included in the supporting documents to this report.

The NCE raise the importance of third party audit to ensure that all components of the intervention (including construction quality) have been followed. This is essential and it is recommended that in the first instance this is done on a blanket rather than sample basis. This also requires that standard designs are developed with indicative unit bills of quantities prepared. Standard auditing procedures and forms should be developed and used. Where audits identify failure to comply, there should be a requirement for the constructing agency to make the required changes at their own cost. It is important that auditing is applied to all water supplies constructed, irrespective of whether this is by Government, private sector or NGOs.

Although designs and construction can provide control measures for hazards, experience from around the world shows that risk management of microbial hazards in particular is dependent on good operation and maintenance. Even within the short timeframe envisaged in the emergency response, poor operation and maintenance may lead to a significant increase in risk.

Ensuring good operation and maintenance in community supplies requires two key interventions. Operators must be provided with adequate training and provided with the basic tools with which to undertake maintenance tasks. Training should also include basic skills in monitoring the water supply through action-oriented inspection to ensure that incipient problems are resolved. The second activity should be a process of ongoing support through a surveillance programme that ensures that periodic inspection and testing of the water supply is carried out and results used to support communities in ensuring effective operation. This latter point is briefly discussed further below in Section 4.

For options that use groundwater, controlling contamination requires both proper wellhead/sanitary completion and control of contaminant sources around the facility. The latter are termed protection zones and are typically defined for both microbial and chemical contaminants. This includes, for instance, exclusion of on-site sanitation close to the tubewell to prevent contamination of the aquifer. Simple methodologies are available and have been based on work in Bangladesh. Further assessments are proposed to define safe distances between latrines and tubewells in the country through DPHE/UNICEF.

3.2 Pond sand filters

Pond sand filters (PSF) were designed based on the principles of slow-sand filtration although actual designs violate several these principles, including depth of filter bed, flow rate and intermittent supply (head) above the top of the filter. As the PSF draw water from surface water sources, the potential for microbial hazards to be present in source waters is very high. In addition to contamination by human faeces, the potential for animal faecal contamination is likely to be significant and hazards of particular concern will include E.coli O157, Cryptosporidium parvum and Camplyobacter spp. In ponds affected by algal blooms or receiving high nutrient loads, the risk from cyanobacteria toxins will also be increased.

Although some reports suggest that PSFs are efficient in removing microbes, this has only addressed thermotolerant coliforms. Other results indicate that in practice performance is commonly poor and that microbial contamination of final waters is common. Concerns have been raised about the ability of pond-sand filters to remove pathogen loads in very heavily contaminated ponds and would require a further disinfection stage to be effective.

Overall, the generally poor performance of the PSFs suggests that these have significant potential for risk substitution and would not be a preferred solution in most cases.

3.3 Slow-sand filters

UNICEF are considering trying to modify the PSF design to become slow-sand filters, with potentially use of pre-filtration. In a variety of studies at both bench and field slow-sand filters, removal rates of viral and bacterial pathogens have been shown to be effective. Up to 5-log removals

of bacterial index organisms and viruses are recorded in the literature. Interestingly, although removal of Giardia cysts is relatively good, in general the removal of cryptosporodium is far less effective.
The influence of turbidity on slow-sand filter performance is well-known and has led to the development of multi-stage filtration units that provide effective turbidity removal prior to the slow-sand filter. Roughing filters should be capable of removing reasonably fine material and algae. However, if the turbidity is principally clay material, removal may not be as efficient, although with microbial colonisation of the media this could be expected to improve. The potential for use of geotextiles to improve the speed of schmutzdecke formation could also be considered.

Slow-sand filtration is effective in removing algal cells, which may be enhanced where there is some form of pre-treatment to reduce algal cell loading to prevent increasing frequency of removal of the schmutzdeke. There have been laboratory-based studies of toxin removal that showed removal of various toxins in the range of 30% to 80%, but reporting of performance in the field is not available.
In developing a slow-sand filter, consideration should be given to development of two units in parallel, which would be usual recommended practice. Although there are clearly good financial reasons for use of a single unit, this will lead to a significant increase in risks of microbial breakthrough during the ripening period. Although this risk could be mitigated by applying a final disinfection stage, this may not provide full protection (for instance if breakthrough also includes particles) and would increase both cost and operation requirements. In ponds with algal blooms, the filter ripening period would almost certainly increase the risk of toxin breakthrough, although this would not be likely to be at levels that are acutely toxic.

If slow-sand filters are to be used, clear criteria will be required to determine which ponds are suitable for use, for instance clearly defined set-back distances for animal rearing. The development of a standardised format (similar to those available in the WHO Guidelines for Drinking-Water Quality Volume 3) is an important tool in determining whether PSF is a viable and appropriate option. Such a tool logically needs to include measures for assessing risks of cyanobacteria presence. Simple tools are available for such assessments using visual inspection and, where available, assessment of total phosphorous as a limiting nutrient for biomass development.

3.4 Dug wells

Hand-dug wells of various descriptions are a familiar technology in Bangladesh and several standardised designs are available approved by DPHE for use. However, there is evidence emerging that some dug wells are contaminated with arsenic above the Bangladeshi standard of 50µg/l. This makes their use more problematic as investment in dug wells may not result in any reduced risk from arsenic, but an increased risk from microbial hazards - thus a double risk substitution.

The vulnerability of dug well to microbial contamination is significant. The problems of direct ingress may be overcome through the use of designs that include concrete aprons, concrete linings, raised headwalls and covers. Nonetheless, it is often difficult to ensure that the linings are watertight and ingress of water through the lining at the upper levels is common. Where dug wells have been installed in other countries with heavy seasonal rainfall, difficulties have been found in maintaining microbial quality in wet seasons. The few available studies indicate that this more often due to poor maintenance of the headworks than from sub-surface leaching from, for instance, pit latrines.

Risks may be further reduced by ensuring a sanitary means of abstraction from the well, either through use of a handpump or by windlass and bucket systems. In the latter case, however, theory is much better than practice as commonly designs where the bucket need never touch the ground are rapidly modified by users to maximise their user-friendliness. Pumps installed on dug wells have proven in many cases to provide significant improvements in quality.

In addition to the need for good operation and maintenance, risks can be further reduced by installing a system of chlorination or where a handpump is used, to install a filter at the base of the well covering the screen.

Chlorination could well be limited to only the monsoon season when risks would be expected to significantly increase. Projects in other countries have shown that chlorination can be effective, but requires good training and follow-up. In some areas it is likely that dug wells may become inaccessible during flooding and would also become heavily contaminated. In these situations, emphasis during training must be given to the need for disinfection of the well prior to re-starting use in the dry season.

As noted by UNICEF Bangladesh, it may be more appropriate to consider renovation of dug wells rather than construction of new wells. In both cases, evidence would be required that the shallow aquifer was not arsenic contaminated.

3.5 Deep hand tubewells

Deep hand tubewells have been identified as an attractive emergency response measure. This is in part because of the limited evidence of arsenic contamination of the deep aquifer and because in parts of Bangladesh there is a significant aquiclude/aquitard between the shallow and deep aquifers that should minimise the potential for leaching provided construction is properly carried out. There is a recognition of the need to ensure designs are effective in preventing leaching within Bangladesh and recommended practice is outlined in available documents.

In terms of risk substitution, deep hand tubewells are attractive, because microbial contamination is relatively easy to prevent through good wellhead/sanitary completion and by restricting pollution within protection zones. Wellhead completion is relatively easy and cheap to assure during construction and require only limited maintenance to prevent rapid contaminant pathways developing.

Despite the generally positive prognosis of the use of deep hand tubewells, reservations remain regarding their use as an emergency measure. In some parts of Bangladesh, notably the coastal area, the deep aquifer has been exploited for many years and has not shown arsenic contamination. Use of deep hand tubewells in these areas is therefore a sensible option.

The same situation was largely assumed to be the case in other parts of Bangladesh, but this is becoming less certain. More recent testing of deep tubewells have indicated a significant proportion with arsenic contamination. One problem with interpreting this data is the significant uncertainty regarding the accuracy of the records on well depth. Therefore, it is possible that some of the deep tubewells are in fact shallow tubewells drawing water from the contaminated aquifer. This needs to be clarified as a matter of some urgency.

There is a current survey being undertaken by the USGS of the deep aquifer in order to develop a better understanding of arsenic movement in the sub-surface and the scale and degree of arsenic contamination in the deep aquifer. Until this study is completed, it would seem unwise to promote deep hand tubewells as an emergency response, although they may become more viable in the longer-term response.

3.6 Rainwater harvesting

Rainwater harvesting is an attractive emergency response technology because it can be located at the home, thus preventing an additional burden on women and children to collect water and because of the abundant rain in Bangladesh. Good designs of rainwater tanks are available and relatively low cost.

The major risk associated with rainwater harvesting comes from faecal matter that may get washed into the tank (one particular risk is associated with Salmonella from bird faeces). This is easily mitigated through use of a first-flush diversion system and through cleaning of the roof and guttering. The critical time for this is the start of the monsoon, as once this is underway it is unlikely that there will be significant build-up of faecal material. In rural areas it is unlikely that there will be a significant risk related to chemical hazards, but this will increase in urban areas due to air pollution from traffic. It is essential that the designs of rainwater systems have meshing on the overflow pipes in particular to prevent the water in the tank becoming a vector breeding site.

In relation to hazards from ingestion of water, rainwater harvesting is generally a relatively low-risk option, although large-scale studies have not been carried out. However, as rainwater harvesting is unlikely to provide drinking-water to last the entire dry season, unless larger tanks are provided. This may therefore mean that the promotion of rainwater use must be linked to provision of alternative options to provide water security throughout the year. Nonetheless, rainwater harvesting offers significant potential for improvement in water safety with acceptable risks attached.

3.7 Arsenic removal technologies

The NCE recommended that arsenic removal technologies should not be considered in the emergency response because none of the technologies had been formally verified through the ETV. The NCE has highlighted a range of benefits and disadvantages in the use of arsenic removal technologies at both household and community levels and these are not reviewed in detail here. However, it is pertinent to note that some disadvantages highlighted would equally apply to the water supply options recommended.

The results of the rapid assessment of arsenic removal technologies showed concerns that the use of most household units were associated with an increase in microbial contamination compared to feed water. As discussed in the report of the assessment, this is primarily due to poor hygiene and handling. However, it is likely that re-contamination of water from communal water sources will also be common and many studies world-wide have shown that this occurs even where households use sources of good microbial quality.

Although the disadvantages noted by the NCE are not insignificant, it is debatable whether these are sufficient to disbar consideration of arsenic removal technologies within an emergency response. Although none of the technologies has been formally verified, for a number of these technologies there is a large body of evidence of their effectiveness in removing arsenic. Although there may some risk substitution for microbial hazards, this is not considered to be any greater than for any technology where water must be transported and stored within the home.

Much of the evidence already available for these technologies (including from the manufacturers and the rapid assessment of arsenic removal technologies) is at least as good as the evidence of risk reduction offered by alternative water sources. In terms of overall health risks, it is far from clear that the risk posed by some of the outstanding questions is greater than those posed by the alternative water sources proposed.

The use of arsenic removal technologies at either a community or household level offers significant efficiencies as an emergency response. In the case of household technologies, the capital investment costs to Government will be negligible and significant risk reductions can be expected to accrue at a household level. If the purpose of the emergency response is in effect to gain additional time to permit the development of longer-term improvements in water supply, such a process is attractive.

The installation of a community level technology would potentially offer not only the short-term response but could feasibly develop into a longer-term solution for communities that were interested in purchasing a unit. In such a scenario, initial installation may be free of charge, but retention of the unit beyond the immediate response would entail the same processes of cost-recovery as alternative supplies. Effectively, the treatment unit would become a further option that could be considered in a demand-responsive approach to long-term water supply.

There remain issues around the operation of community-level removal plants, notably the monitoring of the performance of arsenic removal and the timing of media replacement. This is complicated in some areas where phosphate in groundwater competes with arsenic for adsorption sites. These represent areas where solutions must be found in the short to medium term, but may not be as significant in the context of an emergency response as external monitoring and support could be provided to communities.

As noted at the start of Section 3, when considering the potential for risk substitution for alternative water supply options, the rational for excluding arsenic removal technologies appears inconsistent. Arsenic removal technologies may provide a viable emergency response where the potential risk substitution can be managed.

3.8 Household treatment of water for microbial hazards

This was not considered by the NCE, but has been raised as an option by some NGOs and other working on developing emergency interventions. A number of options exist for undertaking household treatment of water, including low-cost chlorination (notably the CDC Safe Water System), solar disinfection (for instance SODIS) and within Bangladesh the development of a system that uses household cooking stoves to pasteurise water is being developed. Operation and maintenance of most systems for improving microbial water at a household level are simple.

The CDC Safe Water System has been shown to be a very effective means of reducing diarrhoea, with a range of between 25% (from a study in slums in Dhaka with no sanitation) to 85% (in a study in Uzbekistan where sanitary conditions were poor). The data for other interventions is less well developed and as these result in increased water temperature may lead to problems with acceptability. However, it is known that the SODIS system may also remove arsenic.

WHO has recently completed a review that concluded that this was an effective interim solution to obtaining water of acceptable microbial quality. There may be risks of disinfectant by-product formation if very organic-rich surface waters are used.

