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Water Quality Monitoring in Pacific Island Countries



SOPAC Technical Report 381

Handbook for Water Quality Managers & Laboratories, Public Health Officers, Water Engineers and Suppliers, Environmental Protection Agencies and all those Organisations involved in Water Quality Monitoring

Luke Mosley Sarabjeet Singh Bill Aalbersberg

SOPAC

The University of the South Pacific

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LIST OF ABBREVIATIONS

EC	electrical conductivity (measure of salinity)
L	litre
L/day	litres per day
m^3	cubic metre
m^3/day	cubic metre per day
mg/L	milligrams per litre
ppm	parts per million
ppb	parts per billion
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Orgainisation
UNEP	United Nations Environmental Programme
UNESCAP	United Nations Economic and Social Commission for Asia and the Pacific
SPREP	South Pacific Regional Environmental Progamme
PWA	Public Water Association
GPA	The Global Program of Action
COD	Chemical Oxygen Demand
BOD	Biochemical Oxygen Demand
WHO	World Health Organisation
Cl	chlorine
HACH	HACH Company (suppliers of water quality test kits)
MERCK	MERCK Company (suppliers of water quality test kits)
APHA	American Public Health Association
NIST	National Institute of Standard Technology
NRCC	National Research Council of Canada
Orion	Brand Name of Water Quality Meters
ANZECC	Australian and New Zealand Environmental and Conservation Council
UNCDF	United Nations Capital Development Fund
UNDP	United Nations Development Programme
WEU	Water Engineering Unit (within MWPU)
WHO	World Health Organisation
μS/cm	microsiemens per centimetre (unit of electrical conductivity, and used as an indicator of salinity; also shown in some publications as μmhos/cm)

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This revised version follows amendments to the handbook by Tasleem Hasan and Marc Overmars; USP/SOPAC Water Quality Officer and SOPAC Adviser – Water/Hydrogeology, respectively. The amendments were prompted by new guidelines on water quality published by the World Health Organisation (WHO), in 2004.

1. INTRODUCTION

In order to protect their populations from the health risk of drinking contaminated water and consequences of poor coastal water quality, Pacific Island countries must have, or should develop the capacity to regularly and accurately monitor their water quality. This handbook is designed to assist personnel and organisations involved in measuring water quality of drinking water, surface waters and coastal waters in Pacific Island Countries.

Small Island Countries in the Pacific have special physical, demographic and economic features. Their limited land areas, shortage of natural resources (arable land, freshwater, minerals and conventional energy sources), geological complexity, isolation and widespread nature of their territories and exposure to natural disasters (cyclones, earthquakes, volcanic eruptions, tsunamis) cause serious water resources, solid waste and wastewater problems (UNESCO 1991).

Good quality drinking water is essential for the well being of all people and the United Nations has recently declared access to clean water a basic human right. Unfortunately in many countries around the world, including the Pacific Islands, some drinking water supplies and surface waters have become contaminated which impacts the health and economic status of the populations. Contaminants such as bacteria, viruses, heavy metals, nitrates, and salt have entered into drinking water supplies as a result of poor treatment and disposal of human and livestock waste, industrial discharges and over-use of limited water resources (Lee and Brodie 1982). This has led to a large number of deaths and health problems from diarrhoea, cholera and hepatitis B, and shortages of potable and safe drinking water. The current trend of increasing urbanisation in many countries will compound the difficulties in disposal of liquid and solid waste, and may lead to increased occurrence of diseases related to poor and unsanitary living conditions (UNEP 2002b).

There have been few published studies of drinking water quality in the Pacific islands (e.g. Lee and Brodie, 1982; Brodie *et al*. 1983; Singh and Mosley 2003; Mosley *et al*. 2004). Most of the limited data available is held by water utilities and health agencies on parameters such as faecal and total coliforms, pH, conductivity, turbidity, and nitrate. There has been insufficient investigation of the levels of metals and other possible contaminants such as pesticides in drinking water (Singh and Mosley, 2003). This is probably due to the inability of many Pacific Island countries to accurately measure these parameters in water or a lack of funding to send samples elsewhere for analysis. The shortage of data is of concern given the increasing development and industrial activity on many islands (UNESCAP 2000).

