Designing A Drinking Water Quality Monitoring Programme

A Practical Guide for Pacific Island Countries

Tasleem Hasan

William Aalbersberg

SOPAC Technical Report 407

Copies of this report may be obtained from:

SOPAC Secretariat
Private Mail Bag
GPO, Suva
Fiji Islands
Phone: (679) 338 1377
Fax: (679) 337 0040
http://www.sopac.org
E-mail: director@sopac.org

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PREFACE

Contamination of drinking water is a significant concern for public health throughout the world. Microbial hazards make the largest contribution to water-borne diseases in developed and developing countries. In addition, chemicals in water supplies can cause serious health problems, whether the chemicals are naturally occurring or derive from sources of pollution.

It is important for Pacific Island Countries (PICs) to identify, prioritise and analyse water quality parameters that are of greatest risk to human health. This will ensure that viable and useful information on the status of drinking water quality is achieved within the existing resources (budget, staff and laboratory capacity).

This guide provides direction for PICs to design a feasible and useful drinking water quality monitoring programme that recognises their existing and perhaps limited resources. It draws heavily from the following resource documents:

- WHO, (2004). ***Guidelines for Drinking-water Quality***. 3rd Edition, Volume 1, World Health Organization, Geneva.
- Thompson, T. *et al.* (2007). ***Chemical Safety of Drinking-water: Assessing Priorities for Risk Management***. WHO, Geneva.
- Howard, A.G. (2002). ***Water Supply Surveillance: A Reference Manual***. WEDC, Loughborough University, UK
- Mosley, L. *et al.* (2004). ***Water Quality Monitoring in Pacific Island Countries***. SOPAC Technical Report 381.

The authors/compilers have extracted information from the above-mentioned references and combined it with the practicalities observed in PICs based on their experiences. The guide also acknowledges that the monitoring programme should fall within the larger framework of a drinking water safety plan.

The crafting of this guide resulted from a NZAID-funded Pacific Water Quality Monitoring Capacity Building (WQM) Programme (2006-2008) coordinated by the Pacific Islands Applied Geoscience Commission (SOPAC), the World Health Organization (WHO) and the Institute of Applied Sciences of the University of the South Pacific (IAS-USP). The WQM Programme was initiated in response to the Pacific Regional Action Plan on Sustainable Water Management (2002) and the Framework for Action on Drinking Water Quality and Health (2005), in both of which PICs identified the need for assistance in improving and strengthening their water quality monitoring capacity.

1. A list of acronyms used in this report is compiled in Annex 3

EXECUTIVE SUMMARY

Designing a drinking water quality monitoring programme can be difficult and often presents a challenge. It is important for the person(s) designing the monitoring programme to identify and prioritise the testing of water quality parameters that are of the greatest risk to human health. This will ensure that practical and useful data on the quality of drinking water is obtained within the existing resources (budget, staff and laboratory capacity).

An integrated approach should be adopted when designing a monitoring programme. This will promote the involvement of various agencies that have responsibility for specific areas associated with water quality thus leading to a holistic design of the monitoring programme.

Before going into the details of designing the monitoring programme, it is important to describe the drinking water supply for which the monitoring plan is being set up. It is also important to know your role when designing a drinking water quality monitoring programme, whether you are monitoring as a water supplier or as a surveillance agency. It has been proven to be effective if the roles and responsibilities of the water supplier and the surveillance agency are kept separate (WHO, 2004).

The purpose of monitoring is the core of the monitoring programme design and should be stated upfront. Once the purpose is determined the other steps of the design, like the selection of sampling sites, sampling points, parameters and sampling frequency, evolve.

Selection of sampling sites requires consideration of the monitoring purposes and accessibility of the station both physically and within the resources. It is very important that the sampling site and the surrounding area/environment are known very well by the person(s) designing the monitoring programme.

The next step in the design is to know what parameters you should analyse. An important prerequisite to parameter selection is having good knowledge of what the different parameters indicate about the water quality in relation to the purpose of monitoring.

There are more than 200 water quality parameters that could be measured but testing for all is impractical, time consuming and costly. It is important to make a good judgement of what are likely to be the most important in a particular water supply.

Monitoring microbiological quality of drinking water is of principal importance because of the acute risk to health posed by bacteria and viruses in drinking water. Therefore, microbial organisms should be the top priority parameter to consider when designing a drinking water quality monitoring programme. Microbial organisms that are pathogenic (disease causing) make the largest contribution to water-borne diseases in developed and developing countries. The presence of pathogens in drinking water is usually due to human and animal waste entering into water sources.

It is difficult and expensive to test for all pathogens that may be present in drinking waters. Therefore, indicator organisms such as thermotolerant (faecal) coliforms and *E.coli* are recommended to be tested for instead to indicate contamination of drinking water from faecal origin. However, greater emphasis should still be placed on adopting the drinking water safety plans approach of risk assessment and risk management where the major control measure that could be applied to manage potential risk from pathogens would be source water protection.

In addition to monitoring the microbiological quality of drinking water, there is also a set of physical and chemical parameters that either influence the microbiological quality or cause rejection of water on acceptability grounds. These critical physical and chemical parameters should be next on the priority parameters to include in a drinking water monitoring programme. The critical parameters include turbidity or suspended solids, pH, residual chlorine or free available chlorine and electrical conductivity or chloride.

Few chemical parameters may be included in the monitoring programme in PICs, where resources and capacity are limited, unless there is good reason to suspect that there is a problem with that parameter. Where chemical parameters are routinely tested, this is done at lower frequencies than the microbiological indicators and the critical parameters.

Source waters can be naturally enriched with chemicals and be contaminated; or contamination can occur from anthropogenic sources like agricultural activities, human settlements and industrial activities. Regular monitoring of nitrate is recommended in areas where chances of contamination are high from anthropogenic sources to ensure early warning of increase. Periodic analysis of metals and pesticides is recommended for monitoring of contamination from anthropogenic sources unless a specific risk is identified through investigation or historic data.

The sampling frequency (how often a sampling point can be visited) and numbers (how many samples can be analysed) should also be given consideration during the design process. Sampling and analysis are required more frequently for microbial and critical parameters and less often for chemical contaminants. The availability of funds and the monitoring role (water supplier or surveillance agency) also determines the frequency and numbers.

It is best left with the person(s) designing the monitoring programme to decide on the frequency and numbers of sampling taking into consideration the resources available. It should be noted, however, that the frequency and numbers should provide data that is meaningful and able to fulfil the purpose of monitoring.

The proper reporting of results, communication to the relevant stakeholders and follow-up action should be in place and functioning for a successful monitoring programme. Proper reporting and feedback will support the development of effective follow-up actions required. The ability of a monitoring programme to advocate follow-up actions (remedial actions) is highly dependent on the ability to interpret and present results in a meaningful manner to different target audiences.

Finally, the monitoring programme needs to be reviewed continually in event of new risks identified that may have the potential to contaminate drinking water supplies.

Any drinking water quality monitoring programme would be specific to the country, situation and the available resources; even in PICs.

1.0 INTRODUCTION

Various international guidelines and standards for drinking water quality exist. Examples are the WHO guidelines for drinking water quality, the US EPA standards for drinking water and the New Zealand drinking water standards.

These guidelines list nearly 200 chemical and microbiological parameters for which guideline values have been set or considered. It is important to note that the parameters for which guideline values have been set do not imply that they are all present in drinking water and need to be tested (Thompson *et al.*, 2007).

Water quality can be described by a single parameter or by any combination of more than 100 parameters. For most purposes, however, water quality can be adequately described by fewer than 20 physical, chemical and biological characteristics (Bartram and Balance, 1996). National or local authorities need to design a water quality monitoring programme that meets their purposes. They need to prioritise and select parameters that would make sense to their monitoring requirements.

Selecting the parameters to include in a monitoring programme will often require a compromise between "like to know" and "need to know" (Bartram and Balance, 1996). However, some parameters must be measured if the basic programme objectives are to be achieved. These parameters must be prioritised keeping in mind the existing resources (budget, laboratory capacity and trained staff).

Often, identification and assessment of risks to health from drinking water relies excessively on analysis of water samples. The limitations of this end-point testing approach have now been well recognised. The detection of contaminants in drinking water from monitoring water quality parameters indicates that something has already gone wrong, and that consumers may have already been exposed to unsafe water.

To overcome such limitations, the latest edition of the World Health Organization (WHO) ***Guidelines for Drinking–water Quality*** (WHO, 2004) emphasises effective preventive management through a "framework for drinking water safety" that incorporates "drinking water safety plans".

Drinking water safety plans is a new risk-assessment/risk-management approach to ensuring safe drinking water. It deals with identifying risks within the water supply (from catchment to consumer) and trying to manage the risks by eliminating or reducing them.

For example, if a river is used as a drinking water supply, then the immediate risks that could contaminate the supply are assessed. Are there animals roaming in or around the intake area? Yes – there is a risk. What risk? Animal faeces can contaminate the drinking water source. Risk management – remove animals from intake area or fence off intake area. In this example, monitoring the levels of thermotolerant (faecal) coliform or *E.coli* will indicate whether the drinking water safety plans is effectively implemented, that is, if there is a noteworthy decrease in faecal contamination in the water supply after animals are removed from the intake area.

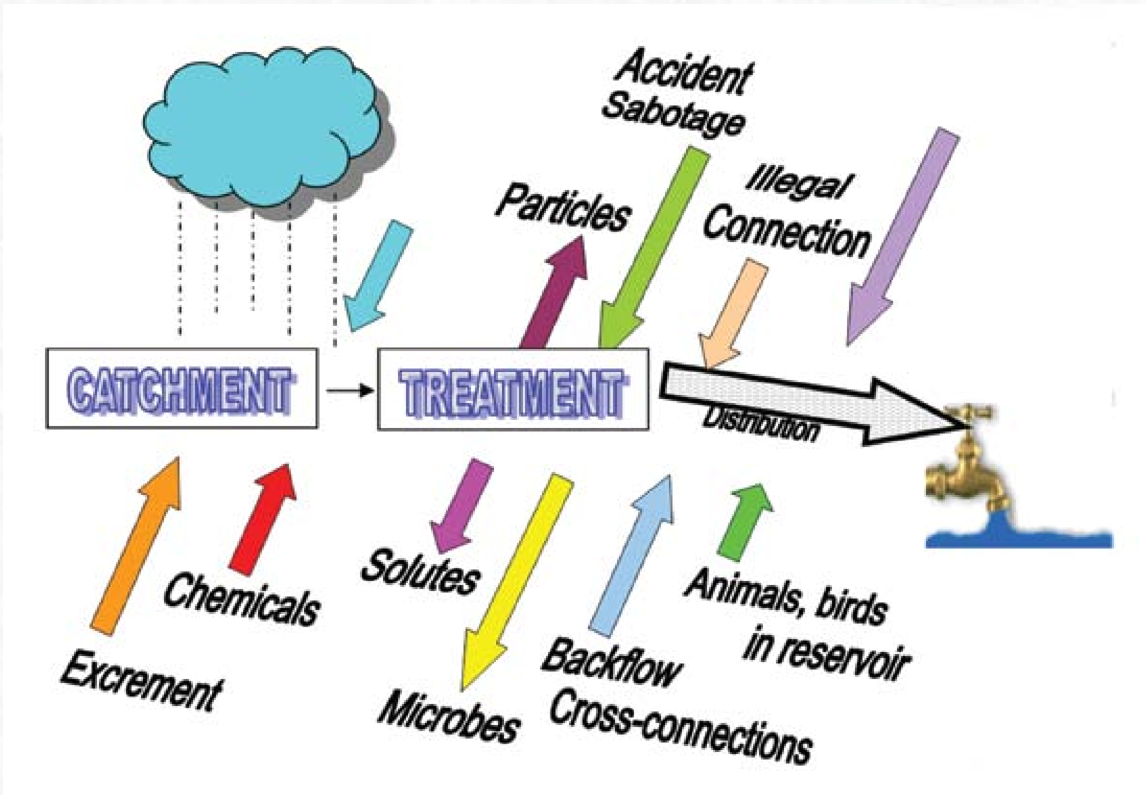
For a drinking water safety plan this sort of risk identification and management is done throughout the water supply system (catchment, treatment/storage, distribution network) and monitoring parameters identified that verify the effectiveness of the drinking water safety plan.

2. For further reading on how drinking water safety plans have been applied in some Pacific Island Countries, refer to WHO/SOPAC (2008). Drinking Water Safety Planning: A Practical Guide for Pacific Island Countries. SOPAC Joint Contribution Report 193. In press.

It is highly recommended that drinking water supplies have a drinking water safety plan in place, which requires a monitoring programme only as verification for the plan. No amount of monitoring will ensure the safety of drinking water, hence a proactive approach promoted by a drinking water safety plan should be considered.

As mentioned, it is important to identify and prioritise the contaminants of concern, to overcome the limitations of direct analysis of water quality, and ensure that limited resources (budget and capacity) are allocated towards the monitoring, assessment and control of the contaminants that pose the greatest health risks.