The promotion of low-cost household water treatment could accompany any of the interventions currently considered under the emergency programme. It could potentially also be used as stand-alone intervention to treat surface water, although additional treatment steps will be needed to reduce turbidity for disinfection and there would be a need for ongoing testing to ensure that it remained effective. This approach should be considered for inclusion within the emergency programme and linked to hygiene education programmes.

4.0 Ongoing surveillance and support

The development of ongoing surveillance should be an essential component of the mitigation programme. Pilot activities in developing surveillance of water supplies have been undertaken in urban areas of Bangladesh (for example Rajshahi and Mymensingh) by DPHE with support from WHO and DFID via a WEDC research project. and in Rajhahi and Mymensingh from DFID (via WEDC). Work has also been undertaken on development surveillance activities for small towns.

Surveillance in urban areas has involved testing of both piped and non-piped water sources for microbial and chemical quality, sanitary inspections of facilities and testing of household water. The use of surveillance information has been used in developing improvements undertaken by City Corporations and by communities to improve water quality and sanitary conditions. Both laboratory methods and field kits have been used to undertake these activities. In addition, there has been development of widespread testing of water quality, particularly testing for arsenic, in rural areas. A protocol for the development of a rural water quality surveillance programme has been prepared for DPHE, which includes recommended parameters for inclusion, frequency of testing for different technologies and household water, and provides an institutional framework for surveillance implementation.

There is a need to develop and roll-out surveillance programmes as part of the mitigation programme. This will help to ensure that operation and maintenance of technologies introduced during the emergency response is effective. It will also provide opportunities to support hygiene education and to use water quality testing and as an entry for point for improving overall water safety. The implementation of a surveillance programme will also greatly strengthen the evaluation of the impact of the emergency response and in refining policy and strategy for arsenic mitigation.

The surveillance programme should include testing of microbial quality using in the first instance E.coli or thermotolerant coliforms, but increasing aiming to introduce other index organisms. Sanitary inspections should also be undertaken. It should also include testing of arsenic in tuebwells, both those previously identified as being contaminated and those previously identified as being arsenic safe. Other parameters as per the protcol for surveillance should also be included. Ongoing collection of this data is important in order to assess whether temporal changes occur in arsenic concentrations.

Surveillance programmes in rural areas should not attempt to visit and test every water supply on a regular basis. A rolling program of visits to water supplies should be developed with an aim to visit each supply once every 3-5 years and either stratified random sampling or cluster sampling used to select specific supplies to be visited.

5.0 Summary

The table below summarises the major issues in relation to risk substitution and the potential for control within design and construction and operation and maintenance. This table does not attempt to rank the technologies with regard to their use, which has been done by the NCE, but simply sets out what issues will need to be considered.

For all technologies, ongoing support through surveillance and hygiene education will be essential to ensure risk management is effective in the long-term up to the point of consumption.

It is recommended that arsenic removal technologies, particularly those that work at a community level, be considered as an option for the emergency response.

Technology	**Risk substitution potential**	**Control through design & construction**	**Control through O&M**
Pond sand filter	Certain and high for microbes; potential for cyanobacterial toxins & chemicals	Control may be difficult to achieve unless new designs developed	Essential, significant potential for risk increase with poor O&M
Dug well	Certain for microbes; potential for chemicals	Control can be achieved, but likely some risk will remain	Essential, significant potential for risk increase with poor O&M
Deep hand tubewell	Limited potential for microbes and arsenic	Control can be achieved for microbes, uncertain for arsenic	Important for microbes; insignificant for arsenic
Rainwater	Certain for microbes, potential for chemicals from air or roofing; potential for vectors	Can achieve control for microbes, no impact for chemicals	Essential for microbes; no impact for chemicals
Community-level arsenic removal technologies	Potential for microbes to substitute	Can achieve control for both arsenic and microbial quality in some technologies	Essential for arsenic; important for microbes
Household treatment for microbial quality	Potential for THM if organic-rich surface water used	Can achieve control for microbes and THMs	Essential for microbial and chemical quality

Annex 1: Water safety issues and examples of 'model' Water Safety Plans

This annex provides an overview of how the microbiological quality of drinking water may be controlled through protection of water sources, control of treatment processes and management of distribution and handling of water. It uses the principles of water safety plans and provides guidance on how WSPS and codes of practice can be defined for a range of water supply technologies and for household water handling and storage. For a range of technologies, 'model' water safety plans are defined.

WSPs should be subject to approval by the regulatory body who should have access to a range of statutory tools to impose penalties for non-compliance. This may be in response to failure to prepare an adequate management plan or failure to comply with it once established. However, as with all regulatory regimes, flexibility will be required and a range of other tools (relaxations, exemptions etc) may also be needed.

In some circumstances national or regional authorities may wish to establish a suite of basic management plans to be used by local suppliers either directly or with limited adaptation. This may be of particular importance when the supplies are community-managed. For community managed supplies, an approach focusing on ensuring operators received adequate training and support to overcome management weaknesses will be more effective than enforcement of compliance.

Hygiene codes are also presented for household treatment of water and water hygiene. These should by used in conjunction with education programmes as a way of promoting good hygiene. However, there should also be enforcement of minimum design criteria by manufacturers of water treatment technologies.

The following sections provide examples of outline management plans for some of the more frequent types of supply. In many cases several components may be needed to prepare an overall management plan. Thus for piped supplies it may be appropriate to link the management plan components of source protection and treatment with those for distribution. Where water supplies are not continuous, then household management of water will be an important additional component to be included.

The hygiene codes that follow are indicative and should be modified to meet local needs and to suit local conditions. Hygiene codes are presented for the following types of water supply and household management of water:

1. Tubewell from which water is collected by hand
2. Spring from which water is collected by hand
3. Simple protected well
4. Rainwater catchment
5. Storage and distribution through community managed piped systems
6. Groundwater from protected boreholes/wells with mechanised pumping
7. Household handling and storage of water
8. Household disinfection
9. Household filtration systems

In each section there is an initial introduction to provide an overview of the situations when the type of supply may be found and the evidence of health risks derived from the use of the technology. Each section then addresses four groups of issues.

Selection of reference pathogens and assumptions made. These sections provide an outline for the basis of identifying key challenges to health and therefore the water resource, design and control measures required to minimise the risk to public health. The reference pathogens relate to those discussed in a report of a WHO meeting on regulation of microbiological quality held in Adelaide, Australia, 2002, but it should be noted that not all these pathogens are applied to all technologies.

Hazard assessments. These sections review the process of conducting a qualitative assessment of hazards that may cause contamination of the water supply. For surface waters this means an assessment of the catchment and for groundwater an evaluation of the recharge area. In groundwater hazard assessments, the type of aquifer must be taken into account.

IWRM and regulatory issues. This section outlines the major controls that should be in place at national and regional level in order to enable local action to be effective. These are aspects which may be outside the direct control of the supply agency itself but which are important to the management plan. These primarily concern national legislative frameworks, local laws and integrated water resource management. They also cover basic issues of importance such as training needs.

Design Issues. This section looks at the basic design criteria required to ensure the adequacy of the installation to provide water reaching water quality targets. Many design issues are also control measures in a water safety plan.

Small, community-managed point source groundwater supplies

The following drinking water quality management deal with a series of small, usually community-managed water supplies that use shallow groundwater. These supplies are mainly 'point' supplies – i.e. water must be collected from the source by hand.

The majority of these supplies are to be found in low and middle income countries, although occasional examples may be found in wealthier countries. Whilst such supplies are generally considered to be found primarily in rural areas, there are very large numbers of such supplies in poor urban and peri-urban settlements throughout the developing world. This includes small towns as well as some of the World's largest cities such as Dhaka. The use of such supplies may not be the preferred water supply solution in such situations, however, the reality is that millions of people in cities worldwide have little prospect of access to treated piped water in the short term. This emphasises the need to address the quality of all such sources whether urban or rural.

The nature of community-managed supplies also suggests that while engineering interventions may do much to reduce risks, training and support to communities in water supply management is likely to be more critical and this should not be neglected by the water supply and surveillance bodies.

The collection of water from such sources by hand implies that controlling the quality of the water at these sources will not be sufficient on its own to reduce water-related health risks to an acceptable level. Additional interventions are also likely to be required in water handling and potentially household water treatment as discussed further below.

Selection of reference pathogens and assumptions made

The selection of reference pathogens and key assumptions do not significantly differ between the different types of technology and are therefore presented here. The comments will therefore apply to the next three drinking water management plans.

Critical to the establishment of water quality targets for point source groundwater supplies is an understanding of the movement, survival and attenuation of different pathogens within the sub-surface environment. For a full review of this please consult Chapter 3 of the monograph Protecting groundwater for health.

Evidence suggests that control of the risk posed by viruses in groundwater is difficult to achieve solely through land-use control and wellhead protection measures. There is good evidence of greatly extended survival and travel of viruses within the sub-surface and attenuation processes may only retard and not remove viral pathogens. One consequence of this is that elution of viral pathogens may occur due to changes in environmental conditions caused by recharge. Therefore, for greater confidence that risks from viruses have been controlled, contact disinfection is likely to be required. Whilst the land-use control measures outlined below provide some confidence in reducing viral risks (particularly at the longer travel times) this may not reduce levels to those deemed acceptable. Furthermore, such controls may not be feasible even when using vertical as well as horizontal flow in many settings and therefore an elevated residual risk from viral pathogens may need to be tolerated (ARGOSS, 2001). In most cases, as first exposure to viral pathogens is likely to occur during childhood rather than adulthood, control of virological quality may be less urgent. In most cases, unless disinfection is practised this would be difficult to achieve.

The principal basis for the control of microbiological quality of these supplies is in relation to risks posed by bacterial and protozoan pathogens. For bacterial pathogens, *E.coli 0157* is used. The measures put in place to reduce risks from *E.coli 0157* would be adequate to deal with other bacterial pathogens. *Cryptosporidium parvum* is used as the reference pathogen for protozoan agents as it has been shown to be present in some groundwater supplies.

Hazard assessments

Hazard assessments for point water supplies should, like for most water sources, be undertaken prior to construction and commissioning of the source and on periodic visits to the source. This will usually be undertaken through a sanitary inspection. Initial hazard assessments should be used to plan and design the water supply. It may be that hazards exist that are associated with a significant risk due to distance from proposed water source or because of flow rates. In such cases, risk management strategies may require careful thought such as deepening the intake.

IWRM and regulatory issues

The IWRM and regulatory issues for all three principal forms of point water supply from groundwater sources are covered in a single section here as they are all basically the same. The linkages between some key IWRM issues for point groundwater sources and those identified for deep boreholes with mechanised pumping should be noted. Groundwater management and protection strategies should cover all forms of groundwater abstraction found within the country and it is important that shallow point sources of groundwater are not disadvantaged by measures to protect deeper abstraction.

Issue	Justification/explanation (includes cross-referencing to support texts for checking in finalisation	Appropriate actions
Groundwater assessment and mapping	Critical to control of water quality in groundwater is to understand the nature of the groundwater regime and the unsaturated zone.	Establish national borehole archive Prepare national groundwater maps
Legal basis for groundwater protection established with lead agency identified.	The need for a defined legal mandate is crucial for protecting groundwater. A lead agency is needed to develop policy and implement strategy.	Institutional analysis to identify lead agency Groundwater issues incorporated into water resource legislation Statutory power defined and statutory instruments established
National groundwater management and protection strategy developed	Strategies that incorporate concepts of vulnerability of groundwater. Within areas defined as vulnerable, land-use control measures will be required and groundwater abstraction are controlled.	Determine protection zone basis (usually a function of travel time) Review groundwater maps and delineate protection zones
Protection areas/set-back distances established based on local conditions	In each area protection areas or zones should be established on an understanding of the groundwater flow, potential for attenuation and engineering measures available for mitigation.	Minimum safe distances defined for each type of technology and aquifer type defined
Material specification	Poor quality of materials used on construction is closely linked with infrastructure deterioration and water quality failure	Minimum design criteria established and enforced Materials allowed for use specified Material quality certification
Abandoned wells and other excavations close to the source and which could affect water quality should be filled in	This is an important aspect to control as abandoned wells and even shallow excavations left open may provide rapid recharge routes into the aquifer. This may lead to either localised (source specific) or widespread (aquifer-wide) contamination.	Requirement that all non-water excavations to be filled Specification of capping materials & techniques
Proper training of community operators to ensure operation and maintenance can be performed	A significant amount of the deterioration in microbiological water quality can be ascribed to poor operation and maintenance. Thus skills and schedules must be developed to support community operators	Establish training needs Establish training programmes Ensure tools available for basic maintenance

Tubewell or borehole from which water is collected by hand

Design issues

Shallow tubewells or boreholes are used in many developing countries and are often the preferred method of water provision in rural communities. Many different techniques exist for drilling tubewells and some of these, particularly some of the very low-cost methods themselves raise the risks of contamination. Tubewells are usually fitted with handpumps, although some designs of windlass have been used. A variety of types of handpump are available and again these may themselves represent water quality risks, particularly where water is need for priming. Sustaining handpump-based water supplies is often difficult because of associated costs and this should be borne in mind when promoting their use.