Maintaining good coastal water quality in the Pacific Islands is equally important, particularly where coral reefs are present which are very sensitive to pollution. Coral reefs are highly productive and biodiverse ecosystems that are important as fishery resources, tourist attractions, and protection of the coastline from damaging effects of waves. Over recent years, increased development of the coastline and utilisation of coastal resources have caused significant degradation of reef habitats and a loss of species diversity (Hodgson 1999). These impacts have been observed as the result of factors such as increased erosion on land and siltation of reefs, water pollution, overfishing, and coral harvesting. If left unmonitored, whole coral ecosystems will be destroyed, unnoticed until it is too late. Sewage discharges to coastal waters may result in serious health problems, particularly for people consuming shellfish or swimming in the vicinity of sewage outfalls.

The Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA) aims at preventing the degradation of the marine environment by facilitating the duty of states in preserving and protecting it. Some 80% of the pollution load in the oceans originates from land-based activities of which sewerage is a large contributor. In the Pacific region, a consultation process was facilitated by SOPAC, SPREP, PWA and the UNEP/GPA Coordination Office on wastewater management. An outcome was the Pacific Wastewater Policy Statement and Framework for Action with guiding principles and actions on wastewater management which includes aspects on water.

This handbook contains background information on water quality problems in the Pacific, information on designing an appropriate water quality monitoring programme; ways of determining the appropriate water quality parameters; suggestions on sampling and analysis methods; as well as general laboratory information. The handbook is aimed at drinking water suppliers, public health officers, water engineers, environmental protection agencies and all those organizations involved in potable, non-potable and coastal water monitoring.

2. DESIGNING A WATER QUALITY MONITORING PROGRAMME

The routine monitoring and assessment of water quality should be a key priority for both water suppliers and surveillance agencies. The water quality data gathered should be properly assessed or evaluated, to enable effective management related to the health of humans and protection of the environment. Monitoring water quality will only be effective and efficient if it is properly planned and implemented. Careful planning should be undertaken before the start of data collection to ensure that sample sites, frequency of sampling, and water quality parameters analysed are appropriate for the objectives of the monitoring.

2.1 Water quality parameter selection

An important part of undertaking water quality studies is to know what parameters you should sample and analyse. There are a number of water quality parameters that could be measured and it is important to make a good judgment of what are likely to be the most important in a particular situation. An initial assessment should be made of the study location to attempt to obtain information on any known activities that might affect water quality (e.g. proximity to sources of human and animal wastes, industrial activities) and any potential pollutants. During this analysis, essential parameters to be measured would be those that might indicate a risk to human health or the environment, those with potential to cause public complaints, and those which indicate a likelihood of causing operational problems in water treatment plants.

A suggested checklist of what are typically the most important parameters to analyse in different water types is provided in Table 1. Detailed information on these parameters is provided in the next section. Note also that not all potential water quality parameters are listed here, only the minimum number of parameters that the authors considered to be of most relevant to the Pacific Islands whilst taking into account the capacity of most laboratories. Other parameters should be examined where the need, resources and/or

funding exist. Many of the parameters shown in Table 1 are explained in more detail elsewhere in this handbook.

Table 1: Typical water quality parameters to measure in different water types.

	WATER TYPE		
	Drinking	**Surface/Waste[1]**	**Marine**
Microbiological			
Total Coliform	Yes	No	No
Faecal Coliform	Yes	Yes	Yes
Physical			
pH	Yes	Yes	No
Temperature	Yes	Yes	Yes
Colour	Yes	No	No
Turbidity	Yes	Yes	Yes
Conductivity/ Total Dissolved Solids	Yes	Yes	No
Salinity	No	No	Yes
Dissolved Oxygen	No	Yes[2]	Yes[2]
Total Suspended Solids	No	Yes	No
Chemical –Inorganic			
Ammonia	No	Yes	Yes
Nitrate	Yes	Yes	Yes
Nitrite	No	Yes	Yes
Phosphate	No	Yes	Yes
Hydrogen Sulphide	Periodically	No	No
Sulphate	Periodically	No	No
Fluoride	Periodically[3]	No	No
Chlorine Residual	Yes (if chlorinated)	No	No
Chloride	Yes	No	No
Hardness	Periodically[4]	Periodically[4]	No
Metals			
Aluminium	Periodically	Periodically[5]	Possibly[5, 6]
Cadmium	Periodically	Periodically[5]	Possibly[5,6]
Copper	Periodically	Periodically[5]	Possibly[5, 6]
Iron	Periodically[4]	Periodically[5]	Possibly[5,6]
Manganese	Periodically[4]	Periodically[5]	Possibly[5,6]
Lead	Periodically	Periodically[5]	Possibly[5,6]
Zinc	Periodically	Periodically[5]	Possibly[5,6]
Chemical- Organic			
BOD	No	Yes[2]	Yes[2]
COD	No	Yes[7]	No
Oil and Grease	No	Posibly[8]	Possibly[8]
Pesticides	Periodically[6,9]	Possibly[6]	Possibly[6]
Radioactivity	Posibly[10]	Posibly[10]	Posibly[10]