This guideline is aimed at assisting agencies involved with water quality monitoring roles to design a practical and workable monitoring programme for their country and purpose, which is within their existing and often limited resources.



Drinking Water Safety Plan approach of identifying potential risks/contaminants throughout a water supply system

2.0 DRINKING WATER QUALITY MONITORING PROGRAMME

Designing a drinking water quality monitoring programme can be difficult and often presents a challenge. The following sections attempt to provide guidance for person(s) designing a drinking water monitoring programme to select and prioritise important parameters that can be measured in a laboratory or on-site to define the quality of the drinking water.

2.1 Collaborative Approach

It is recommended that before a monitoring programme is designed relevant agencies and professionals form a team or committee. If the supply already has a drinking water safety plan team then that team (or a sub-team from within that team) would be of ideal composition for designing the monitoring programme.

Since many aspects of risk identification, parameter selection and risk management of drinking water quality are discussed in this guide; it is recommended that a multidisciplinary approach be adopted to ensure that agencies with responsibility for specific areas associated with water quality are involved. This will ensure a more integrated management approach to ensuring safe drinking water quality. It will also strengthen the multi-agency cooperation and improve the communication and follow-up strategies of water quality results.

2.2 Description of the Water Supply

Before going into the core of designing the monitoring programme, it is important to briefly, but accurately, describe the drinking water supply for which the monitoring plan is being set up. The description should include information such as:

- the drinking water source;
- any form of treatment (coagulation, flocculation, filtration, disinfection);
- storage (reservoirs, water tanks);
- distribution (piped or reticulated water supply, point source); and
- population served.

In the Pacific, drinking water is supplied from various sources like groundwater (well, borehole), rainwater and surface water (river, creek, stream, spring, dam). Treatment options range from large treatment plants to on-site filtration to no treatment at all. Disinfection is done using chlorine and the plumbing (pipes and fittings) materials are made from a range of copper, iron, zinc, lead and polyvinyl chloride (PVC).

2.3 Monitoring Role

It is important to know your role when designing a drinking water quality monitoring programme, whether you are monitoring as a water supplier or as a surveillance agency. This will have a bearing on the steps undertaken during the monitoring programme designing such as purpose, site selection, parameter selection, frequency of sampling and follow-up action.

It has been proven to be effective if the roles and responsibilities of the water supplier and the surveillance agency are kept separate (WHO, 2004).

The water supplier has a responsibility to ensure that the water they supply is fit for human consumption. It is the supplier who is responsible for the quality of the water they supply and who must safeguard this. Hence they are responsible for monitoring the quality of the raw water, treated water (if applicable) and water at storage and along the distribution network.

The surveillance agency is also expected to monitor the water supplied by the supplier to verify that the quality is indeed fit for human consumption. They are responsible for monitoring the quality immediately after treatment (if applicable) and storage and distribution (up to the point of consumption). Occasionally they could monitor the source water quality to ensure that the supplier is doing its job of source water protection.

The surveillance agency often also takes the responsibility for monitoring rural or outer island and community-managed water supplies, in which case they monitor the quality of the water from catchment to consumer. The surveillance agency is also likely to take the responsibility for hygiene and environmental health education in communities. In PICs the surveillance agencies are mostly the Ministry of Health (or Public Health) or the Environmental Protection Agency.

In developed countries the surveillance agency is supported by strong and enforceable legislation and has the authority to penalise or fine a water supplier if it fails to fulfil its obligation. In PICs this approach may not necessarily work hence it is important that the surveillance agency develops a positive and supportive relationship with the water supplier for the improvement of water quality. In many countries the supplier and the "surveillance agency" are in the same department, which creates a potential conflict of interest.

In terms of monitoring, the water supplier does more frequent routine monitoring of parameters than surveillance agencies.

2.4 Purpose of Monitoring

When designing any water quality monitoring programme it is vital to state the purpose of monitoring upfront.

The purpose of a drinking water quality monitoring programme, traditionally, has been to provide data that shows that the water is safe and aesthetically acceptable for drinking, or if unsafe water is supplied then people can be advised to take precautionary measures like boiling.

The water quality monitoring data obtained is often used to demonstrate compliance with national or international guidelines/standards to indicate that the water is safe and acceptable for consumption.

The data can also be used to verify that the drinking water safety plan for a water supply is being implemented successfully.

There can be more than one purpose of monitoring but it should be noted that the consecutive steps depend upon the purpose stated.

2.5 Selecting Sampling Sites and Sampling Points

A sampling site is the general area from where samples are to be taken for monitoring. The exact place at which the sample is taken is commonly referred to as a sampling station or, sometimes, a sampling point.

For example:

Sampling site	Sampling point
A borehole in a community	Borehole pump
A household rainwater harvesting system	Tap at the rainwater tank
The distribution network of a reticulated water supply	Kitchen tap at John's house

Selection of sampling sites requires consideration of the monitoring purposes and accessibility of the station both physically and within the resources (budget for transport and staff costs).

It is very important that the sampling site and the surrounding area/environment are known very well by the person(s) designing the monitoring programme. This could include information on aspects such as geology, industrial and agricultural development and human settlements and activities within the sampling area.

A good knowledge of the sampling site and surrounding area would assist greatly during parameter selection and prioritising of parameters.

2.6 Parameter Selection

The next step in the design is to know what parameters you should analyse. An important prerequisite to parameter selection is having good knowledge of what the different parameters indicate about the water quality in relation to the purpose of monitoring. For example, testing for electrical conductivity (EC) in groundwater. What is EC and what will the result indicate about the water quality?

The description of some of the essential parameters to assess in drinking water quality is listed in Annex 1.

The purpose of monitoring is very important during parameter selection. For example, if the purpose of your monitoring is to determine if saltwater is intruding and mixing with your fresh groundwater drinking source then the simplest parameter you could monitor is EC.

As mentioned in the introductory chapter, there are more than 200 water quality parameters that could be measured but testing for all is impractical, time consuming and costly. It is important to make a good judgement of what are likely to be the most important in a particular water supply.

The key word here is to prioritise which parameters are most relevant and can be measured within the available resources (capacity and funding).

2.6.1 Microbial Organisms

Monitoring microbiological quality of drinking water is of principal importance because of the acute risk to health posed by bacteria and viruses in drinking water. Therefore, microbial organisms should be the top priority parameter to consider when designing a drinking water quality monitoring programme. Microbial organisms that are pathogenic (disease causing) make the largest contribution to water-borne diseases in developed and developing countries. The presence of pathogens in drinking water is usually due to human and animal waste entering the water sources.

It is difficult and expensive to test for all the pathogenic organisms that may be present in contaminated drinking water. Therefore indicator organisms are used to determine the risk that these organisms might be present in drinking water. Indicator organisms are always present in large quantities in faecal material, whether pathogenic organisms are present or not. A high level of indicator organisms in a water sample indicates a high risk that pathogenic organisms might also be present (Mosley *et al.*, 2004).

The usual indicator organisms that are tested for in PICs are total coliforms, thermotolerant (faecal) coliforms and *E.coli*.

E.coli is considered the most suitable indicator of faecal contamination and where possible should be tested for. Thermotolerant (faecal) coliforms are the next best indicator of faecal contamination. They are composed mostly of *E.coli*, however, the presence of other species such as *Klebsiella spp* makes the group a less (but still acceptable) index of faecal contamination.

Total coliforms are not an ideal indicator in the tropics as they can naturally persist and reproduce in soil and water at the ambient temperatures (WHO, 1996). Faecal contamination can incorrectly be assumed to be present in pristine water sources where there is none as positive results in total coliform tests may be obtained. Therefore, total coliforms are not recommended as a water quality indicator in the Pacific islands, except where the presence of these coliforms in treated drinking water supplies would assist to indicate a treatment failure or leakage in the system (Mosley *et al.*, 2004).

Similarly, total coliforms if measured for an untreated water source over time can assist in determining the natural baseline of coliforms prevalent in the source. If the total coliform count shows a sudden high value (spike) that would indicate possible contamination and warrant investigation.

The methods used for testing the microbial indicator organisms in the Pacific mostly provide results for total coliforms and either thermotolerant coliforms or *E.coli* (best indicator). Though only the results of thermotolerant coliforms or *E.coli* are needed for microbiological quality of drinking water, it would not hurt if the results for total coliforms are recorded. This could assist determine a trend over time and the total coliform results are obtained at no additional cost any way.

It should be noted that while *E.coli* is a very good indicator for faecal contamination, the absence of it however, does not necessarily indicate that the drinking water is free of all pathogens. For example, *E.coli* is not a suitable index for the presence/absence of *Giardia, Cryptosporidium* and *Legionella* in drinking water. The specific analysis for these organisms would be impractical for PICs to do and is not recommended. Instead, greater emphasis should be placed on adopting the drinking water safety plans approach of risk assessment and risk management. Within a drinking water safety plan, the major control measure that could be applied to manage potential risk from *Giardia, Cryptosporidium* and *Legionella* would be source water protection from human, animal and livestock waste.

2.6.2 Critical Physical and Chemical Parameters

In addition to microbiological quality, there is also a set of physical and chemical parameters that either influence the microbiological quality or cause rejection of water on acceptability grounds. These critical physical and chemical parameters should be next on the priority parameters to include in a drinking water monitoring programme. It should be noted that these critical parameters vary slightly with different water sources and treatment options (if applicable).

The critical parameters are:

- turbidity or suspended solids (all water sources);
- pH (chlorine treated water and piped water at source);
- residual chlorine or free available chlorine (chlorine treated water); and
- electrical conductivity or chloride (groundwater, at source location).

Turbidity

Turbidity is the measure of "cloudiness" of the water and is often used as a simple substitute for suspended solids. Turbidity may cause rejection of water by consumers, but is also associated with bacterial survival, as adsorption onto suspended solids by microorganisms is common. Turbidity should always be tested whenever a sample is taken for water quality testing. High turbidity protects micro-organisms from chlorine and other disinfectants and interferes with the maintenance of residual chlorine. An increased turbidity during distribution may indicate leakage or breakage of piped system and therefore an increased likelihood of microbiological contamination (Howard, 2002).

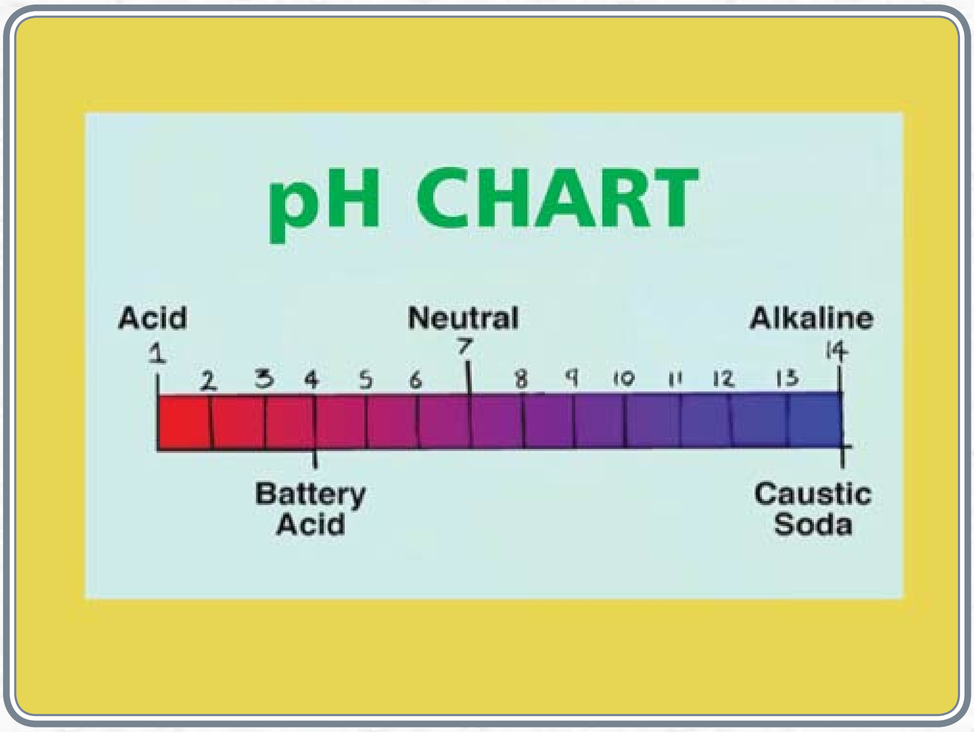
Residual Chlorine or Free Available Chlorine

Chlorine is a relatively cheap and readily available chemical that, when dissolved in clear water in sufficient quantities, will destroy most disease causing organisms without being a danger to people. However, chlorine is used up as organisms are destroyed. If enough chlorine is added, there will be some left in the water after the organisms have been destroyed, this is called free chlorine. Free chlorine will remain in the water until it is either lost to the outside world or used up destroying new contamination. Therefore, if we test water and find that there is still some free chlorine left, it proves that most dangerous organisms in the water have been removed and it is safe to drink. We call this measuring the residual chlorine or free available chlorine (FAC).