Design issue	Justification/explanation (includes cross-referencing to support texts for checking in finalisation)
Lining/casing of tubewell should extend at least 30cm above the ground level/apron	If lining does not extend above the ground level or level of the platform/apron, then wastewater or surface water may be able to directly enter the riser pipe, leading to contamination.
The annulus around the lining/casing should be sealed for the top 3-5 metres.	This represents a highly vulnerable component of the tubewell as this may create a direct short-circuit route into the rising main.
An apron/platform should be cast around the top of the lining (at least 1m radius).	The lack of an apron/platform may allow wastewater or surface water to infiltrate close to the rising main and cause contamination is short-circuits exist. The joint between the annulus seal and the apron should be sound
Pipe joining technique	Glued joints tend to be weaker and more likely to develop. Threaded screw joints are preferred.
Handpump specification	Handpumps that require priming may be more vulnerable to contamination. Therefore lift pumps are preferred to suction pumps.
Setting screen as deep as possible	Greater depth increases vertical movement of water. This tends to be much slower than lateral movement and therefore small increases in depth to the intake may increase travel times significantly
Drilling method	Lower-cost drilling methods may reduce the possibility of implementing some of the protection measures noted above (particularly sealing the annulus around the casing). They may still be used in soils that collapse easily around the lining, but it is likely a significant residual risk will remain.
Filter pack placed around intake to remove suspended sediment and larger organisms	Without filter packs suspended sediments may be able to enter the rising main. Ingress of larger micro-organisms has occurred in some consolidated aquifers
Disinfection prior to commissioning	The tubewell should be fully disinfected by leaving a chlorine solution inside the rising main (which by preference should be nearly full) in order to remove contaminants introduced during sinking. Water should be pumped to waste.
Surface water diversion ditches provided to protect against inundation	Inundation by contaminated surface water during rainfall and flood events can lead to pathogen presence.
Wastewater from tubewell drained away from the riser pipe	Waste or spilt water may potentially re-enter the tubewell and carry contamination from the surface. This may lead to introduction of contaminants especially if the area is not fenced. The apron should be sloped away from the riser pipe and a drainage channel installed to remove wastewater away from the tubewell.
Area around tubewell and apron fenced	The lack of fencing may allow animals to damage the apron and cause flow paths to develop close to the tubewell. They may also defecate on the apron leading to a direct hazard

'Model' water safety plan for boreholes fitted with handpumps

Hazard event	Cause	Risk	Control measure	Critical limits		Monitoring			Corrective action	Verification
				Target	Action	What	When	Who		
Ingress of contaminated surface water directly into borehole	Poor wellhead completion	Unlikely/ Major	Proper wellhead completion measures	1m concrete apron around wellhead; lining extends 30cm above the apron; drainage ditches in place	Lining stops at ground level. Apron damaged or cracked. Ditches full, faulty or absent	Sanitary inspection	Monthly	Community operator	Extend lining Repair apron Clean and repair drainage ditches	Sanitary inspection. *E.coli* Faecal streptococci Bacteriophage
Ingress of contaminants due to poor construction or damage to the lining	Poorly maintained welllhead completion	Moderate/ Major	Proper wellhead completion	Top 5 metres of the annulus sealed Rising main in good condition	Annulus sealed for less than 3 metres. Colour changes Increased pumping required to raise water	Sanitary inspection Water clarity	Annual/as need arises	Community operator	Insert seal around annulus. Replace worn and corroded rising mains. Use materials less likely to corrode (e.g. plastics)	Sanitary inspection; analysis of colour and iron
Borehole area is inundated with contaminated surface water	Lack of diversion ditches	Unlikely/ Major	Good drainage around wellhead	Diversion ditches of adequate size, in good condition and clear of rubbish	Ditch has rubbish or shows signs of wear	Sanitary inspection	Monthly	Community operator	Repair and clean ditch Increase size of ditch using	Sanitary inspection
Contamination introduced as handpump requires priming	Priming water contaminated	Almost certain/ Minor	Use direct handpump or clean water for priming	Water for priming stored in secure container	Priming water comes from contaminated source or is stored poorly	Inspection	Weekly	Community operator	Select handump that does not require pumping.	Test priming and borehole water for *E.coli* and faecal streptococci
Contaminated shallow water drawn into aquifer	Hydraulic connection exists between shallow and deeper aquifers allowing draw-down into deeper aquifer	Almost certain/ Minor	Pumping regimes do not induce leaching	No evidence of drawdown of shallow groundwater	Evidence of shallow water drawdown (e.g. shallow wells start to dry up)	Colour Taste Odour Inspection	Annual/as need arises	Community operator	Set intake deeper (microbes) Water treatment (microbiol) blending (chemicals)	*E.coli* Faecal streptococci Bacteriophages Nitrate Tracer studies Hydrological models Electric conductivity Redox potential
Leaching of microbiol contaminants into aquifer	Leaching of faecal material from sanitation, solid waste, drains	Moderate/ Moderate	Provide adequate set-back distances defined on travel time	No sources of faecal material within set-back distance	Latrines/sewers built or solid waste dumps within separation distance	Inspection by community	Monthly	Community operator	Move pollutant sources, improve sanitation design, reduce sewer leakage	Inspection *E.coli* Faecal streptococci Bacteriophages Nitrate Chloride Tracer studies

Groundwater contains naturally occurring chemicals	Geological setting means chemicals present at toxic levels	Moderate/ Moderate	Select groundwater with acceptable levels of natural chemicals	Water quality assessments indicate water quality is acceptable	Evidence of natural contaminants	Risk assessment of geological setting Water quality assessment	Before construction Periodic evaluation	Water development agency	Use alternative source Treatment of water	Risk assessment Water quality assessment Monitoring of chemicals of concern
Leaching of chemicals into groundwater	Leaching of chemicals from landfills, waste dumps, discharges to ground	Moderate/ Minor	Provide adequate set-back distances defined on travel time	No sources of chemicals within set-back distance	Pollutant discharges within set-back distance	Inspection by community	Monthly	Community operator	Move pollutant sources, improve pollution containment	Inspection Analysis of chemical composition of pollution Analysis of water quality

Protected spring from which water is collected by hand

Springs serve a significant proportion of rural populations in many countries and have lower capital investment costs and usually lower maintenance requirements. Springs located uphill of communities are often linked to simple community-managed gravity flow pipe systems which provide greater convenience and may improve hygiene through greater water use. A water quality management plan for such supplies has been previously outlined. In this section, only springs that have been protected are covered as unprotected springs are open to contamination and their use may represent a significant health risk.

Design issues

Design issue	Justification/explanation (includes cross-referencing to support texts for checking in finalisation)
Backfill properly designed and constructed to provide adequate protection	The area between the 'eye' of the spring and the outlet through a retaining wall or spring box is highly vulnerable to pollution. There is usually some distance between the 'eye' and retaining wall that must be provided during construction. This area should be filled with a fine gravel/sand filter matrix up to the point of maximum water rise. The filter should be overlain by several protective layers (fine sand, clay and grass) to prevent downward pathogen movement during recharge. See Groundwater monograph.
Ditches construct to divert uphill surface water	Direct inundation of the immediate backfilled area may lead to erosion of protection measures noted above and may lead to direct contamination by surface water. Ditches should extend some way above the 'eye' of the spring and be adequate to carry specified flood flows based on set return periods – see Groundwater monograph.
Spring catchment area properly fenced and access restricted	Lack of fencing allows direct access to the backfilled areas by animals and humans. This may lead to erosion of the protective measures noted above and provide direct flow paths to spring outlet. A lack of fencing may also allow human and/or animal faeces to accumulate on the backfilled area. The areas should be fenced as far as possible, see Groundwater monograph.
Latrines, waste disposal sites and animal husbandry sited well away from spring (based on risk assessment using attenuation, die-off and travel time concepts) and preferably downhill	There is limited flexibility on the water source location in this context and therefore siting of polluting activities becomes important. This relates to the groundwater protection areas/zones and set-back distances referred to in the design issues.
Unused water from spring should be properly drained and not allowed to inundate the spring outlets.	Drains are also required to remove water that comes from the spring and is not collected. Lack of drainage may result in flooding of the spring leading to submersion of the outlet and difficulties in preventing contamination during water collection

'Model' water safety plan for protected springs not connected to piped water supplies

Hazard event	Cause	Risk	Control measure	Critical limits		Monitoring			Corrective action	Verification
				Target	Action	What	When	Who		
Contamination able to recharge spring in backfill area	Backfilled area becomes eroded	Moderate/ Major	Effective spring protection measures maintained	Area has grass cover; fence and diversion ditch in good condition No surface water uphill	Fence is broken Diversion ditch is damaged Surface water pools develop	Sanitary inspection	Monthly	Community operator	Repair fencing and ditches; drain surface water. Re-lay grass. Rehabilitate protective measures	Sanitary inspection and analysis of: *E.coli* Faecal streptococci
Contamination in spring box or outlet	Spring box or retaining wall in poor condition, inundation from wastewater	Moderate/ Major to moderate	Maintenance of protection and drainage works	Masonry in good condition, wastewater ditch clear and in good condition	Masonry deteriorated; wastewater ditch blocked	Sanitary inspection	Monthly	Community operator	Repair masonry and covers; clear ditch	Sanitary inspection and analysis of: *E.coli* Faecal streptococci
Contaminated surface water causes rapid recharge	Surface water is allowed to form pools uphill and leads to rapid recharge of contaminants and limited attenuation	Moderate to Unlikely/ Major	Establish set-back distance based on travel time; drainage	No surface water, solid waste dumps uphill Faecal disposal methods available	Surface water close to springs Low sanitation coverage Poor solid waste removal Springs show rapid response in flow and quality to rainfall	Sanitary inspection Colour change response to rainfall	Monthly/ seasonally	Community operator	Drain surface water pools uphill of springs, promote improved sanitation and solid waste disposal	Sanitary inspection and analysis of: *E.coli* Faecal streptococci
Contaminated shallow water drawn into aquifer	Hydraulic connection exists between shallow and deeper aquifers allowing draw-down into deeper aquifer	Almost certain/ Minor	Pumping regimes do not induce leaching	No evidence of drawdown of shallow groundwater	Evidence of shallow water drawdown (e.g. shallow wells start to dry up)	Colour Taste Odour Inspection	Annual/as need arises	Community operator	Set intake deeper (microbes) Water treatment (microbiol) blending (chemicals)	*E.coli* Faecal streptococci Bacteriophages Nitrate Tracer studies Hydrological models Electric conductivity Redox potential
Ingress of animal faeces	Animal husbandry uphill and close to the spring Animal damage to backfill area	Moderate/ Moderate	Set-back distance to Control animal husbandry; good fencing	No kraals or sheds in set-back distance; fence in good condition	Animal husbandry found within controlled area Fencing damaged or absent	Sanitary inspection	Monthly	Community operator	Remove animal sheds or kraals from uphill of spring or move to safe distance Repair or erect fences	Sanitary inspection *E.coli* Faecal streptococci Bacteriophages Nitrate

Leaching of microbiol contaminants into aquifer	Leaching of faecal material from sanitation, solid waste, drains	Moderate/ Moderate	Provide adequate set-back distances defined on travel time	No sources of faecal material within set-back distance	Latrines/sewers built or solid waste dumps within separation distance	Inspection by community	Monthly	Community operator	Move pollutant sources, improve sanitation design, reduce sewer leakage	Inspection *E.coli* Faecal streptococci Bacteriophages Nitrate Chloride Tracer studies
Groundwater contains naturally occurring chemicals	Geological setting means chemicals present at toxic levels	Moderate/ Moderate	Select groundwater with acceptable levels of natural chemicals	Water quality assessments indicate water quality is acceptable	Evidence of natural contaminants	Risk assessment of geological setting Water quality assessment	Before construction Periodic evaluation	Water development agency	Use alternative source Treatment of water	Risk assessment Water quality assessment Monitoring of chemicals of concern
Leaching of chemicals into groundwater	Leaching of chemicals from landfills, waste dumps, discharges to ground	Moderate/ Minor	Provide adequate set-back distances defined on travel time	No sources of chemicals within set-back distance	Pollutant discharges within set-back distance	Inspection by community	Monthly	Community operator	Move pollutant sources, improve pollution containment	Inspection Analysis of chemical composition of pollution Analysis of water quality

Protected dug well

Design issues

The key design issues for dug wells that should provide basic protection against most pathogens are outlined below. However, although exclusion of protozoan pathogens should relatively easy to ensure, controlling bacterial and viral pathogens is often more problematic as ensuring impermeability of lining material is difficult. Disinfection is possible using low-cost techniques and is included here as an option that should be considered. However, it should be borne in mind that sustaining disinfection may be difficult in low-income communities and a balance should be maintained between water quality targets desired and practical implementation.