1. Refers to raw wastewater, wastewater-treated effluents, rivers and streams.
2. Analyse if wastewater discharges that may deplete oxygen are present (e.g. sewage or industrial discharges containing organic material).
3. Analyse periodically especially if volcanic or industrial discharges containing fluoride are present.
4. Unlikely to be toxic but can cause operational problems in treatment systems or problems for consumers, e.g. hard water makes washing of clothes difficult and may cause scaling of pipes, high levels of iron and manganese may cause water to look unsafe and scale pipes.
5. Analyse periodically especially if industrial discharges containing metals are nearby to water sources and for drinking water in areas where rainfall may be acidic (e.g. active volcanic islands).
6. Difficult and expensive to accurately analyse without specialist laboratory facilities. If contamination problems are suspected it may be best to measure levels in the sediment where these substances are more likely to accumulate.
7. COD analysis is important for wastewater analysis because the results could be used to estimate BOD value which is usually 2-3 times lower than COD, and unlike BOD the results could be obtained the same day.
8. Should be analysed if an oil or fuel spill has occurred.
9. Analyse drinking water if it is likely to have been exposed to runoff from agricultural activities involving pesticide use.
10. Only analyse if water is suspected to be in contact with radioactive sites, material or atmospheric fallout.

Some chemical analyses are expensive and difficult to carry out (e.g. pesticides). If the analytical capability is present and analysis is required for particular parameters which requires sophisticated equipment, this should be done occasionally when the laboratory has enough samples to make it economical to start up the equipment and run the analysis. If significant risk to human health or the environment exists, and the samples cannot be analysed in-country, then samples should be sent overseas for analysis.

This handbook does not provide detailed information on individual analysis methods. Samples should be analysed by reliable and internationally accepted methods (e.g. American Public Health Association Standard Methods for the Examination of Water and Wastewater).

3. DRINKING WATER QUALITY MONITORING

In the Pacific, drinking water is supplied from various sources such as rainwater, groundwater (well, borehole), and surface water (river, creek, stream, spring, dam). The objective of drinking water quality monitoring is to provide data which will prevent the supply of any unsafe water, or if unsafe water is supplied that people can be advised to take precautionary measures such as boiling.

3.2 Selection of sites and frequency of sampling

Samples should be taken from locations that are considered representative of the water source, treatment plant, storage facilities, and household supply. However, there are a number of constraints in trying to achieve a comprehensive description of water quality in a country. The number of samples taken is largely dependent on:

1. Number of water supply systems and relative importance of these.
2. Funds available for travel, equipment and analysis.
3. Number of trained staff and their available time.
4. Laboratory analytical facilities.

In most cases, there are limited funds available and this inevitably affects how many water supply systems can be included, how often they can be visited, and how many samples can be analysed. It is therefore essential that the following items are identified and the associated costs calculated so that achievable aims and objectives can be set:

1. The number and location of water supplies to be included in each stage of surveillance.
2. Sampling location and frequency.
3. Parameters to be monitored.
4. Sampling methods and equipment.
5. Responsibilities and necessary qualifications of staff.
6. Reagent and other consumable requirements.
7. Equipment maintenance.
8. Transport and fuel costs.
9. The cost of reporting results to suppliers and communities.
10. The cost of follow-up activities.