Residual chlorine or FAC of above about 0.6 mg/L or more may cause problems of acceptability for some consumers on the basis of taste, depending on local circumstances. Monitoring residual chlorine where the treated water leaves the treatment point indicates that the disinfection process is working properly. Measuring it at different points in the distribution system is sometimes used to check that there is not an excessive chlorine demand in distribution that may indicate other problems in the system, such as ingress of contamination (WHO/SEARO, no date).

pH

pH is a measure of the hydrogen ion (H+) concentration in water and is an important parameter for describing the likely state of other chemical processes occurring. The pH of piped or reticulated drinking water supplies should be regularly monitored as low levels (< 5-6) may cause corrosion of metal pipes and fittings, releasing metals into the water. Water with a pH > 8.5 could indicate that the water is hard. pH is important as an operational parameter, particularly in terms of the efficacy of chlorination or optimising coagulation. Where the pH is > 8.5, the chlorination efficiency becomes impaired. The optimum pH for chlorination is between 6.5 and 8.5. Wherever possible, the pH of water should be tested when residual chlorine is measured (Mosley *et al.*, 2004).



Electrical Conductivity

Electrical Conductivity (EC) is a measure of how much total salt (inorganic ions such as sodium, chloride, magnesium and calcium) is present in the water. The more ions, the higher the conductivity. Monitoring of this parameter is important in drinking water, especially for water supplies that are taken from boreholes or wells on atoll islands containing a freshwater lens on top of underlying saltwater. If the water supply demand exceeds the capacity of the lens to replenish itself through rainfall, infiltration and recharge, the freshwater lens becomes thinner and increasing concentrations of salt may be observed. At high salt levels, consumers will detect an unpleasant taste, washing clothes will be difficult, the water may not quench thirst, and diarrhoea may occur (Mosley *et al.*, 2004).

Increasing conductivity over time in water indicates that one or more inorganic constituents are also increasing; this situation should trigger further investigations. For atoll islands using groundwater this could be for example, measuring the chloride content of water. Seawater intrusion in groundwater can be a cause of increased chlorides. Hence the pumping rates can be lowered or stopped altogether for the freshwater lens to replenish.

2.6.3 Other Chemical Parameters

There are many other chemical parameters that can be tested but as mentioned earlier measuring all is impractical, costly and sometimes beyond existing laboratory capacity.

Chemical contaminants of drinking water are often considered a lower priority than microbial contaminants, because adverse health effects from chemical contaminants are generally associated with long-term exposures, whereas the effects from microbial contaminants are usually immediate. Nonetheless, chemicals in water supplies can cause very serious problems.

Chemical contamination of drinking water is mostly situation-specific and/or country-specific and is restricted to certain areas or source water types. Hence careful and practical parameter selection has to be done in order to identify priority parameters for monitoring.

When a source is identified for drinking water, a full profile of chemical analyses should be undertaken combined with a pollution risk assessment in order to evaluate whether the source should be used and whether additional treatment may be required. However, this may not always be the case in most PICs.

Few chemical parameters may be included in the monitoring programme in PICs, where resources and capacity are limited, unless there is good reason to suspect that there is a problem with that parameter. Where chemical parameters are routinely tested, this is done at lower frequencies than the microbiological indicators and critical parameters identified earlier.

Certain chemicals can only enter a water supply through contamination of the water source while some can enter through chemicals used in water treatment or from plumbing materials of reticulated/piped water supplies. Hence when prioritising the chemicals for testing, it is important to consider whether the sampling site is the source water, the treatment point or the distribution network.

2.6.3.1 Source Waters

It would be useful if the chemical contaminants are grouped into four categories on the basis of their potential sources and then priority parameters selected for source waters. The four categories are: (1) naturally occurring; (2) from agricultural activities; (3) from human settlements; and (4) from industrial activities.

When selecting parameters based on the above four categories, a good knowledge of the surrounding environment of the source water is important.

Naturally Occurring

There can be a number of naturally occurring chemicals present in drinking water derived from the rocks and soil through which water percolates or over which it flows and/or from the breakdown of plant material or from algae and other microorganisms growing in the water or on sediments.

The key is to prioritise and select the parameters which are of the greatest health concern or which can result in consumer rejection of the water source (aesthetic).

Some important parameters to consider in PICs are:

- Hardness (mainly groundwater – aesthetic);
- Iron (mainly groundwater, only if resources and capacity available – aesthetic); and
- Manganese (mainly groundwater, only if resources and capacity available – aesthetic and health concern).

These parameters are basically tested for aesthetic properties of water as they can result in consumer rejection of an otherwise clean and reliable water source. The technology to treat for hardness or excessive levels of iron and manganese are not present in PICs hence frequent sampling is not needed. Periodic checks (annually) of the above parameters would suffice to collect information on the overall quality of the water source.

Hardness

A high hardness level is one of the most common problems with groundwater supplies for drinking water. Hardness is determined by the amount of naturally occurring calcium and magnesium compounds that are dissolved in water during its passage through rock and soil material. Hardwater does not pose a health risk, but can cause aesthetic problems. These problems include: formation of a "scale" or precipitate on piping and fixtures causing water pressures and interior diameter of piping to decrease; causes an alkaline taste to the water and can make coffee taste bitter; formation of a scale or deposit on dishes, utensils, and laundry basins; and decreases efficiency of electric water heaters (Mosley *et al.*, 2004).

Iron and Manganese

Iron (Fe) and Manganese (Mn) are naturally occurring metallic elements that closely resemble each other in the way they react in water. Small amounts of iron and manganese will seriously affect the usefulness of water. WHO recommended limits in drinking water are 0.3 mg/L iron and 0.1 mg/L manganese, which are based on aesthetic reasons. The health-based guideline value for Mn is 0.4 mg/L, whereas Fe is not a health concern.

The presence of iron and manganese is common in boreholes and water from wells. The metals are dissolved from soils and rocks as the water passes through the earth. When dissolved in water, iron and manganese are colourless. However, if allowed to stand, the iron will react with oxygen in the air forming reddish deposits on the bottom of the container. Manganese reacts similarly, forming black deposits. Iron and manganese will give water a bitter, metallic taste which makes such water highly undesirable. Water with high levels of iron and manganese should be treated in order to remove these metals (Mosley *et al.*, 2004).

Other chemicals, which occur naturally and are of health significance in drinking water include fluoride (F), arsenic (As), selenium (Se), aluminium (Al), antimony (Sb), boron (B), barium (Ba), chromium (Cr), uranium (U) and molybdenum (Mo). Generally, these are not of particular concern in PICs as no historic illness related to contamination from these exists. Hence routine monitoring is not needed and occasional periodic checks (every 3-5 years) would be sufficient.

Arsenic received a lot of attention in the international world hence testing for it might seem enticing for PICs. However, consideration should be given to the wise utilisation of resources. Arsenic is more likely to be found naturally in high volcanic islands instead of low-lying or raised coral atolls.

It is useful to refer to past reports of water quality testing done in the area or country of interest. These past reports could be the initial report on the full profile of chemical analysis before commissioning a drinking water source or it could be one-off baseline assessments of certain parameters present in a water body. For example, a baseline investigation of heavy metals present in drinking water sources. The reports would point out if the natural geography of the area or country needs a certain parameter to be tested for frequently. An example would be high levels of arsenic present naturally in water sources in Bangladesh. Hence monitoring programmes in Bangladesh would require the testing of arsenic as a priority need.

A study done by Singh and Mosley (2003) on the levels of heavy metals (including arsenic) in source waters in Viti Levu, Fiji concluded that there was no risk of metal contamination of drinking water source from the natural geology of Fiji. Fiji is a high volcanic island and the chances of natural levels of arsenic in groundwater and surface waters are high if the water is derived from volcanic sediments. However, the study concluded otherwise. Hence instead of analysing for arsenic routinely, only periodic checks (every 3-5 years) would be sufficient to oversee changes in the source water quality in relation to naturally occurring metals like arsenic.

Algal toxins like cyanobacteria (also known as blue-green algae) occur widely in lakes, reservoirs, ponds and slow-flowing rivers. Many species are known to produce toxins, a number of which are of concern to health. Health hazards from algal toxins are primarily associated with overgrowth (algal bloom) events. Algal blooms are frequently associated with the presence of nutrients, particularly phosphate. Levels of nutrients are often increased by agricultural activity (see also following section on agricultural activities), increasing the likelihood of cyanobacterial blooms. The analysis of algal toxins is slow, difficult and expensive and not recommended for PICs to undertake. The preferred approach is to protect and control source water from nutrient (particularly phosphate) runoff or seepage, which has bloom-forming potential, and to regularly visually inspect such sources.

Agricultural Activities Nearby

As mentioned earlier, a good knowledge of the surrounding environment of the source water is needed for parameter selection. The person(s) designing the monitoring programme should be aware of any agricultural activity being done in close proximity to the source water.

The most common chemical contaminants in drinking water sources arising from agricultural activities are nitrates and pesticides.

Chemical fertilisers and animal manure are mostly used in PICs for fertilising agricultural land. These contain nitrate, which during periods of heavy rainfall or during irrigation can leach from farms into drinking water sources (groundwater or surface water) and be of health concern, particularly for infants.

Therefore, monitoring of nitrate is recommended in many drinking water supplies and in particular those located near agricultural areas where the water supply is from a borehole or a well.

Nitrate

Nitrate pollution may occur from fertiliser runoff or seepage into groundwater and from discharge of human and animal waste (explained in the next section). At very high levels in drinking water, nitrate may impact human health, particularly of infants. Infants less than 6 months of age may develop a condition called methemoglobinemia (blue baby syndrome), which causes a bluish colour around the lips that spreads to the fingers, toes and face, and eventually covers the entire body. If the problem is not dealt with immediately, the baby can die. Consuming water from a source containing 10 mg/L, or less, nitrate-nitrogen provides assurance that methemoglobinemia should not result from drinking water (Mosley *et al.*, 2004).

High nitrate levels from agricultural sources may also indicate that there could be a problem with other agricultural pollutants such as pesticides. Nitrate contamination, which can be linked to a sewage discharge, may also indicate unacceptably high levels of microbiological contamination and should be addressed as a matter of priority.

Regular monitoring of nitrate is recommended in areas where chances of contamination are high (from agricultural activities or human settlements) to ensure early warning of increases.

Some chemical fertilisers also contain phosphate. Phosphate is not of health concern in drinking water and as such does not have a guideline value. However, if surface water (especially a slow-flowing river) is used for drinking then the runoff or seepage of phosphate-based fertiliser into the source water needs to be controlled by best practices. This is because excessive phosphate into the water source can lead to algal blooms increasing the chances of contamination from cyanobacterial toxins. Regular monitoring of phosphates is not recommended for PICs; however, periodic testing (annually) at source waters located near agricultural farms could be performed to detect possible leaching.

Pesticides (herbicides and insecticides) are often applied in agricultural areas to control pests or weeds, which destroy or damage crops. The degree to which pesticides can be leached into groundwater through normal agricultural use depends on a number of factors. These include the extent to which the chemicals are adsorbed onto organic matter in soils, the extent to which they are volatilised from the soil, the rate of degradation within the soil, their solubility in water and the amount of percolating water that is available to mobilise them. The degree to which pesticides can contaminate runoff to surface waters depends mainly on local rainfall and the extent to which the chemicals are adsorbed onto soil (Thompson *et al.*, 2007).

Analysis of pesticides is difficult and expensive and it requires specialist equipment (example gas chromatography) and extensive training. It is impractical for PICs to do routine monitoring. It is recommended that best practices be followed to prevent pesticide contamination of a water source. Not applying pesticides near open wells, and immediately before or during rainfalls; as well as strictly adhering to the recommended application rates are some measures that need to be practised. A drinking water safety plan for a water supply will assist in identifying and managing pesticide contamination.

If a pesticide contamination risk is identified (like accidental spillage of pesticides in a water source) and unless the capacity to analyse it in-country exists, it would be best if representative samples of water from the source are preserved properly and sent to an external overseas laboratory for analysis.

Since pesticide analysis does not need to be performed routinely but instead periodically (or if a risk is identified), it is not worthwhile investing resources (budget and staff) into establishing the capacity in country.

Human Settlements Nearby

Often in the Pacific it is seen that human settlements (villages or communities) are located within close proximity of water supply sources. For example, a village on a river bank where the river is the primary source of drinking water.

The major source of contamination of drinking water source from human settlements is from improper sanitation facilities, which in many PICs are septic tanks and pit latrines. Contamination may also result from animal (pigs, poultry and cattle) husbandry practices that are associated with human settlements in most rural/outer or even peri-urban centres around the Pacific. The waste from the improper sanitation facilities and from animals can travel several hundred metres through the porous coral limestone found on many PICs and contaminate the underground drinking water source (bore or well). During periods of heavy rainfall, the waste can flow into surface (rivers or streams) drinking water sources and contaminate them.

For surface waters used for drinking it is also important to consider potential pollution by human habitation upstream from other settlements, which means that the concept of catchment management under a drinking water safety plan should be borne in mind when considering this situation.

The chemical parameter of priority concern from the discharge of human and animal waste is nitrate. As mentioned earlier, at high levels in drinking water, nitrate may impact human health, particularly infants.