Design issue	**Justification/explanation (includes cross-referencing to support texts for checking in finalisation)**
Well lining extends above ground level as a parapet or wall	Increasing the height of the parapet so that users cannot put feet into water will stop guinea worm transmission. If combined with a cover, apron and handpump, contamination by other pathogens can be reduced
Cover slab placed on top of well	Placing a cover slab on the well will prevent direct entry by contamination that is introduced from buckets. Covering the well may lead to significant reductions in pathogen loads.
Handpump/windlass/sanitary bucket system used to withdraw the water	Limiting introduction of many buckets prevents direct contamination from dirt on the base/outside of the bucket. Handpump provides greater sanitary protection and are preferred for water quality control.
Extend apron/platform around well (preferably at least 1.5m radius) from the wellhead	Lack of an apron may lead to the development of short-circuit routes for water on the surface and may also eroded the area around the well. This may also compound problems with permeable well linings. The apron should be sloped away from the well to ensure that spilt water is properly drained.
Wellhead area protected from animals through fencing (including apron and immediate surroundings).	Lack of fencing will allow animals direct access to the wellhead. This may increase the risks of damage of apron and the potential for creating short-circuit flow paths into the well. It may also lead to build up of faecal matter close to the well.
Diversion of surface water away from well through diversion ditches	Diversion ditches should be located some way from the well and the large enough to carry at least 10 year return period flood. The diversion ditches should encircle the well and lead the drainage water away from the well. The use of sumps or soakaways close to the well should be avoided.
Good drainage of spilt water from the well	Poorly drained spilt water may form pools close to the well and lead to rapid recharge into the well leading to contamination
Wells properly sited based on hydrogeological assessment of risks	Minimum set-back distances may be required to reduce the risks of contamination from excreta disposal facilities or solid waste dumps. This should be based on hydrogeological and microbial assessments of risk.

'Model' water safety plan for dug wells

Hazard event	Cause	Risk	Control measure	Critical limits		Monitoring			Corrective action	Verification
				Target	Action	What	When	Who		
Ingress of contaminated surface water directly into well	Well does not have a cover; lining stops at ground level; faulty or absent apron; drainage ditches faulty or absent	Moderate/ Major	Proper wellhead completion with raised wellhead, cover and apron. Good drainage	Well covered Lining extends 30cm above the apron. Apron with radius of 1.5m around well. Drainage ditches in good condition	Lack of cover on well; lining stops at ground level; apron damaged or cracked; ditches full, faulty or absent	Sanitary inspection	During construction Monthly	Water development agency Community operator	Provide cover on well Extend lining. Repair apron. Clean and repair drainage ditches.	Sanitary inspection *E.coli* Faecal streptococci
Ingress of contaminants due to poor construction or damage to the lining	Entry of contamination in top few metres of dug well because of cracks in lining or poor sealing of lining	Moderate/ Minor	Proper construction and use of a mortar seal on lining	Lining in good condition; no signs of weep holes in lining during rainfall	Well lining is pitted, evidence of seepage into well during rainfall	Sanitary inspection	Seasonal	Community operator	Improve well lining	Sanitary inspection *E.coli* Faecal streptococci
Animal damage allows contamination routes to develop	Animals not excluded from immediate wellhead	Likely/ Moderate	Fencing	Fence in good condition	Lack of fence or faults in fence	Sanitary inspection	Monthly	Community operator	Repair or install fence	Sanitary inspection
Contamination introduced by buckets	Handpump or other sanitary means of abstraction not installed or non-functioning	Almost certain/ Major	Install and maintain handpump or other sanitary means of abstraction	Abstraction by handpump or other sanitary method in good working order	Lack of handpump or other sanitary means of withdrawal	Sanitary inspection	Monthly	Community operator	Install or repair handpump or other sanitary means of withdrawal	Sanitary inspection
Wellhead area is inundated with contaminated surface water	Lack of diversion ditches mean that source is not protected against flood events	Unlikely/ Major	Diversion ditches surround the dug well, designed	Diversion ditch clear of rubbish and in good condition	Ditch has rubbish or shows signs of wear	Sanitary inspection	Monthly	Community operator	Repair and clear ditches	Sanitary inspection
Leaching of microbiol contaminants into aquifer	Leaching of faecal material from sanitation, solid waste, drains	Moderate/ Moderate	Provide adequate set-back distances defined on travel time	No sources of faecal material within set-back distance	Latrines/sewers built or solid waste dumps within separation distance	Inspection by community	Monthly	Community operator	Move pollutant sources, improve sanitation design, reduce sewer leakage	Inspection *E.coli* Faecal streptococci Bacteriophages Nitrate Chloride Tracer studies

Groundwater contains naturally occurring chemicals	Geological setting means chemicals present at toxic levels	Moderate/ Moderate	Select groundwater with acceptable levels of natural chemicals	Water quality assessments indicate water quality is acceptable	Evidence of natural contaminants	Risk assessment of geological setting Water quality assessment	Before construction Periodic evaluation	Water development agency	Use alternative source Treatment of water	Risk assessment Water quality assessment Monitoring of chemicals of concern
Leaching of chemicals into groundwater	Leaching of chemicals from landfills, waste dumps, discharges to ground	Moderate/ Minor	Provide adequate set-back distances defined on travel time	No sources of chemicals within set-back distance	Pollutant discharges within set-back distance	Inspection by community	Monthly	Community operator	Move pollutant sources, improve pollution containment	Inspection Analysis of chemical composition of pollution Analysis of water quality

Rainwater catchment

Rainwater collection is widely used throughout the developing and developed world. In low-income countries, collection is typically practised at the household level with roof collection being the most common approach used. In many cases, low volumes of rainwater are collected using makeshift gutters and open containers for use the same day or to provide a limited reserve lasting 2-3 days. The methods used in such cases are not protected and contamination is difficult to prevent. Simple improvements in the collection, guttering and storage containers can significantly increase efficiency and provide water reserves that can last several weeks. Simple improvements can also greatly improve the control of water quality and significantly reduce contamination risks. Where water is stored for longer periods (several weeks or more) then increasing problems may be found with vector-borne disease and sometimes taste and odour problems. Some designs are available to reduce such problems, although these typically increase costs.

Highly sophisticated forms of rainwater collection are used in developed countries, often using specially prepared impermeable ground catchments, where rainwater feeds a treatment plant and distribution system. Such catchments need basic maintenance and protection to prevent unacceptable build-up of pollution. A further refinement of rainwater collection that is included for completeness is fog collection. This is applied in only a limited number of countries (notably Chile and Peru) but is attracting increasing attention in other dry areas of the world.

Selection of reference pathogens and assumptions made
Where rainwater is collected from large ground catchments, then it is assumed that this will be part of a public water supply supplying water via treatment works an distribution systems. This water therefore is essentially a surface water source and should meet the criteria outlined above for water treatment. Source protection will be important and should exclude human activity. However, wild animals and in particular birds may represent a particular hazard, although these may be difficult to control. A hazard assessment for such systems would include periodic surveys to ensure that:

- human activity has not encroached into the catchment or controlled areas;
- no discharges of human waste occur upstream of the catchment;
- solid or hazardous waste has not been dumped in the catchment or so that its leachate can run-off into the catchment; ;
- type and numbers of animals likely to be found in the catchment

For large ground catchment rainwater collection systems, the reference pathogens are the same as those for any other surface water source and the control measures will be the same as noted previously for treatment processes.

Household rainwater collection
As it is generally assumed that rainwater is not microbiologically contaminated to a significant degree, most household rainwater collection system will not undergo treatment, although some designs include filtration units (of generally unproven efficacy) or periodic disinfection may be practised. The presence of animal and bird faeces represents a risk of bacterial and protozoan pathogen presence. Human faeces would be unlikely to be a significant hazard, although it is possible that this could occur where excreta disposal is poor

and the ‘wrapper’ or ‘flying’ latrine method is used or where contaminated water sprays can reach the catchment (for instance see Simmons et al).
Roofing material may exert a significant influence of water quality, with hard impermeable surfaces preferred to grass thatch as the latter may harbour significant microbial ecosystems (Uba and Aghogho, 2000). The first rains are likely to represent a time of elevated risk as contamination on the roof and gutters that has built up over the dry period are washed into the collection tank (Gould et al, 1999). Therefore the diversion of water derived from the first rains is an important control measure for microbiological quality.

The cleanliness of the roof will be critical to avoid contamination in the rainwater tank and this should be the primary focus of a hazard assessment. Hazard assessments will typically be regular visual assessment of cleanliness of the roof and gutters (WHO, 1997).

The principal reference pathogen of interest is *E.coli 0157*, as the majority of data available on pathogen presence has suggested that bacterial pathogens (and in particular those with animal as well as human hosts) are of greatest concern. *E.coli 0157* will clearly provide a good reference pathogen in these cases. Viral risks are less certain (few studies have been undertaken) and it would be likely that there was commonly childhood exposure to viral risks where widespread use of unchlorinated rainwater is practised. Furthermore, without disinfection it unlikely that viral risks could be minimised in any case.

Risks of infection by cysts are also uncertain given limited data. It is likely that there is potential for cysts derived from wild animals to be present in rainwater. However, it is not clear in what numbers cysts may be present and therefore a true estimation of risk may be difficult. Furthermore, in many areas where untreated rainwater is widely collected, the level of risk posed by drinking water would almost be certainly far lower than those posed by direct human-animal contact. Some rainwater collection systems use sand filters on the inlet. The efficacy of these filters in removing microbiological contamination is far from certain and it is not clear that they could be relied upon to remove cysts. However, they do remove larger debris and so will also remove pathogens adsorbed onto particulate matter.

The combination of the above factors suggests that in most cases establishing drinking water quality management plans for viral and protozoan risks will have limited effectiveness and may be counter-productive by increasing costs.

The regrowth of pathogens within rainwater tanks again is not well researched but could be projected to be significant. It is certainly possible that biofilms could be developed within a rainwater tank and that this could harbour pathogens introduced through poor tank maintenance or poor catchment hygiene. This area requires further work in order to establish whether this is a real risk, or simply a theoretical problem.

The water quality management plan outlined below assumes that the system of rainwater collection follows some form of improved systematic design – i.e. a tank or other container is linked to a system of gutters. It is not designed where rainwater is occasionally collected in a bucket. As rainwater collection in most countries is a household activity, it is implicit that the process of monitoring of quality requires support from local health bodies, although the cost implications of such an approach are significant (Simmons et al, 2001).

Fog collection is a relatively new technology and is not widely practised. The risks associated with this are not widely reported but it can be assumed that they potentially exist primarily from contamination by birds or animals. Direct control may be difficult and disinfection is likely to be the principal control measure available. However, pathogen loads would not be expected to be high. Furthermore, in areas where fog collection is practised tend to have quantity problems in water supply and therefore undue attention on controlling drinking-water quality may be counter-productive as the primary risk may result from poor hygiene caused by inadequate volumes of water.

IWRM and regulatory issues

Issue	Justification/explanation (includes cross-referencing to support texts for checking in finalisation	Appropriate actions
Sufficient rainfall to meet basic needs	Rainwater collection should take into account available rainfall in comparison to overall water needs and available sources. Rainwater use may be restricted to non-potable uses thus less stringent controls on quality are required. Exacting measures for water quality may not be either technically or financial feasible, nor of particular importance to health and may prevent use of rainwater which would provide benefits to users.	Hydrological evaluation of feasibility. Assess whether rainwater can be principal or supplemental source based on likely consumption patterns. Asses current water collection practices and differential uses of water.
Zoning of groundwater catchment	Where groundwater catchments are used to supply large volumes of rainwater for domestic supplies, the control of land-use in areas within or close to the catchment may help to reduce contamination. In such zones, sanitation technologies, waste disposal, industrial development and other hazards can be controlled through design and construction specifications. However, in small island states this may represent political problems.	Establish legal basis for land-use zones and identify practices allowed within each zone type.
User hygiene education	Households need training in basic operation and maintenance and in particular the need to divert the first foul flush from the drinking water tank (which may be problematic in areas of low rainfall). Where foul-flush diversion is difficult, then hygiene education could focus on treatment of water in the home.	Responsible agency should be identified and programme developed. Simple materials should be developed to help guide households.
Specification of catchments that may be used under different circumstances	Ground catchments should be avoided unless they are linked to water treatment works. Where rainwater will be consumed untreated, then only roof catchments should be used. Thatch catchments should not be used when water is used directly for consumption.	Establish a set of regulations for catchments that may be used for which purposes. These are likely to only cover construction and apply to agencies promoting rainwater catchment.
Materials specification	The materials that can be used to seal tanks and transport water through gutters should be specified to bacterial colonisation to reduce biofilm development.	Regulations/standard developed specifying which materials are acceptable. Periodic inspection required.
Assessment of rainwater quality	An overall assessment of water quality should be undertaken to identify whether any major quality issues may derive from air pollution. This need not prohibit rainwater use, but risks should be properly understood from the outset.	Undertake assessment based on prevailing wind and industrial discharges. Air quality assessment may also be needed.
Definition of responsibility for routine surveillance and monitoring	As rainwater collection tends to be household (as opposed to community) focused, support is likely to be required for ongoing monitoring. This should be linked to operation and maintenance and hygiene education.	Identify national and local agencies. Identify NGO/ CBOs that could perform support role.