It is vital that all these elements are accurately budgeted for and cost-effectiveness achieved. Once a cost is calculated this can be taken to the funding provider(s) with a request for the necessary funding (whether they be the national government, regional or international organisations).

Frequency of Sampling

The frequency of sampling will be largely determined by the resources available. The chances of detecting the pollution that occurs periodically is increased if samples are picked at different times of the day and on different days in a week and across seasons. Sampling frequencies for raw water sources will depend upon their overall quality, their size, the likelihood of contamination, and previous analytical results. The frequency of sampling should be greater where the number of people supplied is large, because of the higher number of people at risk. Below is a simple guide (from the World Health Organization) for the **minimum** number of samples that should be taken for drinking water testing:

- *Population below 5,000*: **5 samples** - 1 at treatment works outlet, 1 at storage tank, 3 in the distribution network.

- *Population between 5,000 - 10,000*: **7 samples** – 1 at works outlet, 1 at storage tank and 5 in the network. 2 visits per month

- *Population over 10,000*: **7 samples + 1 extra sample** per 5,000 population – 1 at works outlet, 1 at storage tank, rest in network.

One set of monitoring samples for every 5000 people should be taken each month (e.g. for a population of 15,000, 3 sets of monitoring samples per month should be taken).

If water supplies are taken from a point source, for instance a borehole or well, not connected to a piped network, analysis need not be as regular. However, there should be a minimum of two analyses per year (e.g. one in the wet season and one in the dry season) to take into account water level fluctuations and to assess whether water quality varies seasonally. These may vary with time and it is important that the surveillance programme remains flexible and open to modification in response to evolving water quality priorities. For example if high-risk areas are identified in routine monitoring, these should be sampled to a greater extent and more often.

Monitoring microbiological quality (faecal and total coliforms etc) of drinking water is of principal importance because of the acute risk to health posed by viruses and bacteria in drinking water. Where chlorinated water supplies are surveyed, from whatever source, turbidity and chlorine residual within the network should be tested regularly to see if levels are compliant with WHO guidelines (Table 2). As the equipment and consumables required are very cheap and testing is field based, it is feasible to test frequently and this may help reduce the number of microbiological sample analyses required. For example, if free Cl residual is sufficient no coliform bacteria should be present. Strategies for monitoring of microbiological quality of water should also include hazard identification and risk assessment. Monitoring and assessments can be undertaken simultaneously with educating households/communities on sanitation issues, water treatment methods and

water source protection. A record of monitoring should be maintained and the monitoring programmes should be reviewed periodically (e.g. once each year).

Chemical testing (e.g. nitrate, heavy metals) is generally not undertaken as frequently as microbiological analysis because, in general, the health risks posed by these substances are chronic rather than acute and because changes in water chemistry tend to be longer-term unless a specific pollution event has occurred. However, routine testing of the chemical quality of water should be undertaken. Priority should be given to those substances which are known to be of importance to health and which are known to be, or likely to be, present in significant concentrations in drinking-water such as faecal coliform, fluoride, arsenic, etc.

In the case of water supplies taken from rivers and lakes, chemical testing of drinking-water supplies should be linked to water resources monitoring which can include factors such as water levels, flow rates and sediment ratios.

3.3 World Health Organization (WHO) Drinking Water Quality Guidelines

Selected WHO guidelines relevant to drinking water are shown in Table 2 below. In many cases, WHO guideline values are adopted as the national standards for drinking-water quality as national guidelines do not exist. For some parameters critical values are given in order to protect human health while for other parameters the values given are levels that are likely to result in consumer complaints (e.g. due to poor taste) but may not necessarily be toxic.

Table 2: World Health Organization (WHO) Drinking Water Quality Guidelines.

Parameter	WHO Guideline value
Faecal coliform or E. coli	Not detectable in a 100 mL sample
Aluminium	0.2 mg/L*
Arsenic	0.01 mg/L
Ammonia	1.5 mg/L*
Cadmium	0.003 mg/L
Arsenic	0.01 mg/L
Chloride	250 mg/L*
Colour	15TCU*
Copper	2 mg/L
Fluoride	1.5 mg/L
Hydrogen Sulphide	0.05 mg/L*
Iron	0.3 mg/L*
Lead	0.01 mg/L
Manganese	0.1 mg/L*
Nitrate	10 mg/L
Sodium	200 mg/L*
Sulphate	250 mg/L*
Turbidity	5 NTU*
Total dissolved solids	1000 mg/L*
Zinc	3 mg/L*

*May not be toxic but could result in consumer complaints

A positive test for *E. coli* or faecal coliform organisms in drinking water indicates the need for immediate remedial action and additional measurements. As soon as possible,

analyse several repeat samples of finished water from the same location to see if they consistently give positive results.