Therefore, monitoring nitrate is recommended in many drinking water supplies (except rainwater) and in particular those where the water supply is located in the surrounding area of human settlements.

Another source of contamination associated with human settlements is dump sites (household and general waste). The leachates from a dumpsite can sometimes be a source of metal (As, cadmium [Cd], Cr, lead [Pb], zinc [Zn], Al, Fe, Mn) contamination for surface and groundwater. As with pesticides, the analysis of metals is difficult and expensive especially at low levels. It is impractical for PICs to do routine monitoring. It is recommended that best practices be followed to prevent metal contamination of a water source by not dumping general household waste near surface waters or on top of groundwater sources. A drinking water safety plan for a water supply will assist in identifying and managing metal contamination from dumping sites.

If metal contamination risk is identified and unless the capacity to analyse it in country exists, it would be best if representative samples of water from the source are preserved properly and sent to an external overseas laboratory for analysis.

Since metal analysis does not need to be done routinely but instead periodically (or if a risk is identified), it is not worthwhile investing resources (budget and staff) into establishing the capacity in country. There may, however, be existing capacity in government agriculture or mineral sections in the country, which could be used.

Industrial Activities Nearby

The waste products (effluents) of industrial activities, such as mining, discharged to air and water can contain significant levels of metals, which may contaminate drinking water sources directly or indirectly.

The sampling site needs to be assessed properly to identify any major industries present around the drinking water source. The principal industries to be aware of are the extractive industry (mining) and manufacturing and processing industries (chemical, metal, textile dying, tannery, paper and pulp, electroplating and battery-manufacturing). In addition, information should be gathered through research and consultations on the potential contaminants being discharged by a particular industry.

For example, for a gold mining company, the potential contaminants in the effluent would be arsenic and mercury. Hence emphasis would be placed on testing for arsenic and mercury instead of testing for the whole range of metal parameters. Cyanide contamination from spills is also possible and would usually be indicated by fish kills.

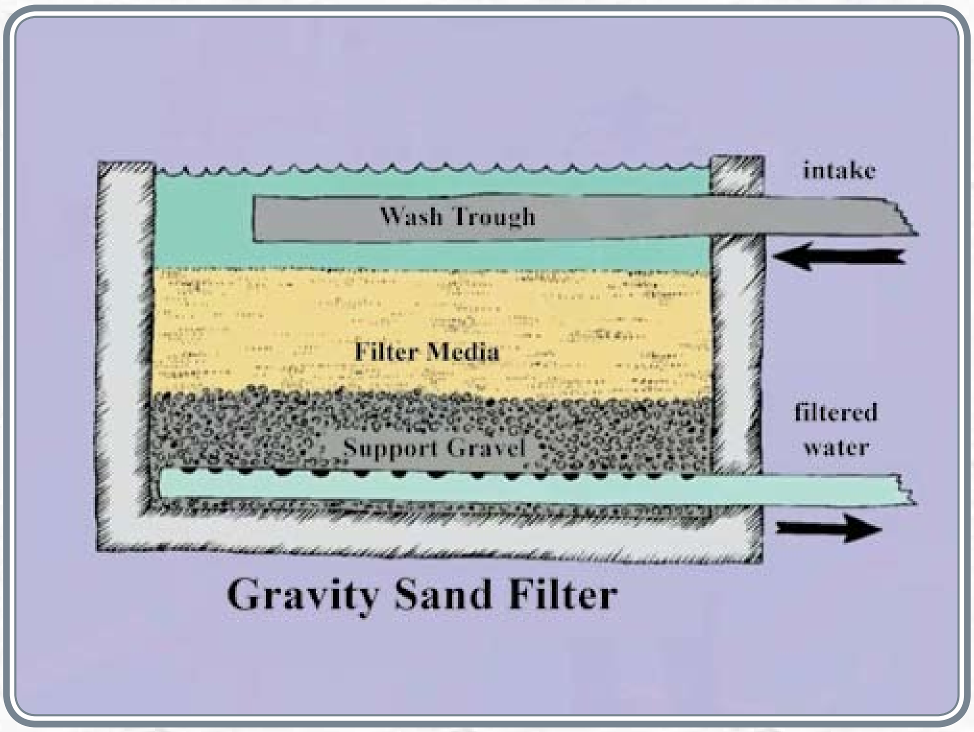
The most common chemical contaminants in drinking water sources arising from industrial activities are metals.

The analysis of metals, as previously stated, is difficult and expensive. It is impractical for PICs to do routine monitoring. Unless a specific risk is identified through investigation or historic data, it is recommended that metals be tested periodically (2-3 years) to monitor for contamination from industrial activities.

Nitrate, hardness, iron, manganese and other chemical contaminants discussed above will be expected to largely derive from source waters and it is not expected that contamination during distribution will be a major problem. Thus these parameters are best tested for and controlled during water production. The protection of source waters from contamination as mentioned in a drinking water safety plan should also be undertaken.

2.6.3.2 Water Treatment

In PICs various methods are used for treating water ranging from large treatment plants (coagulation, flocculation, slow sand filters and addition of chlorine) to only the addition of chlorine to reticulated groundwater. There are also examples of semi-treatment (just settling or on-site filtration of source water with non disinfection) and no treatment at all.



The monitoring parameters are dependent on the type of treatment used and the water supplier is responsible for monitoring these at the treatment works outlet.

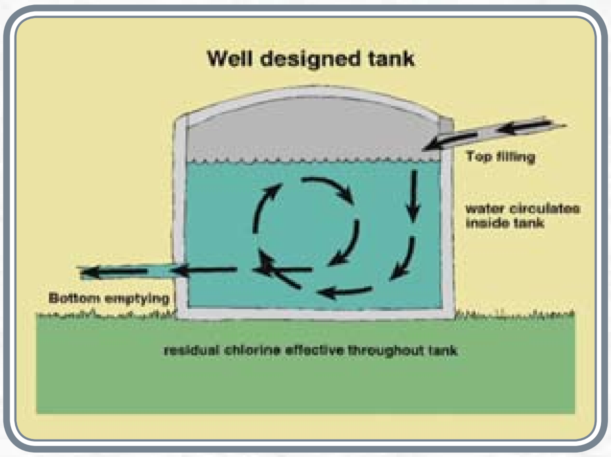
Large treatment plants mostly use coagulation and flocculation to treat surface waters. Coagulation and flocculation are important barriers to microbiological contaminants and are key processes for reducing naturally occurring organic matter and turbidity, which can seriously affect the efficiency of disinfection. Chemicals used as coagulants in drinking water treatment include aluminium and iron salts, such as aluminium sulfate, polyaluminium chloride or ferric sulfate. In such cases, the water supplier needs to monitor the levels of aluminium and iron in the finished treated water. Although no health-based guideline value is set for aluminium and iron, both substances can give rise to discoloration and deposition of sediments in distribution. The best management strategy for both aluminium and iron when used in treatment is to ensure that coagulation is optimised to prevent excessive amounts remaining in the drinking water.

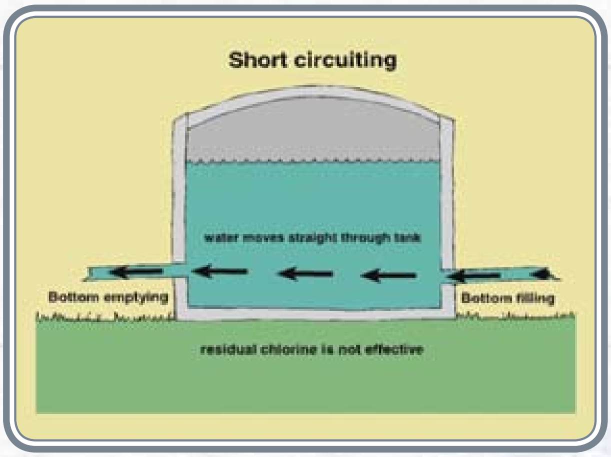
Similarly, if other chemicals are added to treat water then the levels of these should be monitored in the finished product to ensure that it does not give rise to any health problems or cause consumer rejection of the treated water.

Chlorine is the most widely used primary disinfectant and is also often used to provide residual disinfection in the distribution system. Monitoring the level of residual chlorine in treated drinking water has been given top priority and appears earlier in the critical parameters section of this guide.

Chlorine reacts with naturally occurring organic matter in raw water to form a range of unwanted by-products. Guideline values have been established for a number of these by-products. The compounds most widely considered as representatives of chlorination by-products for the purposes of setting standards and monitoring are the trihalomethanes (THMs), which include chloroform, bromodichloromethane, chlorodibromomethane and bromoform (Thompson *et al.*, 2007). THMs are primarily of concern in surface waters as groundwater rarely has high levels of organic matter. THMs are difficult and expensive to analyse and routine monitoring of these may not be possible for PICs. Instead where chlorinated surface waters are used for drinking, optimising filtration (and if applicable coagulation) is most important in helping to remove the precursors of these by-products and will, in turn, reduce the formation of THMs and other unwanted by-products.

It is important to note that in order to ensure the microbial safety of drinking water, disinfection (for example chlorination) should never be compromised in trying to meet guidelines for any disinfection by-products.





2.6.3.3 Distribution

Drinking water can also get contaminated in the piped or reticulated system by substances that leach from materials used in distribution or plumbing, or that arise from the corrosion of pipes. Leaching and corrosion mainly results when the raw or source water is of a low pH (acidic).

The most widely used metal for pipes and fittings in distribution systems is iron, which may give rise to corrosion products. These products can cause discolouration at the tap if the distribution system is not managed correctly. In some circumstances, iron hand pumps can give rise to discoloured water if they are corroded by water that is too acidic. Lead, copper and sometimes zinc may be present in drinking water, as a consequence of the use of these metals in pipework in public, commercial and domestic buildings.

Monitoring of metals in water arising from plumbing is difficult because of variations in concentration with time and the fact that the levels are frequently property (building) specific. Copper, zinc or iron do not pose a health risk but can cause consumer rejection of the piped water supply. Lead does pose a health risk hence buildings, which have lead piping, should be identified and periodically their water tested.

The pH of the raw water can be neutralised by treatment to minimise the leaching of metals from pipeworks to overcome this problem. This is normally not an option for most PICs where water supplies are reticulated straight from the source with minimum treatment or no treatment at all. In such cases, it would be appropriate to screen the pH of raw water, and where a low pH is detected, consider using alternative materials for the pumps. For existing infrastructure, periodic monitoring of the metals from which the pipeworks are made can be done if the pH of the source water is low (<5-6).

Concentrations will usually be greater the longer the water is standing in the pipe, so first-draw water will usually have higher levels than water from a fully-flushed system. Therefore, if a problem is identified the consumers can also be notified to flush their systems well before using water from the tap.

Testing for metals is difficult and expensive, especially for PICs, hence routine monitoring of these in distribution systems is not recommended. A more preferred approach is to monitor the pH of raw water (already in critical parameters), which if low would indicate the likelihood of metals leaching from the pipeworks. In such cases, periodic (1-2 years) monitoring of the metal of concern can be done through sending representative samples overseas for testing.

2.7 Sampling Frequency and Numbers

Sampling and analysis are required more frequently for microbial and critical parameters and less often for chemical contaminants.

In most PICs there are limited funds available and this inevitably affects the sampling frequency (how often a sampling point can be visited) and numbers (how many samples can be analysed). The monitoring role (water supplier or surveillance agency), as mentioned previously, also determines the frequency of sampling. The water supplier does more frequent routine monitoring of parameters than surveillance agencies.

It is best left with the person(s) designing the monitoring programme to decide on the frequency and numbers of sampling, taking into consideration the resources available. It should be noted, however, that the frequency and numbers should provide data that is meaningful and able to fulfil the purpose of monitoring.

For example:

Description	:	A water supplier is providing reticulated drinking water that is being chlorinated
Monitoring purpose	:	To ensure that the disinfection process is working properly thereby providing safe water
Sampling site	:	Treatment point
Parameter selection	:	Residual chlorine (critical parameter)
Frequency	:	Once a month

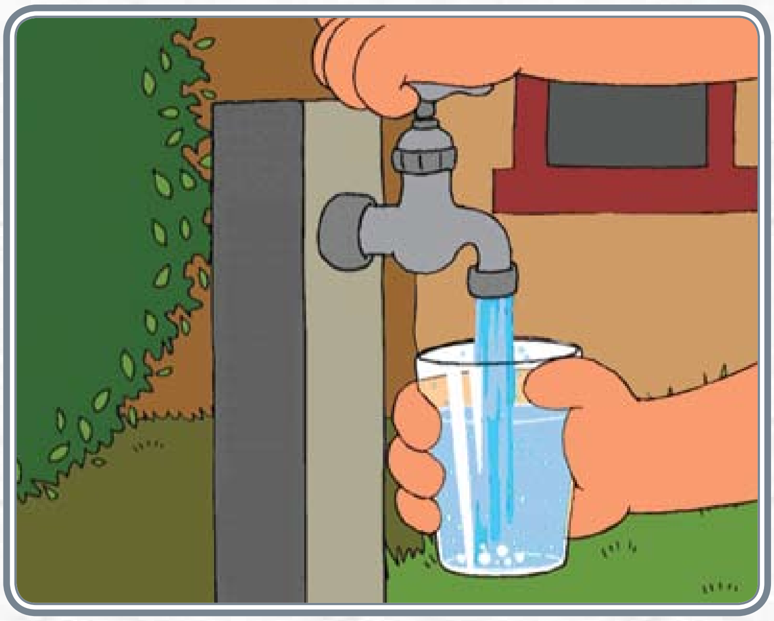
Comment:

A sampling frequency of only once a month from the treatment point does not truly reflect the purpose of monitoring. If the chlorine dosing pump malfunctions then the monitoring will pick that up only after a month, which would be too late (many people can get sick by then). For this example daily monitoring, if possible, is recommended.