Design issues

Note that many design issues are also control measures and are repeated on the table of verifications

Design issue	**Justification/explanation (includes cross-referencing to support texts for checking in finalisation)**
Tank is above ground	Tanks that are fully or partially underground have a greater risk of contamination, for instance through leakage via weaknesses in the tank. They are also more difficult to clean without pumping out of all wash water.
Tank is watertight	Tank should not allow any water to enter the tank other than through the inlet from the gutters. The join between the inlet pipe and tank should be properly sealed and not allow contamination to enter. Reducing the amount of light entering the tank may also inhibit algal development
Tank has drain valves to allow proper cleaning and drainage of wash water	It should be possible to completely drain down the tank and for dirty water to be removed during cleaning. Drained water should be removed from the tank and flow to a soakaway or drain.
Tank has tap or other hygienic withdrawal system	Unhygienic removal of water from the tank may introduce contamination into the tank. A tap is preferred as this limits direct contamination potential, but the join to the tank should be properly sealed. Water should not be directly drawn from the tank by a bucket to prevent direct contamination.
Tap or draw-off point at least 5cm above base of tank	Such a height difference allows debris to settle on the floor of tank and may reduce pathogen loads in the body of collected water
First flush diversion systems in place	Foul-flush systems allow the first rains collected from the roof which are more likely to be contaminated to be drained to waste. However, whilst this may reduce bacterial loads, it may not completely eliminate them. The design should be simple and easy to use. In cases where there is very limited rainfall, care should be taken to ensure that foul-flush diversion does not seriously compromise the amount of water to be collected. If this is the case, then alternative strategies (e.g. treatment) should be used.
Some form of filter to remove larger debris	Sand and gravel filters may be adequate to remove larger debris (for instance leaves etc) which may have a positive effect on water quality. However, these are unlikely to remove all pathogens.
Roof is hard impermeable surface	Hard impermeable surfaces increase the potential for cleaning and reduce the potential for microbial ecosystems to develop
Drainage of roof and gutter wash water away from tank	When the roof and gutters are cleaned, the dirty water should not flow into the tank but should be diverted into a soakaway or drain
Tanks should have adequate access to ensure proper cleaning	As the inside of the tank should be scrubbed during cleaning to ensure all accumulated
Trees do not overhang roofs used for collection	Avoiding direct overhang of roofs used for collecting rainwater by trees helps reduce the likelihood of bird or rodent faeces building up on the roof
Cover all vents etc with mesh	Putting mosquito and other fine mesh material on the inside of all air vents and overflow pipes reduces potential for direct access to the tank by small animals and also reduces the potential for mosquito breeding

'Model' water safety plan for rainwater collection no disinfection as standard

Hazard event	Cause	Risk	Control measure	Critical limits		Monitoring			Corrective action	Verification
				Target	Action	What	When	Who		
Bird and animal droppings found on roof or in guttering	Roof is not cleaned properly or regularly allows build-up of faecal material	Likely/ Minor	Cleaning of roof and gutters	Roof is clean before rainfall	Roof dirty as rainfall collection starts	Sanitary inspection	Before rains	Owner/ Operator	Clean roof regularly	Sanitary inspection **E.coli** Faecal streptococci
Trees overhang the collection tank	Overhanging branches allow birds and animals to gain access to roof	Likely/ Minor	Tree surgery	Trees branches do not overhand roof	Branches encroach on roof	Sanitary inspection	Annual	Owner/ Operator	Trim branches	Sanitary inspection
Animals and birds can enter the tank	Inspection covers and vents open or improperly sealed	Likely/ Major	Ensure all openings on tank are bird and animal proof	Inspection covers fitted and locked, vents have mesh	Inspection cover damaged, not in place, mesh damaged or not in place	Sanitary inspection	Annual	Owner/ Operator	Install or repair inspection covers and vents mesh	Sanitary inspection **E.coli** Faecal streptococci
Tank dirty or sediment accumulates	Poor cleaning of tank	Unlikely/ Moderate	Cleaning of tank	Tank cleaned regularly and disinfected annually	Dirt seen inside tank Water appears turbid	Sanitary inspection Appearance	Annual	Owner/ Operator	Cleaning of tank, removal of sediment, disinfection	Sanitary inspection Turbidity **E.coli** Faecal streptococci
First flush of water can enter tank	First flush of water from roof is not diverted and so enters tank	Moderate/ Major	Foul-flush diversion unit	Foul-flush system in place and used correctly	Lack of foul-flush system Poor operation of foul-flush system	Sanitary inspection Colour Odour	On installation, then annual	Owner/ Operator	Install foul-flush system and train users	Sanitary inspection Turbidity **E.coli** Faecal streptococci
Unhygienic withdrawal of water allows contamination to enter	Water withdrawn using buckets which introduce contamination	Almost certain/ Minor	Install tap or other sanitary means of withdrawal	Tap in place to allow easy withdrawal of water	Lack of tap	Sanitary inspection	On installation	Owner/ Operator	Install tap with intake at least 5cm from base of tank	Sanitary inspection Turbidity **E.coli** Faecal streptococci
Tank is damaged or allows contaminated surface water or groundwater to enter	Tank has cracks and other damage	Likely/ Minor	Structural integrity of tank	Tank set above ground and in good condition	Cracks in tank structure	Sanitary inspection	Annual	Owner/ Operator	Effect repairs	Sanitary inspection

Roof material introduced into tank	Collection surface is soft and allows material to be leached into the tank	Likely/ Minor	Only use hard surfaces for rainwater collection	Collection from impermeable surfaces	Collection from thatch and other soft surfaces	Sanitary inspection	At installation	Owner/ Operator	Replace roof material	Sanitary inspection Turbidity Colour
Water is not filtered	Water enters into tank with no filtration	Likely/ Minor	Filter installed and maintained	Tanks have working filter installed to remove debris	Lack of filter, increased turbidity	Sanitary inspection Turbidity Colour	Annual	Owner/ Operator	Install filter Clean filter	Sanitary inspection Turbidity Colour
Leaching of chemical from roof material into water	Roof material contains lead or other harmful chemicals	Unlikely/ Minor	Materials for rainwater collection approved	Roof material should not contain lead or other harmful substances	Roof material known to contain lead or other harmful chemicals	Inspection of materials	At installation	Owner/ Operator	Use lead-free roofing material	Inspection of materials Analysis of lead and other chemicals of concern

Storage and distribution through community managed piped systems

In many parts of the world, simple piped water systems are managed by communities. Such facilities are typically fed by gravity and are often drawn from groundwater sources such as springs. In these cases, treatment or disinfection of drinking water is rarely undertaken. Some supplies are also drawn from upland streams where again no treatment or disinfection is performed. In some communities, a mechanised borehole feed a small tank and distribution systems are used. In some cases community managed treatment plants linked to the distribution system are used. Many control measures and management actions are similar to those in the previous section, but are covered here as the absence of disinfection may increase risks.

Selection of reference pathogens and assumptions made

The hygiene code outlined below is based on an assumption that the source is protected in some form and that there is no disinfection of the water prior to distribution. The selection of reference pathogens reflects the likely socio-economic conditions within communities, which are primarily small, rural communities in developing countries. In these communities, first exposure to viruses may be expected to be more likely to occur in childhood rather than adulthood and therefore whilst viral risks should be controlled as far possible, without disinfection this will not be fully effective. *Cryptosporidium* control will be focused primarily at the source and would not be expected to be of great importance during distribution. Furthermore, exposure is likely to occur through other routes and this should be borne in mind. Re-growth may be controlled through pipe materials, but there will be little or no alternative control measures available and therefore *Legionella pneumophila* is not considered as a reference pathogen. As a result, the principal focus of the measures outlined below will be to control risks from *E.coli 0157*, although it is expected that many of these may also have a positive impact on the other pathogens.

Hazard assessments

The hazard assessment for small community-managed systems will have many of the characteristics of those for utility-managed distribution systems. However, the focus will be on the above ground sources of faecal matter in the environment and the physical state of the infrastructure rather than estimating biological stability. Such an approach requires regular sanitary inspection by ‘walking of the line’.

IWRM and regulatory issues

Issue	Justification/explanation (includes cross-referencing to support texts for checking in finalisation)	Appropriate actions
Water source should have adequate capacity to meet demand plus likely level of system losses	One of the major causes of deterioration in water quality is discontinuity or rapid pressure loss in systems which increases the potential for back-siphonage. This may require storage of water where yields are insufficient.	Assessment of demand. Ensure that sources are developed with potential to meet demand plus leakage.
Development of hygiene codes of practice for installation of distribution systems	Hygiene code of practice prepared for use by all agencies and companies constructing community-managed gravity-fed systems.	Hygiene code of practice prepared and disseminated.
Training of community operators	Poor training may lead to fail to operate and maintain system properly. This should include basic monitoring techniques and O&M programmes.	Training programmes developed.
Ongoing support through surveillance and monitoring.	Ongoing support through surveillance and monitoring will help communities to sustain operation and maintenance and reduce the risks of contamination.	Ongoing supervision systems in place to support communities by water supply and/or surveillance bodies.

Design issues

Many factors will influence the design of a piped water system, including ensuring the resulting cost of water remains affordable, that demand can be met and losses are minimised. The control of water quality must be set against decisions relating to affordability and improvement in access. However, designs to improve water quality and in particular those that relate to ingress of contamination water are all likely to also have a positive impact on reducing losses and improving user perceptions of the service. The latter may be important when trying to improve overall access.

Design issue	Justification/explanation (includes cross-referencing to support texts for checking in finalisation)
Source used is protected according to relevant hygiene code.	Entry of contaminated source water may be the major problem and this should be avoided through good design and construction.
Storage tank included in systems to sustain pressure and meet peak demands. All tanks should be covered and located away from trees.	Where storage tanks do not exist, peak demands may result in low pressure or discontinuity within the supply and increased risks of contamination due to back-siphonage. Tanks should be covered and located away from trees for the same reasons as for utility service reservoirs.
Washout and bypass systems incorporated into service reservoir design	Poor design of service reservoirs that make access and cleaning difficult (particularly the removal of wash water) makes hygiene difficult to maintain and may encourage contamination
Low biofilm adherence materials used for supply pipes (uPVC etc)	Pipe material is noted as being important in promoting biofilm formation.
Selection of jointing materials and methods	High quality jointing materials will reduce the likelihood of leakage within the supply and therefore reduce the potential for back-siphonage.
Sluice valves on sections of pipe	When repair to pipe system being undertaken, isolation of sections of mains pipe essential to prevent large scale contamination
Specification of materials allowed for use in drinking-water mains	Materials approved for use in drinking water mains should not readily support microbiological communities.
Proper drainage around all valves, junctions etc	Direct inundation from flooded valves may introduce contamination into the distribution system. All valve boxes should have a permeable base to allow rapid drainage of water.

'Model' water safety plan for community managed distribution system

Hazard event	Cause	Risk	Control measure	Critical limits		Monitoring			Corrective action	Verification
				Target	Action	What	When	Who		
Water entering distribution is contaminated	Failure at source (see spring, borehole WSP)	Moderate/ Catastrophic	Ensure source WSP adhered to	Optimised source protection (see spring/borehole WSP)	Source WSP indicates non-compliance	Sanitary inspection Turbidity Chlorine residual (if chlorinated)	Weekly/daily	Community operator	Take source off-line and apply appropriate corrective action (see appropriate WSP)	*E.coli* Faecal streptococci Bacteriophages Turbidity
Microbial contamination of storage tank	Birds/ animal contamination of storage tanks	Unlikely/ Major	Make sure tank is animal and bird-proof	Vents covered, inspection covers in place and locked No tree branches overhang reservoir. Fence around tank	Vent or inspection covers not in place or damaged; fence damaged, tree branch encroach on tank	Sanitary inspection	Weekly/ Monthly	Community operator	Vents should be designed so as to prevent direct access and covered to prevent access from small birds and rodents. Tree branches should be cut-back and the site made secure.	*E.coli* Faecal streptococci. Bacteriophage Sanitary inspection Turbidity
Ingress of contaminated water into storage tank	Leaks in tanks may lead to contamination. This may occur when tanks are either below ground or allow stagnant water to collect around base	Unlikely/ Minor	Structural integrity and drainage	Tank structure sound with no cracks and drainage channels in good condition	Drainage channels blocked, cracks develop in tank structure	Sanitary inspection	Monthly	Community operator	Clear and repair drainage channels. Take tank off-line to make repairs. Flush tank and distribution before re-commissioning	*E.coli* Faecal streptococci Bacteriophage Sanitary inspection Record audit
Contamination enters distribution system at major valves in distribution or storage tank	Major sluice valves are inundated by contaminated water	Moderate/ Major	Valve maintenance and drainage	Valve box with permeable base and adequate drainage	Water build up within valve box, damage to drains or drains in need of cleaning	Sanitary inspection, turbidity	Monthly	Community operator	Repair leaks drains and valve box. Repair valve if showing signs of wear Disinfect supply	*E.coli* Faecal streptococci Bacteriophage Sanitary inspection
Back-siphonage of contaminated water	Leaks in pipe combined with drops in pressure (either intermittence or transient pressure waves) allow ingress of water containing pathogens from faecally-contaminated soils	Likely/ Moderate (depends on location and population served)	Ensure that supply has sufficient water to meet demand and ensure all connections downstream of tanks	All connections on lines served by tank, leakage is low	Intermittence increases, leakage increases	Sanitary inspection, turbidity, chlorine residuals (if chlorinated	Daily/weekly	Community operator	Reduce intermittence. Leakage control programme.	*E.coli* Faecal streptococci. Bacteriophage Sanitary inspection Turbidity

Contamination introduced during repairs on distribution system	Poor hygiene in repair work allows contamination to enter into the system	Moderate/ Catastrophic	Hygienic codes of practice followed	Hygiene code developed and training provided to all people working on system	Evidence that hygiene code not followed	Turbidity Site inspection	As required	Community operator		*E.coli* Faecal streptococci Bacteriophage Hygiene inspection Review of maintenance records

Groundwater from boreholes with mechanised pumping linked to a distribution system

It is generally assumed that such facilities will be operated by a public entity/utility charged with the supply of drinking water and will therefore have sufficient operational capacity to undertake proper design, construction, operation and maintenance. It is expected that such supplies will be regulated and compared to enforceable water quality targets/standards. It should be noted that the recommendations here regarding disinfection relate solely to the *production* stage of water taken from groundwater and not to *distribution*.