A "boil water" or "chlorine addition" advisory should be issued until the cause of the problem can be identified.

A chlorine addition can be performed, by carefully adding 1/2-teaspoon bleach (active ingredient 5.25% sodium hypochlorite) per 4L of water and leaving to stand for at least 30 minutes (or overnight for large tanks).

The "Control of Communicable Disease Manual" by the American Public Health Association is a useful reference if disease outbreaks occur. It is important that where an outbreak occurs attempts are made to identify its source. Many diseases (e.g. Typhoid) can also be caught from eating contaminated food so all possibilities for disease transmission must be examined. People can be carriers of diseases such as typhoid without showing symptoms of the disease. Therefore it is very important that public education on sanitation and safe food-handling is conducted in the affected areas.

In many Pacific island countries, particularly for wells on outer islands water meeting the total and faecal coliform criteria may not be readily available. This is because in tropical areas many bacteria of no sanitary significance occur in almost all untreated supplies and can reproduce at the temperatures found in tropical soils. Uncritical enforcement of a water quality guideline may lead to unnecessary condemnation of water sources that may be more appropriate or more accessible than other sources. It may even force people to obtain their water from more polluted sources. Under conditions of widespread faecal contamination, national surveillance agencies are recommended to set the above boil water/chlorine advisories and intermediate goals that will eventually lead to the provision of high quality water to all, but will not lead to improper condemnation of relatively acceptable supplies. In urban areas, for treated water entering, or in the distribution system, a provision for up to 5% positive samples for total coliforms is allowed in the WHO guidelines. The rationale for this additional criterion is the greater sensitivity of total coliforms for detecting irregularities (not necessarily faecal contamination) in water treatment and distribution. Rainwater tank systems must also be properly maintained and periodically disinfected to maintain safe drinking water (e.g Mosley 2004).

3.4 Description of drinking water quality parameters

The following parameters are considered some of the most essential to assess drinking water quality in the Pacific.

3.4.1 Microbiological indicator organisms (faecal and total coliforms, E. coli)

Untreated or improperly treated drinking water may contain micro-organisms of faecal origin that are pathogenic (disease causing) such as cholera and typhoid. The presence of pathogens in drinking water is usually due to human and animal waste entering into water sources. The sanitation facilities that are used predominantly in rural/outer islands of the Pacific are septic tanks and pit latrines, and these do not provide sufficient treatment to remove pathogens. The waste outflow from these types of facilities can travel several hundred metres underground in porous coral limestone found on many

islands (Dillion 1997). Animals (e.g. pigs and cows) present near or above water supplies can also be a source of contamination.

It is difficult and expensive to test for 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 high numbers in faecal material, whether or not pathogenic organisms are present. A high level of indicator organisms in a water sample *indicates* a high risk that pathogenic organisms might also be present.

The usual indicator organisms that are tested for are total coliforms, faecal coliforms and *E. coli*. Total coliform is a collective name used for all coliform groups. The faecal coliform is a subset of total coliform and consists mostly of *E. coli* (some others enterics such as *Klebsiella spp* are present). Faecal coliforms are also known as thermotolerant coliform bacteria. The term faecal coliform is less frequently being used and the new guidelines on water quality (WHO 2004) uses the preferred term thermotolerant coliforms.

The total and faecal coliform groups of bacteria, along with many other naturally occurring bacteria, inhabit the intestinal tract of animals including humans and are discharged in their faeces. Thermotolerant coliform presence generally indicates that water is contaminated with faecal matter and is not safe for drinking purposes hence it can be used as microbiological parameter for faecal contamination.