Sampling frequency is also usually based on the population served. The sampling frequency should be greater where the number of people supplied is large, because of the higher number of people at risk.

2.7.1 Piped Distribution Systems

Piped distribution systems should be sampled more frequently than point sources as high chances of contamination are possible from treatment failure or from the distribution network itself. An example of a treatment failure includes the chlorine-dosing pump not working. The contamination in the distribution can result from the growth of biofilms.



A water supplier should have a programme of daily, weekly or monthly sampling frequency depending on the population served and the resources available. A surveillance agency can have monthly sampling (once per month or once every 3 months) depending on resources and their confidence in the water supplier. If a water supplier is implementing its drinking water safety plan effectively then monitoring for verification by the surveillance agency can be less frequent.

In addition, for chlorinated drinking water supplies, measuring the residual chlorine level can be done more frequently to assess the safety of water for microbial quality. This is because if sufficient residual chlorine is present in the water supply then no coliform bacteria should be present. Hence, for example, for every ten (10) samples tested in the piped distribution network for residual chlorine, one (1) *E.coli* test can be performed. Since residual chlorine testing is very cheap and testing is field based, it would be cost saving for the monitoring agency.

The table below shows examples of population-based sampling numbers and frequencies for microbiological parameters in distribution systems drawn from WHO *Guidelines for Drinking-water Quality* (2004).

Population	Sample per month
<5,000	1
5,000 to 100,000	1 sample per 5,000 population
>100,000	1 sample per 10,000 population plus 10 samples

Hence, if the population served is 30,000 then 6 samples are to be taken per month, however; this depends on the resources available as well.

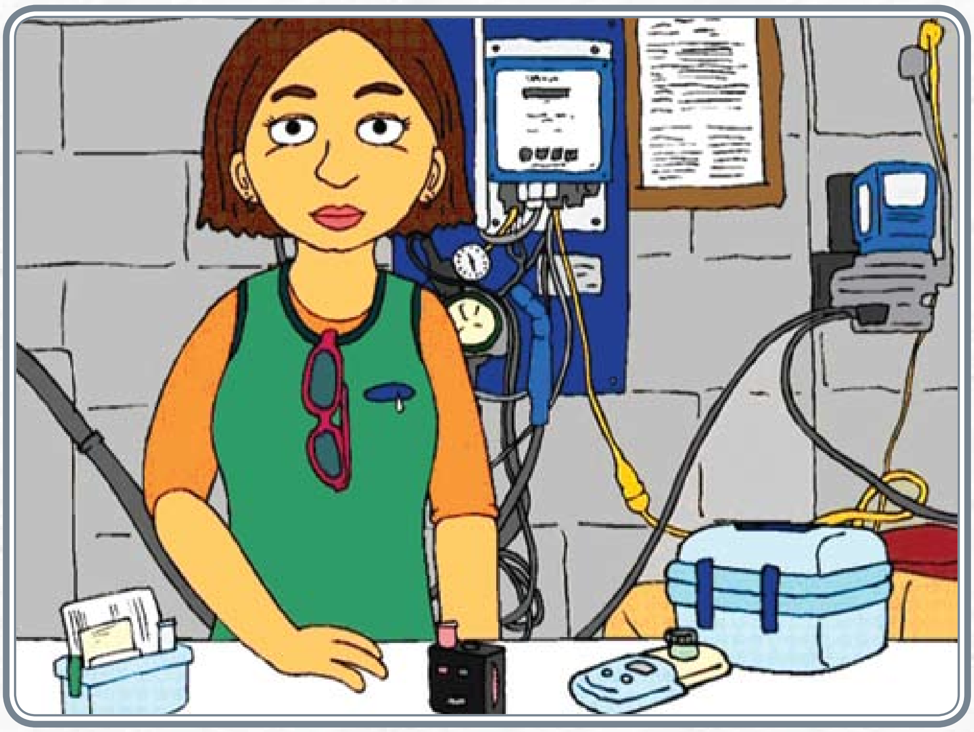
It is advisable that the samples from a distribution system are collected randomly over the network instead of having fixed sampling points. This would ensure coverage of the entire network over time.

2.7.2 Water Sources

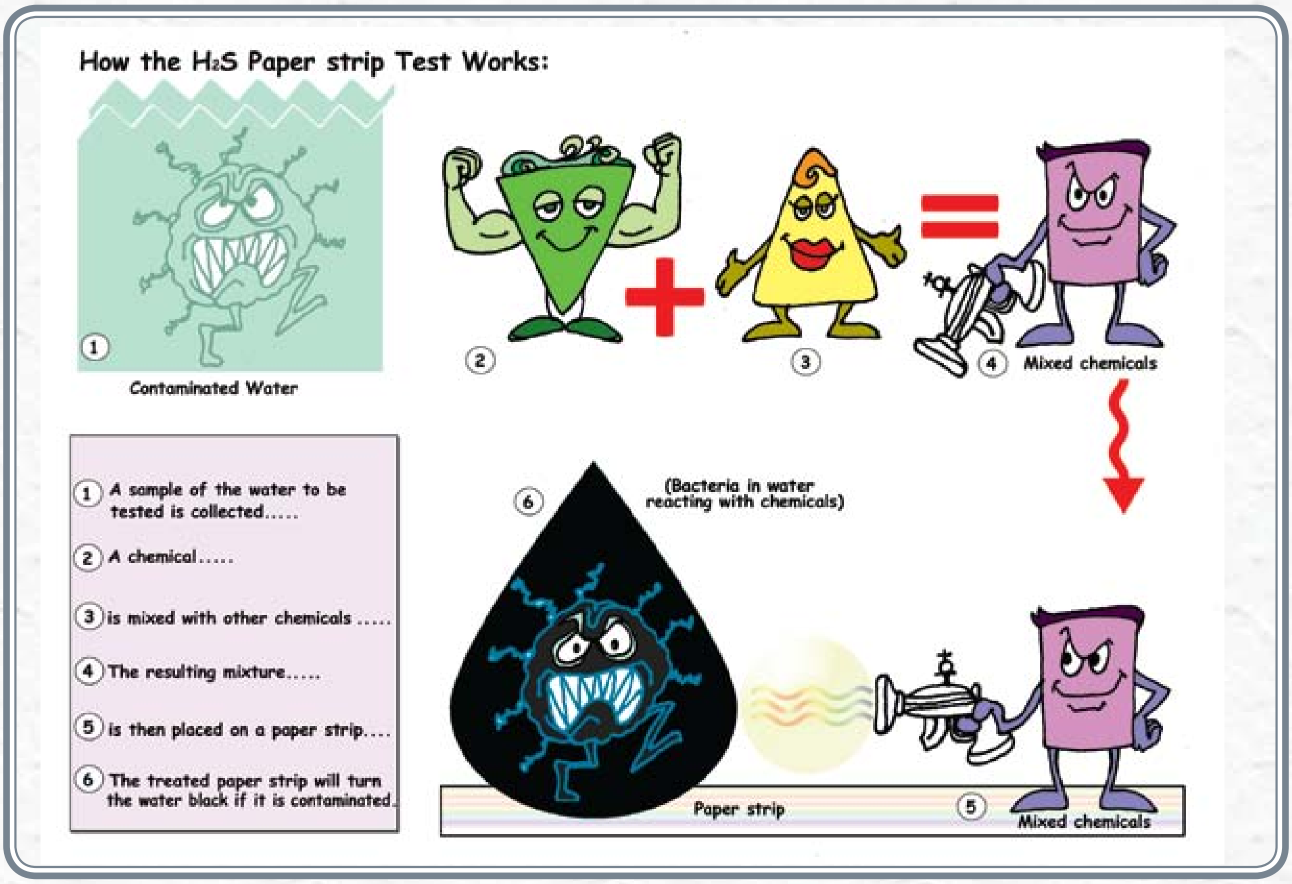
Testing source water is particularly important where there is no water treatment. The frequency may be:

- on a regular basis (population served, degree of treatment, presence of local risk factors);
- on an occasional basis (random or during visits to community-managed drinking water supplies; and
- increased following natural disasters like flooding.

Periodic testing of community drinking water supplies should typically be undertaken by the surveillance agency and should monitor microbial parameters and known chemical contaminants. Frequent sampling is unlikely to be possible, and one approach therefore is that each supply is visited once every 3-5 years, at a minimum (WHO, 2004).



Knowing the limitations of PICs to test for microbiological indicator organisms in all water supplies especially community-managed or rural and outer island water supplies, it is recommended that other cheaper means of microbial testing be explored and taken up. One such cheap test is the hydrogen sulfide (H_2S) paper-strip test. There are many advantages of using this test in rural and remote Pacific island communities particularly where laboratory-based testing is not possible. The H_2S test has relatively good correlation with faecal and coliform analyses making it ideal for widespread use in the remote outer islands of the Pacific. Communities can be empowered to conduct the H_2S test themselves with assistance from outer island health officers. For more information on the usage and production of the H_2S paper-strip test refer to Mosley and Sharp (2004).



[Animation created by late Mr John Robinson, Cartoonist]

2.8 Reporting, Communicating and Follow up

An essential element of a successful monitoring programme is the reporting of results, communicating them to the relevant stakeholders and follow-up action. Often in PICs, the water quality results are compared to national or international guidelines to verify compliance. The communication strategy and subsequent follow-up action is an aspect, which could be strengthened in most PICs. This could be achieved through a multi-sectoral approach where all relevant stakeholders cooperate and support each others collaborative efforts in improving the drinking water supply (see also Section 2.1 on Collaborative Approach).

Appropriate reporting and feedback is necessary and will support the development of required effective follow-up actions. The ability of a monitoring programme to advocate follow-up actions (remedial actions) is highly dependent on the ability to interpret and present results in a meaningful manner to different target audiences. If results were presented to decision or policy makers, who often lack technical interpretive skills, then graphical representation of data would carry more weight with them.

In many PICs, drinking water is untreated hence do not meet the stringent thermotolerant coliform and *E.coli* values of zero set in WHO or US EPA guidelines. Uncritical enforcement of a water quality guideline may lead to unnecessary condemnation or closure of water sources that may be more appropriate and more accessible than other sources. It may even force people to obtain water from other more polluted sources. Under conditions of widespread faecal contamination, water suppliers and surveillance agencies are recommended to issue boil water/chlorination advisories (Mosley *et al.*, 2004). The risk management approach of a drinking water safety plan should be adopted to gradually reduce or remove contamination and lead to provision of high quality water to all, instead of improper condemnation of relatively acceptable supplies.

The monitoring role (water supplier or surveillance agency) and the purpose of monitoring play an important part in the reporting, communication and follow-up process as well.

For example:

Monitoring role	:	Water supplier
Purpose	:	To verify that the drinking water safety plan is being implemented successfully
Reporting	:	At treatment works, *E.coli* before chlorination – 6 cfu/100mL, after chlorination – 5 cfu/100mL
Communicating	:	Results to be shared among the drinking water safety plan committee for remedial action
Follow up	:	Results indicate inefficient chlorination. Water supply operational staff to check chlorine dosing pump and dosage rate. Also check turbidity and pH to optimise chlorination, and residual chlorine

Monitoring role	:	Surveillance agency
Purpose	:	To ensure that the treated water supplied is safe for human consumption
Reporting	:	Residual chlorine in distribution network is 0 mg/L
Communicating	:	Water suppliers, communities and water users, public health officials, local administrations
Follow up	:	Inform public to take precautionary measures like boiling, inform water supplier to investigate problem at the treatment plant, inform public health and local administrations to help disseminate boil water advisories

For surveillance agencies, it is important that they share the results with the communities for community-managed or household drinking water supplies. However, in many communities, sharing only the results will not ensure that individuals are aware of the quality or safety of the water supplied to them. The surveillance agency should develop strategies for disseminating and explaining the significance of the results obtained. It may not be practical for the surveillance agency in PICs to provide feedback information directly to the entire community. Thus, it may be useful to use community organisations, where these exist, to provide an effective channel for providing feedback information to users. These organisations could be local councils, women's groups, religious groups and schools (WHO, 2004).

Perhaps the most critical aspect of the process is the time frame within which the report is communicated to the stakeholders and the follow-up action pursued. If a microbial contamination is detected in a drinking water supply then the longer the delay the greater the risk of more people getting sick. Hence, the protocol for reporting, communicating and follow-up action should be well developed and followed.