Selection of reference pathogens and assumptions made

A full discussion of the survival, transport and attenuation of pathogens in groundwater is given the background monograph. Hepatitis viruses and *Cryptosporidium parvum* are of particular importance as the control of risks from these pathogens would be likely to resolve the problems of bacterial pathogens. However, *E.coli 0157* is retained as a reference pathogen specifically because it inclusion allows a greater flexibility in defining levels of tolerable risk and in land-use control.

The principal challenges in groundwater posed by viruses relate to extended potential survival and more limited potential for attenuation. Attenuation is highly dependent on environmental factors in the sub-surface and often only retards, rather than eliminates viruses. Retardation may be reversible. In most situations where the water supply from the groundwater source undergoes at least disinfection and subsequent distribution, overall socio-economic development and environmental hygiene are often also good. This suggests that first exposure to viruses in adulthood may be more likely.

Whilst control of viral hazards through land-use control is desirable for all groundwater supplies, it is also important to recognise that this may not be adequate to reduce risks. Chapter 3 in the background monograph indicates that viral survival may be greatly extended in comparison to other pathogens. The evidence suggests that once travel times from point of entry into the water body to the point of abstraction exceeds 50-60 days, then the processes of attenuation and die-off result in significant reductions in pathogen densities and therefore the probability of exposure through ingestion of water are greatly reduced. However, a residual risk is retained and in countries with limited alternative childhood exposure routes may be greater than acceptable. In these circumstances, reductions in viral risks can only be achieved through contact disinfection prior to distribution.

With the exceptions of karstic or other fracture dominated aquifers, removal of cysts during recharge is likely to be rapid and primarily a function of filtration. In such cases, the principal means of control will be to ensure that direct entry into the borehole caused by poor completion of surface headworks and the first few metres underground is prevented.

In aquifers dominated by fracture flow, detailed knowledge of the hydrogeological regime are required to estimate risks. Cysts have relatively long survival times (see microbial quality review) and in groundwater systems that have limited filtration capacity it is likely that protozoan cysts will be able to travel extended distances in an infective state. However, for karstic systems, there is a rational for considering these to be surface waters that require full treatment (see groundwater monograph).

In general the measures that are adopted to prevent protozoan **and** virus contamination of drinking water should be adequate to reduce risks from bacteria to an acceptable level. Survival of bacteria in groundwater is significantly lower than for viruses (see microbial review) and attenuation is generally more effective given the greater size of bacteria and increased potential for mechanisms such as microbial predation (see Chapter 3, groundwater monograph).

Reductions in bacterial density occur relatively rapidly and thus the probability of exposure through water to numbers of bacterial pathogens likely to result in infection is reduced rapidly. The application of protection zones geared towards reducing bacterial risks are likely to be effective. Travel times of 50 days would usually be more than adequate and shorter travel times (for instance 25-30 days) may be adequate (Groundwater monograph, Chapter 3). This suggests that land-use control measures may be sufficient to reduce risks to an acceptable level and that contact disinfection designed to inactivate bacterial pathogens should not be required.

There is good evidence that bacterial contamination occurs due to poor wellhead completion. However, the controls put in place to prevent direct ingress designed to control cysts would be expected to reduce bacterial pathogens to an acceptable level, particularly where these increase vertical movement to the point of intake.

However, measures specific to bacterial pathogens are included here for two specific reasons. Firstly, for many countries, control of epidemics remains the primary goal of water quality management and therefore control of bacterial pathogens is an important goal. Secondly, in setting water quality targets in relation to endemic disease which are based on design measures, the use of bacteria (particularly where protection zones are a key control point) could be used when setting a lower (but still acceptable) water quality. This approach supports the principle of local decision-making based on a tolerable disease burdens, available resources and targets for health. The reference bacterial pathogen used is *E.coli 0157* as there is strong evidence of link to outbreaks.

Hazard assessments

The hazard assessment would normally take the form of a sanitary survey of the catchment area and of the integrity of the infrastructure of the borehole, in particular at the wellhead. However, when translating the hazard assessment into a risk assessment, the hydrogeological environment and vulnerability of aquifers should also be taken into account to ensure that a realistic assessment can be made of the risk and its severity. This is of particular importance for groundwater as the nature of the aquifer will determine whether a hazard represent any risk to the water supply.

There are many potential sources of faeces within the environment that may represent a hazard. These include on-site sanitation (septic tanks, pit latrines), sewers, landfill sites, waste dumps and scattered waste, land applications of sewage sludge, animal husbandry and slurry pits. The hazard may be underground (e.g. on-site sanitation, sewers, landfill sites) or may be on the surface (e.g. waste dumps, animal husbandry and slurry pits). The nature of the hazard needs to be considered when undertaking a risk assessment and attention paid the likelihood of pathogen reductions through attenuation, die-off and dilution.

IWRM and Regulatory issues

Issue	Justification/explanation (includes cross-referencing to support texts for checking in finalisation	Appropriate actions
Exclusion of polluting activities from surrounding area (transport of pathogens to well). This includes all sources of pollution that may release pathogens into the groundwater environment. This will include on-site sanitation, animal husbandry, slurry pits, sanitary landfill sites, waste dumps and graveyards. There may also be a need to consider the control low-intensity livestock rearing in sensitive areas.	Pathogens and other pollutants may be able to travel significant distances and survive for extended periods within the sub-surface environment. Retardation rather than elimination may significant for viruses and subsequent elution may be problematic.	Establishment of legislative basis for groundwater protection zones (see groundwater volume). Establishment of legal framework for land use control. Set-back distances defined for on-site sanitation. Allowed stocking densities defined and enforced Landfills prohibited in recharge areas
Groundwater mapping and assessment of vulnerability.	Groundwater flow regimes must be understood in order to define protection measures.	Groundwater mapping programme established and records held.
Borehole archive established to strengthen groundwater database.	Borehole archive provide useful information about aquifers and vulnerability and support groundwater mapping.	Borehole archive established within Government or licensed agency.
Water supply and water resource management agency have veto on acceptable developments within recharge areas	Changes in land-use may introduce pathogens into recharge areas that result in contamination.	Effective local procedures for land use change approval.
Licensing of drilling agencies and certification on commissioning	Licensing of drilling agencies allows greater regulatory control of drilling practice and reduced risk of sub-standard performance.	Licensing system developed, with procedures for application, approval and certification.
Proper remediation of abandoned wells.	Abandoned wells provide rapid short-circuit routes for pathogens in the aquifer and may cause widespread contamination.	Regulations for sealing of abandoned wells established.

Design issues

The proper design of the facility is critical to protecting the borehole against ingress of pathogens. Wellhead completion and control measures in the immediate area are critical to reduce the risks of pathogens entering the supply. However, these measures should be supported by the development of a groundwater protection policy noted above.

Design issue	**Justification/explanation (includes cross-referencing to support texts for checking in finalisation)**
Minimum standards for construction defined	Direct ingress of pathogens may occur where wellhead completion is poor. Setting minimum standards that are enforceable with regulations is important to ensure quality.
Materials specification for use in below ground infrastructure.	The use of poor materials may lead to cracking or damage in below ground infrastructure, providing short-circuit routes for pathogens. These should be enforceable.
Well casing should extend above the ground level (e.g. 30cm/18 inches etc) and annulus sealed at surface	Contaminated water may be able to directly enter the casing if this is below or at ground level. By raising the casing above the level of likely maximum inundation, direct entry from the surface can be prevented (see Groundwater Monograph, Chapter 2.4 and 12.2)
Seal annulus around well lining to a minimum depth (at least to below first joint – usually 5m). In consolidated formations, seal should extend to the top of the intake screen	Unsealed annulus may allow direct ingress of surface water into borehole or may allow short-circuiting of surface water with limited attenuation potential. Evidence of contamination by direct ingress/short circuiting of lining is provided in Groundwater monograph in Chapters 2.4 and 12.2.
Ensure cracks/weakened joints are not formed in the casing or lining	Cracks in casing/lining materials may allow short-circuit routes for contaminated surface water. Joints in casing materials are particularly vulnerable to wear.
Surface plinth extending minimum distance (at least 2m radius) around well.	The ground surface around the casing should be sealed and the apron/plinth designed to slope away from the casing so that spilt water is directed away from the well. If no apron/plinth exists, a direct ingress path may develop for surface water short-circuit routes that minimise filtration times may also develop. Evidence for contamination of wells without plinths or with cracked plinths exists, see Groundwater monograph.
Exclusion of animals and unauthorised people to minimum distance from wellhead for at least 10m.	Lack of exclusion may allow both deterioration of the immediate environment around the wellhead which may cause damage to the wellhead or development of short-circuit routes. Access by animals may lead to a build-up of faecal matter close to the wellhead. There is good evidence that a lack of exclusion may contribute to contamination events.
Drainage adequate to prevent surface water flow travelling to immediate proximity of wellhead. Ditches should be set a minimum distance uphill (e.g. 10m)	Lack of surface water diversion increases the risk for direct inundation of the wellhead by contaminated surface water and may lead to direct ingress of contaminated water. Repeated flooding may cause erosion in the immediate wellhead area and the development of short-circuit routes for pollutants. There is evidence of poor drainage contributing to contamination of wells.
Application of contact disinfectant using an appropriate Ct value	Protected wells may remain vulnerable to occasional contamination and in particular reduction of risks for viruses may be particularly difficult to guarantee. Reducing risk from viral contamination is likely to require contact disinfection. Automated continuous monitoring with permanent retention of records at larger installations. At smaller installations frequent analysis and record keeping.
Sluice valve prevents back-flow into borehole.	When pumping from the borehole ceases, water within the distribution systems will be at higher pressure and may flow back into the borehole.
Distribution	See section on piped distribution

'Model' water safety plan for mechanised boreholes

Hazard event	Cause	Risk	Control measure	Critical limits		Monitoring			Corrective action	Verification
				Target	Action	What	When	Who		
Ingress of contaminated surface water directly into borehole	Poor wellhead completion	Unlikely/ Major	Proper wellhead completion measures	1m concrete apron around wellhead; lining extends 30cm above the apron; drainage ditches in place	Lining stops at ground level. Apron damaged or cracked. Ditches full, faulty or absent	Sanitary inspection	Monthly	Operator	Extend lining Repair apron Clean and repair drainage ditches	Sanitary inspection. *E.coli* Faecal streptococci Bacteriophage
Ingress of contaminants due to poor construction or damage to the lining	Poorly maintained welllhead completion	Moderate/ Major	Proper wellhead completion	Top 5 metres of the annulus sealed Rising main in good condition	Annulus sealed for less than 3 metres. Colour changes Increased pumping required to raise water	Sanitary inspection Water clarity CCTV	Monthly	Operator	Insert seal around annulus. Replace worn and corroded rising mains. Use materials less likely to corrode (e.g. plastics)	Sanitary inspection; analysis of colour, iron and turbidity, CCTV
Borehole area is inundated with contaminated surface water	Lack of diversion ditches	Unlikely/ Major	Good drainage around wellhead	Diversion ditches of adequate size, in good condition and clear of rubbish	Ditch has rubbish or shows signs of wear	Sanitary inspection	Weekly	Operator	Repair and clean ditch Increase size of ditch using	Sanitary inspection
Contaminated shallow water drawn into aquifer	Hydraulic connection exists between shallow and deeper aquifers allowing draw-down into deeper aquifer	Almost certain/ Moderate	Control pumping regimes Set intake at depth	No evidence on induced leakage	Evidence of shallow water drawdown (e.g. shallow wells start to dry up)	Colour (appearance) Taste Odour Electric conductivity	Weekly	Operator	Set intake deeper (microbes) Water treatment (microbiol) or blending (chemicals)	*E.coli* Faecal streptococci Bacteriophages Nitrate Tracer studies Hydrological models
Rapid recharge by rivers, streams and ponds	Hydraulic connection exists between surface water and aquifers	Unlikely/ Major to Catastrophic	Set intake at greater depth	Rapid recharge does not occur or cannot reach intake	Evidence of rapid recharge from surface water bodies	Surface water levels Colour Electric conductivity	Daily	Operator	Set intakes at greater depth or modify pumping regimes	*E.coli* Faecal streptococci Bacteriophages Pathogen assessments Nitrate
Pumping leads to increased leaching of contaminants	Pumping induces increased leaching of chemicals	Unlikely/ Moderate	Pumping regime	Leaching of contaminants is within predicted range	Evidence of increased leaching of contaminants	Monitoring of key contaminants of concern Hydro-chemical models	Monthly	Operator	Modify pumping regime Treatment	Hydrochemical models Monitoring of contaminants of concern