2.9 Review

The monitoring programme needs to be reviewed continually in light of new risks identified that may have the potential to contaminate drinking water supplies. For example, these could be the establishment of new industries, agricultural activities or human settlements around the drinking water source that were not present when the monitoring programme was initially designed. Depending on the risk identified the relevant parameter to monitor would be identified and tested.

The availability of resources at hand should also be considered during the review. Perhaps the funding allocation for water quality monitoring has been increased or decreased which would need the frequency and number of samples collected to change likewise.

3.0 SCHEMATIC

The schematic below summarises the steps undertaken during the design of a drinking water quality monitoring programme.

Collaborative approach
- form team or committee of relevant agencies and professionals

→

Description of water supply
- source
- treatment, storage
- piped or point source
- population served

→

Monitoring role
- water supplier (more frequent)
- surveillance agency (checks)

↓

Purpose of monitoring
- can be more than one
- subsequent steps depend on purpose

←

Selecting sampling site & point
- in line with monitoring purpose
- knowledge of surrounding area necessary
- accessibility of point (physically and financially)

↓

Parameter selection
- need to prioritise
- look at existing resources (lab capacity, staff, budget)

Parameter selection matrix:

Microbial parameters	- thermotolerant (faecal) coliform or *E.coli* (preferred) - all drinking water.
Critical parameters	- turbidity (all) - pH (chlorine-treated water, piped water at source) - residual chlorine - chlorine treated water - EC - groundwater, at source
Other chemical parameters	
Source waters	- Naturally occurring - hardness, Fe, Mn, others (as applicable) - Agriculture nearby - nitrate, phosphate, pesticide (as applicable) - Human settlement nearby - nitrate, metals (as applicable) - Industrial activity nearby - metals (as applicable)
Treatment	- any chemicals added during treatment - residual chlorine (chlorine-treated water, critical parameter)
Distribution	- pH screen for raw source water (critical parameter) - metals from plumbing materials (as applicable, occasionally)

↓

Sampling frequency & numbers
- dependent on existing resources (budget, staff)
- monitoring role
- more frequent for microbial and critical parameters, periodic for other contaminants
- purpose of monitoring
- treated/piped water or point source
- population served

→

Reporting, communicating and follow up
- interpret and present results in a meaningful manner
- communicate to all relevant stakeholders
- suitable and sensible follow-up action
- time frame important

↓

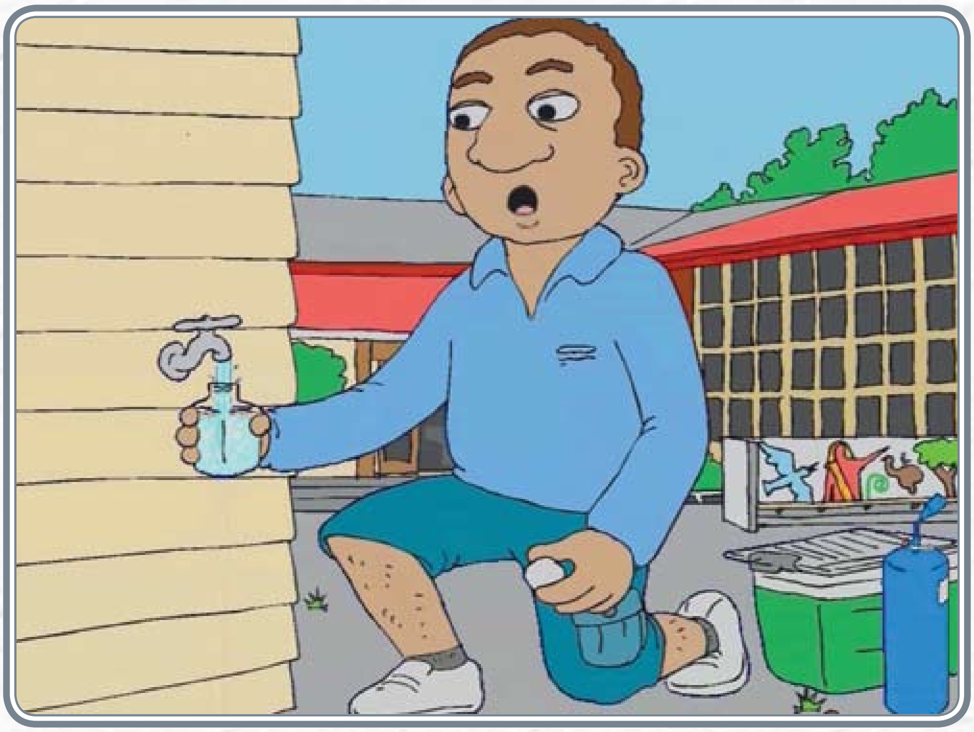
Review
- new risk identified hence new parameters selected
- resources at hand

4.0 RESOURCES FOR A MONITORING PROGRAMME

Implementing a monitoring programme requires access to resources, including an equipped laboratory, office space, equipment for fieldwork, transport and trained personnel. As mentioned previously the drinking water quality monitoring programme should be based upon the existing and available resources.

Two very essential and critical points to remember when starting a monitoring programme are proper sample collection techniques and quality control and assurance during the testing. If proper methods of sample collection and testing are not followed then incorrect data will be generated. Information based on wrong data can do more harm than good hence a lot of emphasis should be placed on ensuring that these are performed properly. Most of the water testing laboratories in PICs are not accredited or certified. However, if best laboratory management practices are followed then it will ensure that the data produced by the laboratory is credible and of high quality. For information on how to improve or strengthen the laboratory management practices refer to Gonelevu *et al.*, (in press).

It is better to have a complete record of reliable data concerning water quality at a few sampling points than to have a lot of data of questionable quality from many sampling points.



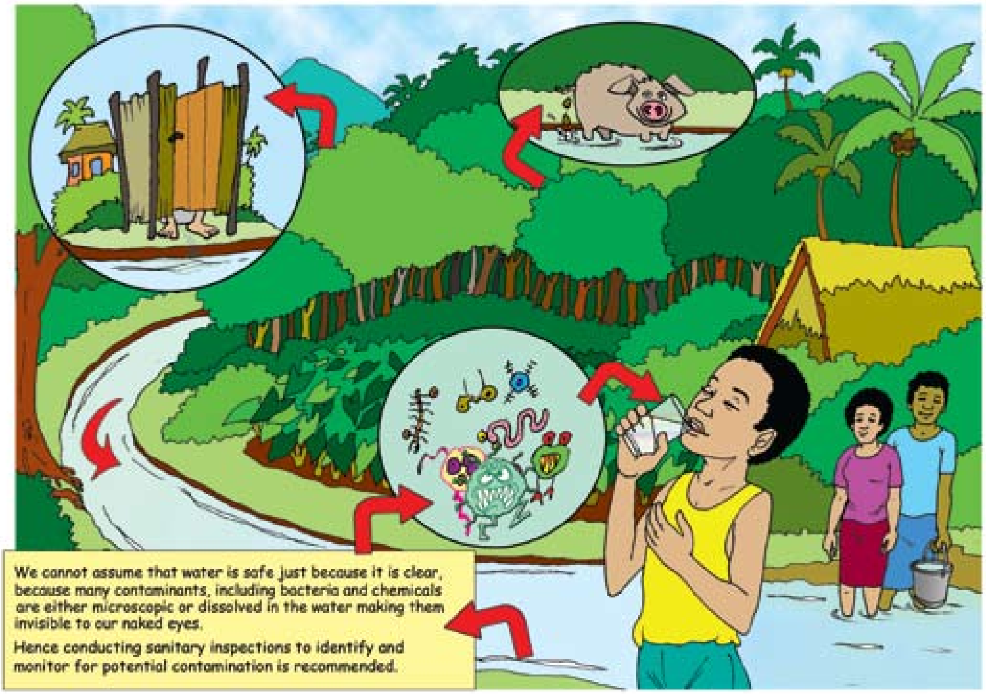
5.0 SANITARY INSPECTION

In the absence of a drinking water safety plan for a water supply, a sanitary inspection could be performed. Sanitary inspections are highly useful for community-managed or household (rainwater systems) drinking water supplies.

Sanitary inspections are designed to provide an overview of the status of risk (microbiological in particular) of the supply to contamination. Sanitary inspections can be done to monitor the potential for contamination in the future, thus providing an early warning function and a chance to fix or rectify the problem before contamination occurs (more like a drinking water safety plan but simpler). Thus it is very useful for use in rural or outer islands in PICs where regular water quality testing cannot be performed. In such places communities could be empowered to use this simple sanitary inspection tool to ensure that their drinking water is kept safe from contamination. The H_2S test kit mentioned earlier could then be used as verification that contamination is reduced or removed using sanitary inspection.

The questions in a sanitary inspection are usually structured so that the answer is either "yes" or "no". A score of one point is allocated for every "yes" answer and zero points for every "no" answer. On completion, a score of all the "yes" answers is totalled and noted. The higher the score, the greater the risk of contamination to the water supply (Howard, 2002).

Sanitary inspections can be conducted on various water supplies including rainwater harvesting systems, piped water, borehole with pump, protected spring and dug wells. An example of a sanitary inspection form is provided in Annex 2. For further details on sanitary inspection, please refer to Howard (2002).



[Animation created by late Mr John Robinson, Cartoonist]

6.0 WORKED EXAMPLES

The following worked examples demonstrate how this guide could be used to design a drinking-water quality monitoring programme in PICs. It should be noted that each monitoring programme is specific to a country, situation and the available resources.

EXAMPLE 1

Description of supply : Secure borehole water reticulated, no treatment, storage reservoir, population served is 1000 people

Role : Surveillance plus on behalf of supplier (Note – water supplier does not have the capacity to perform laboratory based testing)

Purpose : To ensure that water supplied is safe and acceptable for human consumption

Sampling site : Borehole, distribution network

Sampling point : Borehole pump, tap at a resident's house

Parameter selection :

BOREHOLE PUMP

Microbial : *E.coli*

Critical parameters : Turbidity, pH, EC

Other parameters :

Source water (applicable)

- Naturally occurring : Geology of borehole area – atoll island, porous limestone
  Monitor for hardness, iron and manganese (periodically)
  No history of other metal contaminants
- Agricultural activities nearby : No farms located nearby
- Human settlements nearby : Village close to borehole
  Septic tanks used. Monitor for nitrate because of porous nature of atoll
- Industrial activities nearby : None present

Water treatment : not applicable (n/a)

Distribution : n/a

RESIDENT'S TAP

Microbial : *E.coli*

Critical parameter : Turbidity

Other parameters :

Source water : n/a

Treatment : n/a

Distribution : pH of raw water measured (critical parameter) as a screen to indicate metals leaching from plumbing materials

Frequency and numbers: Depends on monitoring role, transport costs, laboratory capacity, staff and budget. (Assumption for this example is that the resources are quite limited)

Sampling point	Parameter	Frequency/numbers
Borehole pump	*E.coli*	Once per month/1 sample
	pH	"
	Turbidity	"
	EC	Once every week/1 sample (on-site)
	Nitrate	Once per month/1 sample
	Hardness	Annually/1 sample
	Iron	1-2 years/1 sample sent overseas
	Manganese	"
Resident's tap	*E.coli*	Once per month/1 sample
	Turbidity	"

Note: Population size is also considered < 5,000 population hence 1 sample/month

Reporting, communicating and follow up:

Reporting : Secure bore so *E.coli* should be zero. If not zero then result compared to last analysis report. If results are significantly higher than the previous report then highlight that action is needed.

Communicating : Share results with water supplier, consumer representative and hoteliers (tourism industry).

Follow up : Depends on results. For example, if *E.coli* value obtained is significantly higher than previous result, then detailed investigation to determine source of *E.coli* contamination should be carried out by the water supplier with assistance from the surveillance agency, if needed. If the EC reading shows increasing values (in the brackish water range) then the water supplier should be notified to either decrease the pumping rate or close the pump for the freshwater lens to replenish.

EXAMPLE 2

Description of supply : Borehole gallery, reticulated, chlorinated, storage reservoir, population served is 20,000 people

Role : Surveillance agency

Purpose : To ensure that water supplied is safe and acceptable for human consumption

Sampling site : After treatment works, distribution network, borehole gallery (occasionally, if resources permit)

Sampling point : Tap immediately after treatment work, tap at multiple houses in the network, borehole pump

Parameter selection :

TAP JUST AFTER TREATMENT WORKS

Microbial : *E.coli*

Critical parameters : Turbidity, pH, residual chlorine

Other parameters :
Source water : not applicable (n/a)
Water treatment : (applicable)
Residual chlorine (already mentioned as a critical parameter)
No other chemicals added
Distribution : n/a

NETWORK TAPS

Microbial : *E.coli*

Critical parameter : Turbidity, residual chlorine

Other parameters :
Source water : n/a
Treatment : Residual chlorine (critical parameter)
Distribution : pH of raw water measured (critical parameter) as a screen to indicate metals leaching from plumbing materials

BOREHOLE PUMP

Microbial : *E.coli*

Critical parameters : Turbidity, pH, EC

Other parameters :
Source water (applicable)
Naturally occurring : No history of any metal contaminants
No need to test for parameters of aesthetic concern by surveillance agency
Agricultural activities nearby : No farms located nearby.
Human settlements nearby : Village close to borehole
Septic tanks used
Monitor for nitrate because of porous nature of atoll
Industrial activities nearby : None present
Water treatment : not applicable (n/a)
Distribution : n/a

Frequency and numbers: Depends on monitoring role, transport costs, laboratory capacity, staff and budget. (Assumption for this example is that the resources are quite limited)

Sampling point	Parameter	Frequency/numbers
Tap just after treatment works	*E.coli*	Once per month/1 sample
	Residual chlorine	"
	pH	"
	Turbidity	"
Residents' taps	Residual chlorine	Once per month/4 samples
	E.coli	Once per month/1 sample
	Turbidity	Once per month/4 samples
Borehole pump	*E.coli*	Once every 3 months/1 sample
	pH	"
	Turbidity	"
	EC	Once every 3 months/1 sample (on-site)
	Nitrate	Once every 6 months/1 sample

Note: Population size is also considered for monitoring of the distribution network. Population of 20,000 hence 4 samples/ month. For cost saving, one *E.coli* is tested for every 4 residual chlorine tests done.

Reporting, Communicating and Follow Up:

Reporting : Drinking water is treated through chlorination. Hence there should be a residual chlorine value after treatment works and at points along the network. If results indicate no chlorine residual then it indicates that action is needed.

Communicating : Share results with water supplier and consumer representative.

Follow up : Depends on results. For example, if no residual chlorine value is obtained then it means that the water supplier should be notified to check the treatment and rectify the problem urgently. If *E.coli* testing shows positive value (in the absence of residual chlorine) then the water supplier should be informed as well as the consumers with possibly boil water advisories.

7.0 RECOMMENDATIONS

1. It is highly recommended that drinking water supplies have a drinking water safety plan in place, which requires a monitoring programme only as verification for the plan.

2. A multidisciplinary approach should be adopted when designing a monitoring programme to ensure that agencies with responsibility for specific areas associated with water quality are involved.

3. A drinking water quality monitoring programme should be based upon the existing and available resources that include an equipped laboratory, office space, equipment for field work, transport and trained personnel.

4. Where possible, the roles and responsibilities of the water supplier and the surveillance agency should be kept separate.

5. When designing a water quality monitoring programme it is vital to state the purpose of monitoring upfront.

6. It is very important to prioritise which parameters are most relevant to analyse that can be measured within the available resources.

7. Microbial organisms should be the top priority parameter to consider when designing a drinking water monitoring programme.

8. Regular monitoring of nitrate is recommended in areas where chances of contamination are high from anthropogenic sources to ensure early warning of increase.

9. Periodic analysis of metals and pesticides is recommended for monitoring of contamination from anthropogenic sources unless a specific risk is identified through investigation or historic data.

10. Cheaper means of microbial testing such as the hydrogen sulfide paper-strip test could be used for community-based water quality monitoring in rural and remote Pacific islands where laboratory based testing is not possible.

11. The proper reporting of results, communication to the relevant stakeholders and follow-up action should be in place and functioning for a successful monitoring programme.

12. Proper sample collection techniques and quality control and assurance during the testing are essential to ensure good quality of data produced from the monitoring programme.

8.0 REFERENCES

Bartram, J. and Balance, R., (Eds) 1996. ***Water quality monitoring: a practical guide to the design and implementation of freshwater quality studies and monitoring programmes***. Published by E & FN Spon, London, on behalf of UNESCO, WHO and UNEP.

Gonelevu, M., Aalbersberg, W. and Hasan, T., (In Press). ***Best Practices Guide for Water Laboratories***. SOPAC Technical Report 405. SOPAC Secretariat, Suva.

Howard, A.G., 2002. ***Water supply surveillance: a reference manual***. WEDC, Loughborough University, UK.

Mosley, L.M. and Sharp, D., 2004. ***The hydrogen sulphide test: a simple test for monitoring drinking water quality in the Pacific Islands***. SOPAC Technical Report 373. SOPAC Secretariat, Suva.

Mosley, L., Singh, S. and Aalbersberg, W., 2004. ***Water Quality Monitoring in Pacific island countries***. SOPAC Technical Report 381. SOPAC Secretariat, Suva.

(New Zealand) Ministry of Health 2005. Drinking Water Standards for New Zealand. Wellington: Ministry of Health. The document is available from the following website: http://www.moh.govt.nz

Singh, S. and Mosley, L.M., 2003. ***Trace metals in drinking water from Viti Levu, Fiji Islands***. South Pacific Journal of Science, 21: 31-34.

WHO/SOPAC (In press). ***Drinking Water Safety Planning: A Practical Guide for Pacific island Countries***. SOPAC Joint Contribution Report 193. SOPAC Secretariat, Suva.

Thompson, T., Fawell, J., Kunikane, S., Jakson, D., Appleyard, S., Callan, P., Bartram, J. and Kingston, P., 2007. ***Chemical Safety of Drinking-water: assessing priorities for risk management***. WHO, Geneva.

U.S. Environmental Protection Agency (2008). ***Drinking Water Contaminants***. Can be accessed from http://www.epa.gov/safewater/contaminants/index.html#listmcl – date cited: 12th February 2008

WHO 1996. ***Guidelines for Drinking Water Quality***. 2nd Edition, Volume 2, World Health Organization, Geneva.

WHO 2004. ***Guidelines for Drinking-water Quality***. 3rd Edition, Volume 1, World Health Organization, Geneva.

WHO/SEARO (no date). ***How to measure chlorine residual***. Technical note number 11. Prepared by WEDC, Loughborough University, UK for WHO Regional Office (South-East Asia).

ANNEX 1

Some Essential Drinking Water Quality Parameters

[Source: Thompson *et al.*, 2007]

Microbial Organisms

Total coliforms, thermotolerant (faecal) coliforms and *E.coli* are discussed in the main body of this guide.

Chemical and Physical Parameters

Aluminium (Al)

Aluminium is one of the most common elements in the Earth's crust; it occurs in a large variety of minerals in almost all geological environments. Aluminium from natural sources is therefore often found in raw waters, but only soluble forms of aluminium are likely to reach drinking-water. One of the major potential sources is aluminium salts, which are widely used as coagulants in drinking-water treatment. Although there is no health-based guideline value for aluminium, high concentrations reaching distribution systems can result in deposits of aluminium flocs, which can cause subsequent problems of dirty water. Concentrations can normally be maintained below 0.2 mg/L, and 0.1 mg/L should be achievable in well-run large treatment works. Monitoring is normally carried out in final water from the treatment works, but control is best achieved by optimizing coagulation and filtration, and by using operational monitoring for parameters such as turbidity.

Ammonia (NH_3)

Ammonia is not of direct health concern but can compromise disinfection efficiency because it exerts a significant chlorine demand, reacting rapidly with chlorine. Although ammonia is not toxic at concentrations generally found in water, its presence in raw water often indicates that the water is contaminated by sewage, by leachate from waste-disposal sites or by animal waste from agricultural activities. Ammonia may also occur naturally in groundwater from peaty sediments, or in slow-moving or stagnant surface water bodies that contain a lot of organic matter and are poorly aerated. Ammonia is occasionally found in distribution systems where chloramine is used as a residual disinfectant, if the process of producing chloramine is not sufficiently well controlled. Monitoring could be carried out in the final water from the treatment works, but other parameters (e.g. free chlorine) are normally considered to be more important.

Antimony (Sb)

High concentrations of antimony may occur in acidic drainage from mining areas, in groundwater known to contain high concentrations of arsenic, and in groundwater in active volcanic areas. Antimony is not usually found in significant concentrations in drinking-water. Concerns that antimony–tin solders would be widely used in place of lead solders have not materialized. Should monitoring be required, this would normally need to be at the tap unless a specific source of antimony in raw water is identified.

Arsenic (As)

Arsenic naturally occurs in a number of geological environments, but is particularly associated with sulfide-containing minerals; principally, arsenopyrite precipitated from hydrothermal fluids in metamorphic environments. It is also formed in low-temperature sedimentary environments under reducing conditions. Major alluvial and deltaic plains and inland basins composed of young sediments (quaternary, thousands to tens of thousands of years old) are particularly prone to developing groundwater arsenic problems. Although the mechanism for the mobilization of arsenic remains unclear, the presence of reducing (anaerobic) conditions in the affected aquifer has been recognized as a key risk factor for high-arsenic groundwater. Slow groundwater movement also appears to be important. As a consequence, high arsenic concentrations in groundwater do not necessarily correspond with areas where rock or sediment has the highest arsenic levels; rather, they occur where chemical conditions are most suitable for mobilization, usually reducing conditions. This is particularly important when planning the drilling of tubewells. Concentrations of arsenic can be significant, and major health effects can occur due to exposure through drinking-water. It is especially important to consider arsenic before establishing a new drinking-water source. The concentrations of arsenic are usually, but not always, stable. Where concentrations are likely to be stable (i.e. deep groundwater), monitoring would normally only need to take place infrequently. Where water supplies for populations are subject to treatment to remove arsenic, samples are normally best taken at the treatment works, where the frequency of monitoring should be sufficient to ensure that the process is effective.

Asbestos

Asbestos can arise from natural sources and from asbestos cement pipe. Exposure to asbestos fibres through drinking-water is not considered to cause health effects in humans; also, the analysis is difficult and expensive.

Barium (Ba)

High concentrations of barium may occur in groundwater in areas with granitic rocks, felsic metamorphic rocks or sedimentary rocks. Concentrations may be high where groundwater contains little or no sulfate (generally where chloride is the dominant anion). There is no evidence to date that exposure to barium through drinking-water has caused health effects in consumers. Should monitoring be required, it would normally be most appropriate at the treatment works or the source.

Beryllium (Be)

Beryllium is primarily found in effluent from specialist metalworking. No formal guideline value has been proposed in the WHO guidelines because beryllium is considered unlikely to occur in drinking-water. It is, therefore, unusual for monitoring to be required.

Boron (B)

Boron concentrations may commonly exceed drinking-water guideline values in groundwater in areas with granitic or volcanic rocks. In areas where there are large accumulations of evaporates, boron concentrations may be high, but in these areas water is sometimes too saline for drinking without advanced drinking-water treatment (e.g. desalination). Boron can also result from wastewater discharges. Boron is very difficult to remove from water and is not usually encountered at concentrations of concern. Should monitoring be required, this is likely to be infrequent and at the treatment works or the source.

Cadmium (Cd)

Cadmium is a heavy metal with similar chemical properties to zinc, but is much less common in the environment than zinc. Cadmium occurs in igneous rocks and some sedimentary rocks, and is generally associated with zinc ore minerals like sphalerite, and with a range of copper ore minerals. Traces of cadmium are often present in artificial fertilizers, and this heavy metal may accumulate in soils in areas that have been used for agriculture for long periods. Concentrations of cadmium in water are only likely to be of health concern in environments where pH is less than 4.5. Other cadmium sources can include solder, galvanized pipes and metal fittings, pollution from disposal of cadmium-containing materials and from mining operations. However, concentrations of cadmium in drinking-water above the guideline value are unusual.

Chloride

Chloride can originate from natural and human-made sources, such as sewage and industrial effluents. Where salt is used for de-icing, chloride can contaminate groundwater through road drainage. Upland and mountain water supplies are usually low in chlorides, whereas, concentrations are generally higher in rivers and groundwater. The main operational issue for chloride is its ability to increase the corrosiveness of water, particularly in low alkalinity water. High concentrations of chloride may result in a detectable taste in water, but consumer acceptability varies widely depending on the form of chloride (e.g. $NaCl$, KCl and $CaCl2$). Should monitoring be necessary, this would usually be at the treatment works. The frequency would depend on the variability in the source water, but would normally be low.

Chlorinated benzenes

Chlorinated benzenes are widely used in industry and are sometimes encountered in drinking-water from surface sources. They usually give rise to taste and odour problems at concentrations below the health-based guideline value, where one has been proposed.

Chromium (Cr)

High concentrations of chromium may occur naturally in groundwater in areas with mafic or ultramafic volcanic or metamorphic rocks (i.e. rocks that consist mainly of ferromagnesian minerals with no quartz). Chromium is usually found in drinking-water at concentrations well below guideline values. However, it has been found at higher concentrations from industrial pollution or mining discharges. Generally, it would only require investigation for monitoring if there were indications that a problem might exist. Measurement would normally take place in final water from the treatment works.

Copper (Cu)

Copper is usually found at very low concentrations in final drinking-water, but concentrations can increase significantly in buildings with copper pipes if the water is aggressive (dissolves metals from pipes and fittings). Concentrations are most likely to increase after the water has stood in the pipes for a few hours. Copper has been shown to cause acute gastrointestinal discomfort and nausea at concentrations above about 3 mg/L. Monitoring for copper therefore needs to take place at the tap. However, meaningful monitoring usually requires a specific strategy to be developed because concentrations will vary from property to property. High copper levels give rise to staining of sanitary ware. Unless a particular problem has been demonstrated, monitoring would not normally be considered to be necessary or would at least be infrequent.