Pumping increases safe distances beyond current protection zone boundaries	Pumping increases cone of depression extends minimum travel time distance beyond protection zone	Unlikely/ Moderate	Protection zones	Protection zones include influence of drawdown on groundwater flow	Drawdown increases distance equivalent to travel time set	Water table levels surrounding borehole when pumping	Annual	Operator	Extend groundwater protection zone to account of the change in distance	Tracer tests Hydrogeological modelling Tracer tests Analysis of key microbiol and chemical contaminants controlled in protections zones
Back-siphonage from pipe into borehole	No backflow preventer installed	Likely/ Minor	Backflow preventer on mains	Backflow preventer installed	Lack of backflow preventer	Inspect pumping works	Installations Periodic checks	Constructor Operator	Backflow preventer installed	Audit of wellhead and pumping works
Failure in disinfection process	Disinfection process fails	Unlikely/ Major catastrophic	Effective chlorination with contact time	Ct value adequate and residual produced	Lack of residual	Monitoring chlorine dosing and residual	Daily/hourly	Operator	Take pump off-line and repair disinfection unit	Audit of results **E.coli** Faecal streptococci Bacteriophages
Mobilisation of toxic chemicals and elution of viruses	Changes in land-use and increased recharge through irrigation leads to mobilisation and elution	Rare/ Minor to moderate	Land-use control, in particular managing irrigation	Little artificial recharge through irrigation, pH and Eh of water stable	Significant changes in land-use Increased use of irrigation	Land-use; pH of groundwater Redox (Eh)	Weekly	Operator	Reduce artificial recharge	**E.coli** Faecal streptococci Bacteriophages Chemicals of concern
Leaching of microbiol contaminants into aquifer	Leaching of faecal material from sanitation, solid waste, drains	Moderate/ Moderate	Protection zones and set-back distances	Lateral separation defined on basis of travel times and hydrogeology	Latrines/sewers built or solid waste dumps within separation distance	Sanitary inspection; inspection of protection zone, electric conductivity, sewer leakage	Monthly	Operator	Remove pollutant sources, improve sanitation design, reduce sewer leakage, insert cut-off walls around sewers	Inspection *E.coli* Faecal streptococci Bacteriophages Nitrate Chloride Tracer tests
Groundwater contains naturally occurring chemicals	Geological setting means chemicals present at toxic levels	Moderate/ Moderate	Source selection	Use of groundwater with no natural chemical at harmful levels	Evidence of natural contaminants	Risk assessment of geological setting Initial assessment of water quality	Before installation	Constructor	Use alternative source Treatment	Risk assessment Water quality assessment Monitoring of chemicals of concern

Agricultural pollution: nitrate	Use of inorganic or organic fertilisers, stock density	Unlikely/ Minor	Protection zone	Nitrate vulnerable zones defined for aquifer prevent excessive leaching	Evidence of increasing nitrate levels	Monitoring of nitrate in groundwater Monitor fertiliser applications Monitor stock densities	Monthly	Supplier Environment agency	Control of fertiliser applications Blending of drinking water	Nitrate levels in groundwater Audit fertiliser applications Audit stick densities
Agricultural pollution: pesticides	Pesticides leached into the groundwater	Unlikely/ Minor	Protection zone	Pesticide applications controlled in recharge area	Evidence of increasing pesticides in water Evidence of pesticide application at high-risk locations and times	Monitor pesticide applications	Monthly	Supplier Environment agency	Control of pesticide applications	Pesticide levels in groundwater Audit pesticide applications
Leaching of chemicals from landfill sites into groundwater	Leaching of chemicals from landfills, waste dumps, industrial discharges to ground	Moderate/ Minor	Protection zone	Landfills are sanitary and properly sealed Landfill presence controlled on basis of travel times and hydrogeology	Monitoring around pollutant sources indicate increasing pollution migration	Monitor for key contaminants around pollutant sources Monitoring bills of lading	Weekly/daily	Waste Managers Environment agency Supplier	Move pollutant sources, improve pollution containment, monitoring network around pollutant sources	Inspection Analysis of chemical composition of pollution Analysis of water quality Audit bills of lading for composition of waste
Pathogens from hospital wastes contaminate groundwater	Poor disposal of hospital wastes allows direct ingress of leaching into groundwater	Unlikely/ Catastrophic	Proper hospital waste disposal	Hospital wastes with pathogenic material incinerated	Hospital waste disposal in dumps or ground containers	Monitor hospital waste disposal methods	Daily	Water supplier Health authorities	Ensure all pathogenic material incinerated or sterilised	Audit of hospital waste disposal
Pollution from urban areas contaminates groundwater	Poorly sealed drains cause recharge of groundwater	Moderate/ Minor	Protection zones	Drainage water unable to recharge groundwater	Poorly constructed drains increase potential for recharge	Inspection	Operator	Weekly	Ensure all drains properly sealed in recharge or vulnerable areas	Audit of drainage channel design, construction and maintenance
Industrial discharges contaminated groundwater	Poorly disposed of industrial waste can inundate groundwater source or leach into aquifer	Moderate/ Minor	Waste containment and treatment	Effective disposal methods prevent spills and leaching	Waste disposal methods do not provide security against inundation and leaching	Monitor containment methods at industrial sites	Supplier Environment agency	Monthly	Ensure all industrial waste is properly contained and treated at the site	Audit of industrial wastewater treatment plants

Household handling storage and treatment of water

The safe handling and storage of water within the home is the final component of a safe water chain. Evidence from around the world suggests that this step is critical and that investments made in improving water source protection, treatment and distribution may not lead to significant improvements in health if household handling and storage is poor. In this section we deal both with storage of water in tanks within houses that are connected to a piped water supply and for storage in smaller containers when water is collected from a communal source of water.

Outbreaks of infectious diarrhoeal disease have occurred in both developed and developing countries resulting from contamination of plumbed in storage tanks in blocks of flats. Contamination of a storage tank by bird faeces has been a common problem. Poor storage and plumbing within buildings has also led to regrowth or bacteria and contamination with *Legionella spp.* remains a major problem in many countries. In these cases, interventions are primarily related to good operation and maintenance of water systems within buildings.

In addition to the problems noted above in relation to plumbing and large-scale storage within buildings, recontamination of water during collection, transport and storage when water is available only from a communal public water source are also widely reported (see background paper for more details). However, whilst clearly a significant problem, many of the studies indicating such problems have focused on indicator bacteria as opposed to pathogens. The relative importance of recontamination of water by pathogens has been questioned, given obvious greater potential for spread by other intra-familial routes (notably food) and likely acquired immunity (Vanderslice and Briscoe, 1995). However, control of recontamination is likely to be a key measure in reducing infectious disease transmission, although it should be integrated with a broader hygiene education programme dealing a variety of transmission routes.

Selection of reference pathogens and assumptions made

The scenarios outlined above relate to two very different aspects to poor water supply within households. To a certain extent, the measures put in place to control risks within piped distribution systems should also be adequate to deal with many of the problems related to poor in-building plumbing and storage. However, a few selected aspects are included within this section because of their particular importance. The rest of the section focuses directly on the safe handling of water and therefore may have greatest relevance to situations where the water supply is provided through a communal level of service.

Within-building storage

For in-building plumbing, two principal areas of concern are noted for which reference pathogens should be selected. The first is regrowth within storage tanks and plumbing. As the principal risk will be relate to *Legionella pneumophila* this is taken as a key reference pathogen. The second area of concern is ingress into the storage or pipe work. The principal reference pathogen for this case is taken as being *E.coli 0157*. The control of all risks related to ingress are likely to be effective for all types of pathogen as they relate primarily to good sanitary integrity of the system as it can be expected that any residual disinfectant will disappear rapidly.

The hazard assessment would clearly need to look for likely sources of faeces within the building and is likely to primarily look at whether there is potential access into the storage tank for rodents and birds. Additional hazard factors to be considered will be the location of the tank and likely temperature and the materials used for storage. Location close to roofs may increase hazards as access for rodents and birds may be greater and may lead to increasing temperatures. Metal tanks may more readily support colonisation and exert a greater chlorine demand and may be likely to heat more quickly in hot weather than plastic tanks.

Household handling and storage when communal sources of water are used
With respect to the handling and storage of water when the source is communal, the principal reference pathogen of concern is *E.coli 0157*. Whilst the recontamination by viruses and protozoa may occur, most of the basic measures to prevent contamination from these organisms do not significantly vary from those associated with bacterial pathogens. The only major difference will come when in-house water treatment processes are used, for which drinking water quality management plans are defined separately. Actual health risks from viruses and cysts in drinking water may in any case be lower in situations where communal source provision predominates. This is because childhood exposure to viruses is likely to occur from other means and because cyst exposure may be likely through direct human-animal contact. It is uncertain to what extent regrowth will be a problem, but certainly could occur if cleaning was not adequately performed.

The hazards relate to the quality of source water (which therefore should be dealt with under the appropriate hazard assessment by source type) and potential subsequent contamination. An additional hazard is the presence of animals within the home. The most important hazard will almost certainly be from contaminated hands and therefore wherever non-piped water storage is practised it is safe to assume that hazards always exist.

IWRM and regulatory issues

Issue	**Justification/explanation (includes cross-referencing to support texts for checking in finalisation**	**Appropriate actions**
Regulations and codes of practice for design & construction of within-building storage of piped systems	Regulations and codes of practice will ensure enforceable standards of design and construction are in place to promote improved within-building water supplies	Set up plumbing codes of practice Design and construction criteria outlined Licensing of design engineers and plumbers
Users committee within large buildings and complaints procedure outlined	Users committees may provide a more effective mechanism for complaints and to enforce compliance with regulations. A complaints procedure will enable residents to initiate actions against sub-standard work.	Establish user or residents committee with legal mandate. Establish complaints procedure
Reduce within-building storage	Reducing within-building storage of water will reduce the risks of contamination. The use of direct supply mains should be promoted as far as possible	Increase numbers of direct mains connections.
Where water is collected from a communal source, promote household water treatment	It is unlikely to be possible to prevent contamination solely through better handling, therefore household water treatment may be more cost-effective in reducing health risks	Identify major microbial hazards and identify acceptable treatment processes. Establish links with private sector to sell treatment products.
Understand water collection patterns	It is important to understand which sources of water used and for what purposes. If water from different sources are used for different purposes, separation of water may be essential.	Water usage studies.
Increase level of service provision and quality of service to reduce storage requirement	Where water sources are beyond the home, storage of household water may become an increasing priority. Equally poor reliability may lead to increased storage requirement.	Create incentives to promote uptake of more connections at higher service level. Attempts to improve reliability of supply.

Design issues

There is usually significant scope for improved designs of within-building storage tanks. Improved storage containers are available for use when water is collected from a communal source by hand, but uptake may be influenced by a number of factors.

Design issue	**Justification/explanation (includes cross-referencing to support texts for checking in finalisation)**
Where water is piped into the home, all residences should have at least one tap direct to the main supply	Provided the water supplier adheres to a water quality management plan for production and distribution of water, the water in main supply should be of good quality and within-building contamination reduced.
Codes of practice for within-building plumbing repairs	Codes of practice for hygiene when undertaking repairs are important measures to prevent contamination during repair work. These should be enforceable through regulations and be subject to periodic assessment.
Within building storage tanks should be covered	Tanks that are not covered are open to direct contamination from rodents and birds. Evidence from a number of outbreaks suggests that this is a major cause of contamination. Inspection covers on tanks should be properly secured.
Tanks should have drain valve and sluice valves	It should be possible to fully drain the tank to allow more effective cleaning. It must also be possible to isolate the tank during cleaning and repairs to prevent contamination being spread throughout the system.
Separate hot and cold water pipes	The close proximity of hot and cold supply pipes has been linked to increasing survival and regrowth of pathogens within water supply systems as temperatures increase. Lagging of cold pipes may significantly reduce this potential.
Prevent back-flow from household connections and within building tanks.	Back-flow from tanks into the wider supply should be avoided to prevent widespread contamination. Back-flow preventers should therefore be placed on all mains connections to large buildings. Back-flow potential may also be desirable within buildings to prevent the potential for contamination from one user affecting the whole building.
System of water withdrawal from household container should be hygienic	Unhygienic systems of water withdrawal may allow users hands to come into direct contact with water, thus potentially leading to contamination. By preference a tap should be used, but a hygienically stored scoop can also be used
Household container should permit thorough cleaning	It should be possible to thoroughly clean the inside of the container. This may require scrubbing or disinfection.
Appropriate materials used for household container	The choice of container material is essential. Clay pots are undesirable as they more readily support microbiological communities and usually require water to be scooped. Plastic materials tend to be less readily colonised.
Hygiene education	A hygiene education programme should be developed to promote safe water handling. This should cover aspects such as container type, cleaning of household water containers, safe withdrawal of water and personal hygiene. Participatory approaches are often preferred as they encourage experiential learning.
Drinking water stored in a separate container to other household water	This is of particular importance where more than one source of water is used and where particular sources are used only for particular purposes. Keeping drinking water in a separate container will help reduce the risk of contamination from water from other sources that are of lower quality and used for non-drinking purposes.
Household storage container should be stored off the ground and away from reach of animals	When storage containers are located at floor level they will be more vulnerable to direct contamination from animals. Keeping water carefully stored away from access to animals will greatly reduce contamination risks.
Storage container should be covered	Open containers will be more likely to become contaminated as faecal matter is more easily introduced into the water by a variety of routes. Direct contamination by rodents and other animals and birds is likely
Promotion of use of protected/treated water sources	Promoting the use of sources that are protected and/or treated and which have some form of water quality monitoring may be an effective mechanism to reduce contamination of drinking-water.

Household disinfection
Household disinfection has been used in a number of countries and proved effective in reducing risks of epidemics and in reducing endemic diarrhoeal disease burdens. Chemical disinfection methods include the use of chlorine, iodine or mixed oxidants. This are generally found in either tablet or liquid form. Physical disinfection includes boiling of water, UV radiation and low-cost solar disinfection techniques that work through a mixture of inactivation through temperature and exposure to UV radiation. Good evidence of efficacy is available for all these approaches, both in terms of epidemiological evidence and in pathogen inactivation rates during operational testing.

The use of household disinfection has until recently received far less attention that it deserves. Some studies have suggested that household treatment of water would have limited impact on health where environmental sanitation or hygiene remained poor (see for instance, Vanderslice and Briscoe, 1993; Moe et al, 1991). However, increasing evidence from a number of initiatives suggests that this is not the case and significant reductions in diarrhoeal disease have been noted (see background document for details).

Heat induced inactivation is very effective for bacteria and cysts and a rolling boil (>95^{o}C) will inactivate all pathogens. Inactivation of all types of pathogen also occurs at lower temperatures, with viruses being most heat resistant, followed by cysts and bacteria. Of the chemical disinfectants, chlorine is highly effective against bacteria and viruses, but far less so against protozoa. It is unlikely that chlorination would be recommended alone for removing *Cryptosporidium spp.* cysts.

Iodine and the mixed oxidants both show greater effectiveness in cyst inactivation. However, as the long-term use of iodine not be acceptable to most users, control of protozoan pathogens may be more effective through filtration prior to disinfection. Polyiodide resins have proved effective disinfectants and release very little residual disinfectant as inactivation occurs on contact with bacteria. However, filtration prior to disinfection is usually essential in order to remove suspended solids from influent water. Commercial units have been produced that incorporate reverse osmosis and iodine resins and prototype units for ceramic filter/resin units are also available.

Solar disinfection has attracted increasing attention as a low-cost approach to producing water of very good microbiological quality. Low-cost solar disinfection systems have also been shown capable of reducing *Cryptosporidium spp.* and other pathogens in water, although this is likely to be primarily be a function of increasing temperature. Many of these techniques operate on a combined action of heat inactivation and UV disinfection. UV filters are also commercially available and known to be effective. These would tend to be larger-scale units and likely to be used for large buildings rather than individual households given the expense.

Selection of reference pathogens and assumptions made
The use of household disinfection is always promoted because of concerns over the quality of the water at sources or because of concerns regarding contamination during transport, handling and storage.

The principal reference pathogens are Hepatitis A virus and *E.coli 0157* to ensure that efficacy was assured. This may be expanded to include *Cryptosporidium parvum* when the disinfectant used is expected to inactivate cysts during practical operation. As household water treatment imply hazards are available, there is little point in undertaking hazard assessments other than those related to risks of source contamination or recontamination during handling.

Colonisation of certain types of household treatment systems have been noted, but would not be expected to represent a major problem for systems that are only for disinfection as colonisation appears most marked in filter units. Furthermore, where disinfection would be expected to directly control re-growth and therefore it would not be expected that the use of *Legionella pnuemophila* would be necessary.

It is important to note that when manufacturers or developers of household disinfection units are promoting their products that evidence is provided on pathogen inactivation and not simply on indicator bacteria reductions. This is essential as many of these units can be expected to be highly efficient with regard to coliform bacteria, but may have far less effectiveness against pathogens. It is also essential that data is presented on the basis of challenge experiments involving both batch and continuos run experiments. The latter should be designed to mimic real operating conditions and following the recommended cleaning procedures and frequencies. Failure to provide this type of data should suggest that licensing for widespread use is not justified, although this data could be collected through pilot field trials in the country.

IWRM and regulatory issues

Issue	**Justification/explanation (includes cross-referencing to support texts for checking in finalisation**	**Appropriate actions**
Environmental technology verification protocols should exist that allow for proper evaluation of all treatment products	Household disinfection technologies should be evaluated properly to ensure efficacy. This would usually require certification from country of origin and assessment to meet national criteria	Technology verification protocols should be developed.
Regulations and licensing system established to ensure standards defined	Regulations should govern manufacturers and wholesalers of household disinfection products. These should cover manufacturing specifications to meet defined water quality targets. It may also cover advertising controls.	Establish registration and licensing procedure and lead agency. Regulations and performance standards should be clearly outlined and compliance a requirement for licences.
All licensed household disinfection systems should provide data on pathogen inactivation based on continuous run and batch experiments	Pathogen inactivation should be proven in order to support claims about effectiveness. Data on indicator bacteria alone should not be accepted. Batch and continuous run challenge tests should be presented. The latter is particularly important and should reflect recommended operating procedures.	Establish scientific review body. Establish procedure for data submission and review. Set up data bank for storing data.
Legal requirement for manufacturers/retailers to make information available to users about source water requirement, pre-treatment needs, maintenance needs and operating conditions	A lack of information about source water requirements, pre-treatment requirements, maintenance schedules and operating conditions may lead to confusion and deteriorating performance and ultimately to increasing health risks	Labelling of products a legal requirement. Establish penalties for non-compliance. Information to be included on labels specified by licensing authority.
Use of household treatment does not preclude investment in public water supply	Household disinfection may well meet short to medium terms needs. However, the presence of effective household technologies should not be result in reduced investment in public water supply	Continued investment in water supply infrastructure.

Design issues

Design issue	Justification/explanation (includes cross-referencing to support texts for checking in finalisation)
Operating and maintenance, specifying any water quality or other environmental control on efficiency information provided clearly	Many household disinfection systems fail because operation and maintenance requirements are not well understood and allow breakthrough of pathogens
Design ensures contact adequate Ct value for inactivation	The inactivation of pathogens by disinfection is a function of the concentration of disinfectant and time for which pathogens are exposed to the concentration.
Systems do not deliver harmful doses of disinfectants	Where chemical disinfectants are used, doses provided should be within safe limits based on national standards or WHO Guidelines. Dose control should be proven for all recommended operating conditions.
Design dose should be maintained throughout working life	Doses of some forms of chemical disinfectants (e.g. some resins) may vary with time and dose delivered decreases with time. This may lead to increasing risks of pathogen survival.
Systems should not allow colonisation by bacteria	Only relevant to combinations systems with filtration/substrate. In these cases, re-colonisation must be controlled with accepted life span.
Consumables (where needed) should be readily available and affordable	If consumables are needed for ongoing operation they should be readily available and affordable to promote widespread uptake.

Household filtration systems

Household filtration systems encompass a wide variety of technologies from sophisticated systems using reverse osmosis or micro-filtration, through less complex systems such as activated carbon cartridges, ceramic filters and combination units with disinfectants included, to very simple techniques using filtration based on sand or other granular media. The more complex systems tend to be those found in commercial units and which may be expensive to purchase. These may be point of entry units (i.e. plumbed into the piped water supply as it enters the home) or much smaller point of use systems. The very simple technologies are more typical of point of use units used at a household levels and less expensive to construct, although not necessarily lower maintenance.

Filtration devices remove particulate matter from water and as a result may lead to reductions in pathogen loads. Direct pathogen removal will primarily be a function of the pore size, although some adsorption onto the filter media may also occur. It is unlikely that either of these processes will be fully effective for viruses or bacteria, although in most fine filters cyst removal should be effective.

Particular attention should be paid to the development of cracks the filter media as this may allow rapid short-circuiting of the filter and increasing risks of pathogen breakthrough. Some ceramic filters are impregnated with silver which it is claimed will function as a disinfectant. There is little evidence of long-term bactericidal effect of silver and studies suggest that the bacteriostatic properties may be limited as silver tolerant bacteria can colonise filters. It is possible that that the limitations of the silver impregnation occur because whilst initial concentrations released are high, they rapidly decline to levels too low to be effective.

More expensive and very fine filters, for instance based on membrane filtration are likely to remove more pathogens. Micro-filtration will be effective against cysts, but would be not be effective against bacteria and viruses, although removal of particulate matter may reduce concentrations to a certain degree. Reverse osmosis would be expected to remove virtually all pathogens, but clogging may be problem. More widely available commercial units using ceramic or carbon filters will remove cysts and some bacteria and viruses. However, breakthrough by of viral or bacterial pathogens is common. Both types of filter may also be prone to colonisation, including by *Legionella pneumophila*. Water from such filters should normally be disinfected prior to consumption.

Simple filtration units are known to be effective for removing larger pathogens and may be useful in guinea worm eradication programmes. Their efficacy in bacterial, viral and protozoan pathogen removal is less certain. There are few available studies that evaluate the effectiveness of many of the much simpler filtration units in pathogen removal, largely because their application has been in very poor and often remote communities. The limited evidence available provides information on reductions in turbidity and indicator bacteria. These show that thermotolerant coliforms are rarely consistently absent, suggesting limited ability to remove pathogens.

Selection of reference pathogens and assumptions made

As filtration of water within the home may be carried out either because the water supply is of poor quality or because of concerns over chemical quality, the use of all four key reference pathogens could be justified to a certain extent. However, this may not be case in all circumstances and the reference pathogens selected may be somewhat dependent on the type of technology and the socio-economic conditions.

All filters would be expected to be effective at least against cysts and therefore *Cryptosporidium parvum* should be considered a reference pathogen against which performance is measured, even in situations where alternative routes of transmission may be more important. For simple granular filters and for ceramic candle filters and carbon filters without disinfectant impregnation this is will be the only valid reference pathogen. Disinfection of the water after filtration should be always recommended (unless specific evidence can be provided on bacterial and viral inactivation). Where the filter unit includes a disinfectant or uses reverse osmosis, then Hepatitis A, *E.coli 0157* and *Legionella pnuemophila* should be considered as reference pathogens.

As the use of household filtration implies that source waters are contaminated, hazard assessments other than those related to the source are not necessary.

IWRM and regulatory issues

These are effectively the same as for household disinfection, but are repeated here for completeness.

Issue	**Justification/explanation (includes cross-referencing to support texts for checking in finalisation**	**Appropriate actions**
Environmental technology verification protocols should exist that allow for proper evaluation of all treatment products	Household filtration technologies should be evaluated properly to ensure efficacy. This would usually require certification from country of origin and assessment to meet national criteria	Technology verification protocols should be developed.
Regulations and licensing system established to ensure standards defined	Regulations should govern manufacturers and wholesalers of household disinfection products. These should cover manufacturing specifications to meet defined water quality targets. It may also cover advertising controls.	Establish registration and licensing procedure and lead agency. Regulations and performance standards should be clearly outlined and compliance a requirement for licences.
All licensed household filtration units should provide data on pathogen inactivation based on continuous run and batch experiments	Pathogen inactivation should be proven in order to support claims about effectiveness. Data on indicator bacteria alone should not be accepted. Batch and continuous run challenge tests should be presented. The latter is particularly important and should reflect recommended operating procedures.	Establish scientific review body. Establish procedure for data submission and review. Set up data bank for storing data.
Legal requirement for manufacturers/retailers to make information available to users about source water requirement, pre-treatment needs, maintenance needs and operating conditions	A lack of information about source water requirements, pre-treatment requirements, maintenance schedules and operating conditions may lead to confusion and deteriorating performance and ultimately to increasing health risks	Labelling of products a legal requirement. Establish penalties for non-compliance. Information to be included on labels specified by licensing authority.
Use of household treatment does not preclude investment in public water supply	Household filtration may well meet short to medium terms needs. However, the presence of effective household technologies should not be result in reduced investment in public water supply	Continued investment in water supply infrastructure.

Design issues

Design issue	Justification/explanation (includes cross-referencing to support texts for checking in finalisation)
Operating and maintenance information provided clearly	It is essential that the conditions under which the filtration process will be effective and the maintenance requirements should be clearly specified on the unit.
Materials specification	Materials allowable for use in filters should be specified. This may have different categories of filter types. Aspects such as pore size and media type should be specified.
Cleaning procedure and guidance on media or cartridge replacement	This should simple and easy to follow. Manufacturers recommendations should err on the side of caution, as most users will probably not follow recommendations exactly
Filtration rate adequate	The filtration rate that is acceptable is dependent in part on what the filter is designed to achieve: whether particulate matter removal or pathogen reduction. However, the filter should be assessed against the performance criteria claimed by the manufacturer.
Pore size is uniform	Poor performance of many filters arises through variations in pore size and the development of short-circuit pathways. This is a particular problem for quality control in ceramic filters
Assessment of efficiency of pathogens/particulate removal	Assessment data should be made available to support evidence of removal so that information can be provided to users on performance expected. If filter does not produce water of acceptable levels, additional treatment steps required should be outlined.