Cyanide

Cyanide occurs naturally only in geothermal water in volcanic areas. However, it is a common contaminant in groundwater and surface water in gold mining areas, particularly near deposits of processed tailings, as a consequence of industrial discharges, and is a major cause of concern through spills. While there is no documented evidence of health effects caused by exposure to cyanide in drinking-water in normal circumstances, potentially high concentrations from spills must be managed to prevent these concentrations penetrating drinking-water supplies. Exposure, especially from industrial activity, would generally only be intermittent. This means that monitoring is difficult and would normally only be carried out in response to a particular incident or circumstance where cyanide was known to be present. Fish can be used as an indicator of high cyanide levels, because they are particularly sensitive to its effects.

Dissolved oxygen

Dissolved oxygen is included as an indicator parameter. It can be measured in the field using a dissolved-oxygen electrode. The dissolved-oxygen content of water depends on its source, temperature, and chemical and biological processes taking place in the water distribution system. Therefore, measurements can only be used in a relative, not an absolute, sense. However, large declines in dissolved oxygen in a water source could indicate high levels of microbiological activity, and should trigger further sampling for microorganisms.Dissolved oxygen is not usually a candidate for routine monitoring unless a specific problem is recognized.

Eh (oxidation-reduction or redox potential)

Many chemical reactions in water involve the transfer of electrons between chemical constituents. Electron transfer is measured with an electrode assembly that includes an inert metallic electrode (usually platinum). Eh is a measure of the extent to which these reactions can take place. A high positive Eh potential indicates oxidizing conditions where chemical species such as oxygen, nitrate and sulfate may be present in water. Very low negative Eh values indicate reducing conditions with no oxygen and where chemical species such as ferrous iron and hydrogen sulfide are frequently present. Very low Eh values in water are often indicative of pollution containing large amounts of organic carbon, such as leachate from septic tanks or landfill sites. Rapid changes in Eh should trigger an investigation as to the cause.

Fluoride (F)

Fluoride occurs in rocks in many geological environments. High concentrations of fluoride may occur in groundwater in areas with granitic, acid volcanic, sodium-rich (alkaline) igneous or volcanic rocks, and in some sedimentary and metamorphic terrains. Widespread dental mottling is a health indicator that water contains high concentrations of fluoride, although other sources (e.g. food) may be equally important. Fluoride is one of the chemical contaminants that must be considered, because high fluoride levels in drinking-water are a major source of adverse human health effects in some parts of the world.

Hexachlorobutadiene

Hexachlorobutadiene is widely used as an industrial chemical. It has been identified in effluent from chemical manufacturing, but has also been found as a contaminant in chlorine gas used for disinfection. Control should, therefore, be primarily through specifications on the quality of chlorine gas. Monitoring would normally be considered only if a specific problem was identified by catchment assessment.

Hydrocarbons

Aromatic hydrocarbons are used as solvents; they are found in petrol and diesel. They are not normally found in drinking-water except as a consequence of spills and or leaking storage facilities. Aromatic hydrocarbons are usually detected by taste and odour at concentrations well below the health-based guideline value. Styrene is sometimes found due to the use of certain pipeline materials (e.g. glass-reinforced plastic) that have not been cured properly. Routine monitoring is normally unnecessary, unless a potential problem has been recognized. Aromatic hydrocarbons are sometimes found, having leached from polyethylene pipes. Thus, monitoring in response to an incident or problem may be more effective at the tap rather than at the treatment works. Polycyclic aromatic hydrocarbons (PAHs) are usually only found in drinking-water as a consequence of leaching from coal-tar linings on cast-iron water mains. The PAH of greatest concern is benzo(a)pyrene, but the most commonly encountered is fluoranthene. Benzo(a)pyrene is normally only detected at significant concentrations in water when particles of coal tar are present.

Hydrogen sulfide

Hydrogen sulfide arises in anaerobic conditions when sulfides are hydrolysed. It causes an unpleasant odour of rotten eggs at very low concentrations as it is lost to air. It is not normally monitored because it is not found in well-aerated systems. If it is detected by smell, it indicates that the system is anaerobic.

Lead (Pb)

Lead is widely dispersed in the environment, occurring in a variety of sedimentary rocks, and in felsic igneous and metamorphic rocks, where it may reach high concentrations in veins associated with hydrothermal fluids. Under pH conditions generally found in natural waters, lead has a low solubility. Concentrations of lead in water are only likely to be of significance in environments where pH is less than 4.5, and it is very rarely found in water at treatment works. When found in drinking-water, lead usually arises from lead pipes and lead solder, mostly from plumbing in buildings. Monitoring is quite difficult and requires samples to be taken at the tap. Assessing the presence of lead pipes, or the ability of the water to dissolve lead, are the most appropriate management approaches. Monitoring is only considered if significant resources are available.

Mercury (Hg)

Mercury is a rare element in the Earth's crust. It is only relatively concentrated in some volcanic areas and in mineral deposits as a trace constituent of ores of other heavy metals. Mercury concentrations in groundwater and surface waters rarely exceed 1 µg/L. High concentrations of mercury may occur in groundwater and surface water supplies in gold-mining areas where mercury has been used for gold extraction. The guideline value for mercury is conservative because it is based on the provisional tolerable weekly intake (PTWI) for methylmercury, which is more toxic than mercury. Monitoring would normally only be justified if mercury were known to be present due to unusual circumstances, such as an industrial or mining discharge.

Molybdenum (Mo)
Molybdenum is a relatively rare element in the Earth's crust, but is commonly associated with base metal sulfide deposits, usually being present as the mineral molybdenite MoS_2. High concentrations of molybdenum may occur in groundwater in mining areas where sulfide ores contain the mineral molybdenite. Monitoring would normally not be justified unless there were clear indications that high levels of molybdenum were likely to be present.

Nickel (Ni)
Nickel has a similar chemical behaviour to iron and cobalt, and commonly substitutes for iron in ferromagnesian minerals. High concentrations of nickel may occur in groundwater in areas with mafic or ultramafic rocks. Concentrations of nickel in water from natural occurrences are only likely to be of health concern in environments where pH is less than 4.5 or where groundwater pumping has introduced oxygen into an anaerobic aquifer. Nickel may also be released from some industrial sources (e.g. nickel plating) and from chromium plating of taps and fittings in which nickel is the base layer. A monitoring programme for nickel in drinking-water would generally only be required if a specific source of pollution were known.

Organotins
The dialkyltins can be used as stabilizers in PVC pipes. They normally leach in very low concentrations, but if control were required, this would be through product specification.

Radon (Ra)
Radon is a colourless, odourless gas that is produced by the radioactive decay of radium that occurs naturally in minerals. Groundwater may contain high concentrations of radon and its daughters in areas where bedrock naturally contains high levels of radioactivity. This includes areas with granitic rocks, and sediments with phosphate nodules or heavy mineral sand deposits. Management of radon in drinking-water is by aeration, in which case it is important that there is adequate ventilation of houses, because a significant proportion of radon in water will be lost to the atmosphere.

Selenium (Se)
Selenium has a similar chemical behaviour to sulfur, and often occurs associated with sulfide minerals in a wide range of rocks. High concentrations of selenium may occur in groundwater in semiarid or arid areas, near known mineral deposits containing sulfide minerals of uranium and vanadium. Irrigated agriculture may substantially increase concentrations in groundwater in areas with high selenium levels in soil. High selenium concentrations are generally only found in groundwater with oxidizing conditions in arid areas. In areas where there is a large amount of organic matter in soils, selenium is generally relatively immobile in water. Selenium is one of the few substances that have been shown to cause adverse human health effects as a consequence of exposure through drinking-water, although it is an essential element and in many parts of the world there is a deficiency. It is, therefore, important to consider selenium in developing new sources in areas where selenium is suspected. Where selenium is present, monitoring at the treatment works would be appropriate.

Silver (Ag)
Silver is not normally found at significant concentrations in drinking-water, but it is sometimes used as a bacteriastat impregnated in activated carbon used in point-of-use filters. It is very unlikely that monitoring of drinking-water would be appropriate.

Sodium (Na)
Sodium can be found in drinking-water at concentrations in excess of 20 mg/L as a consequence of the use of more saline waters. There is no indication of health effects in the general population associated with high sodium levels in drinking-water, although such water may not be suitable for bottle-fed infants. Concentrations in excess of 200 mg/L may give rise to taste problems. Routine monitoring for sodium is unlikely to be a high priority.

Sulfates

The sulfate anion (SO_4^{2-}) is a common constituent in natural water and is usually present in at least mg/L concentrations. While WHO has decided that it is not necessary to develop a health-based drinking-water guideline value for this anion, concentrations in excess of 500 mg/L sulfate may cause a noticeable taste.

Tin (Sn)

Inorganic tin has not been found at concentrations of concern in drinking-water. No guideline value was considered necessary, and tin is not discussed further in this document.

Total dissolved solids

Total dissolved solids (TDS) primarily consist of inorganic salts. Although there are no direct health concerns, high concentrations may be objectionable through taste. Regular monitoring is not usually considered a high priority.

Tributyltin oxide

Tributyltin oxide (TBTO) was widely used as a wood preservative and antifungal agent. It is less widely used now because of its extremely high toxicity to shellfish and its potential impact on the aquatic environment. It has rarely been identified in drinking-water and therefore no health-based guideline value has been proposed. Monitoring would not normally be considered unless a specific problem had been identified.

Uranium (U)

Uranium is widely distributed in the geological environment, but concentrations are particularly high in granitic rocks and pegmatites, and in areas where there is sulfide mineralization. The WHO provisional drinking-water guideline value for uranium is 15 µg/L but there are uncertainties regarding whether concentrations above this would be of concern. Some countries have drinking-water standards for uranium of up to 30 µg/L. Uranium has been found in many parts of the world at concentrations in excess of 30 µg/L and so is considered a high-priority constituent.

Zinc (Zn)

Zinc is usually only found at very low concentrations in raw waters but can be increased by dissolution of zinc from galvanized pipes. Concentrations above about 3 mg/L can give rise to problems with appearance and taste of the water. A monitoring programme for zinc is unlikely to be necessary unless particular problems have been encountered.

ANNEX 2

Example of a Sanitary Inspection Form

RAINWATER COLLECTION AND STORAGE

I. General Information

Province/Village/Island/Community :______________________________

Date of inspection :______________________________

Time :______________________________

Person conducting inspection :______________________________

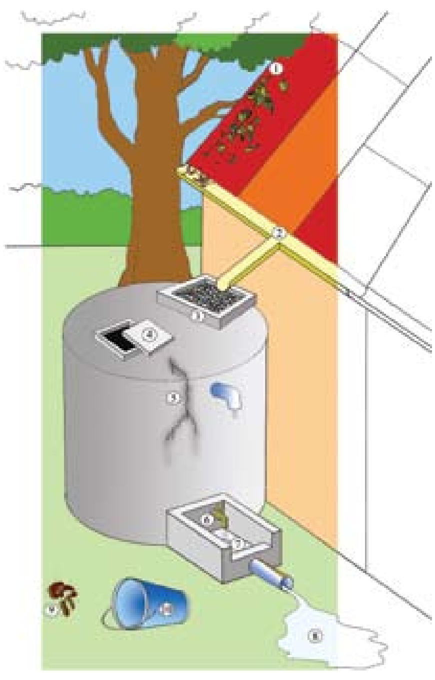
II. Risk Assessment

1. Is there any visible contamination on the roof catchment area (plants, dirt, excreta etc)? Y / N
2. Are the guttering channels that collect water dirty? Y / N
3. Is there any deficiency (something wrong) in the filter box (e.g. no fine gravel)? Y / N
4. Is there any point of entry to the tank that is not properly covered? Y / N
5. Is there any defect in the wall or top of tank? Y / N
6. Is the tap (outlet) defective or leaking? Y / N
7. Is the concrete floor under the tap dirty? Y / N
8. Is the water collection area inadequately drained? Y / N
9. Is there any source of pollution in the area surrounding the tank or water collecting area? Y / N
10. Is a bucket or any other container in use and left in a place where it may get contaminated? Y / N

Total: ....../ 10

Risk: 0-2 low, 3-5 moderate, 6-8 high, 9-10 very high

III. Results and Recommendations:



ANNEX 3

List of Acronyms used in this Report

EC	Electrical Conductivity
FAC	Free Available Chlorine
H_2S	Hydrogen Sulfide
IAS-USP	Institute of Applied Sciences, the University of the South Pacific
mg/L	milligram per litre
n/a	not applicable
NZAID	New Zealand's International Aid and Development Agency
PIC	Pacific Island Country
SOPAC	Pacific Islands Applied Geoscience Commission
THM	Trihalomethane
UK	United Kingdom
US EPA	United States Environmental Protection Agency
WEDC	Water, Engineering and Development Centre
WHO	World Health Organization
WQM	Water Quality Monitoring

Tasleem Hasan

William Aalbersberg

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