However, *E. coli* is considered the most suitable index of faecal contamination (WHO 2004). *E. coli* occurs in high numbers in human and animal faeces, sewage and water subject to recent faecal pollution. Though thermotolerant coliforms are composed mostly of *E. coli*, the presence of other species such as *Klebsiella spp* makes the group a less reliable (but still acceptable) index of faecal pollution.

Total coliforms are not an ideal indicator in the tropics as they can naturally persist and reproduce in soil and water at 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 will be produced. 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 help to indicate a treatment failure or leakage in the system.

Other indicator organisms are sometimes used which are in the *Enterococcus* bacteria group such as faecal streptococci (WHO, 1996), and *Clostridium perfringens*.

The problems noted above with the sophisticated testing procedures and equipment required for the analysis of the above indicator organisms make their use difficult in rural areas and on outer islands. Another less commonly used indicator is sulphide-reducing bacteria and a low cost test for these bacteria in drinking water called the *hydrogen sulphide (H_2S) paper-strip test* can be carried out (Mosley and Sharp 2004). There are many advantages of this test for use in rural and remote Pacific island communities particularly where conventional monitoring is unable to be carried out. H_2S tests has relatively good correlation with results from faecal and total coliform analyses making it ideal for widespread use in the Pacific Islands where water quality monitoring, particularly on remote islands, is difficult. The WHO is currently promoting the use of the tests in the Pacific region with the health officers.

It is possible to access the likelihood of faecal contamination of water sources by a sanitary survey. This often has been more valuable than bacteriological testing alone, because a sanitary survey makes it possible to see what needs to be done to protect the water source and because faecal contamination may vary, a water sample may only represent the quality of water at the time it was collected (WHO, 2003).

Indicator bacteria may be measured using a variety of methods, most involving incubation on an agar media (to provide nutrients for organisms) at a set temperature (e.g. 44.5°C) and period of time (e.g. 24 hours), followed by counting of the number of bacteria colonies present. These operations can be performed in the field using portable battery-powered incubators (e.g. Millipore Field Microbiology Tests Kit).



Figure 1: Bacteria colonies growing on an agar plate.

3.4.2 Chlorine (residual)

Chlorine is added to drinking water supplies for the purpose of destroying or deactivating disease-producing micro-organisms. This is termed *water disinfection*. Chlorine (Cl_2) is usually added to water in liquid form or as sodium or calcium hypochlorite chemicals.

For effective disinfection there should be enough residual chlorine concentration (> 0.5 mg/L free available chlorine) after at least 30 minutes contact time at pH <8.0. The chlorine concentration should not exceed 5 mg/L as the water will not taste good.

Residual chlorine can be measured simply and quickly using kits (e.g. DPD method) available from several suppliers (e.g. HACH).

3.4.3 Chloride

Chlorides (Cl^-), not to be confused with chlorine, are in nearly all water supplies. They are usually associated with salt content and amounts of dissolved minerals in water. The recommended limit for chlorides is 250 mg/L where most people will notice a salty taste. The amount of chlorides in water is determined by the types of rocks and soils it has contacted. Seawater intrusion in groundwater can also be a cause for increased chlorides. The presence of chlorides in drinking water is generally not considered to be

harmful but the most noticeable effect of high chlorides is the salty taste and the increased water hardness could lead to difficulties in washing clothes.

Chloride can be determined by titrating the sample with mercuric nitrate.

3.4.4 Electric Conductivity & Total Dissolved Solids

Electric Conductivity (EC) or Total Dissolved Solids (TDS) is a measure of how much total salt (inorganic ions such as sodium, chloride, magnesium, 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 salt water (see Figure 2). 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, clothes washing will be difficult, the water may not quench thirst, and diarrhoea may occur. Conductivity/salinity measurements are also used to find the interface between the less dense fresh water and the denser seawater and to determine the depth of the freshwater lens.

Although the measured levels of Conductivity/Salinity/Total Dissolved Solids are all related to each other and can be inter-converted, some scales are more useful in certain water types (see Table 1). Conductivity or Total Dissolved Solids are the recommended parameters to measure and report for drinking water.

Conductivity/Salinity/Total Dissolved Solids are all most easily measured using a conductivity electrode (e.g. HACH, Orion). Total dissolved Solids can also be measured by weighing the residue following the evaporation of a measured volume of filtered water.

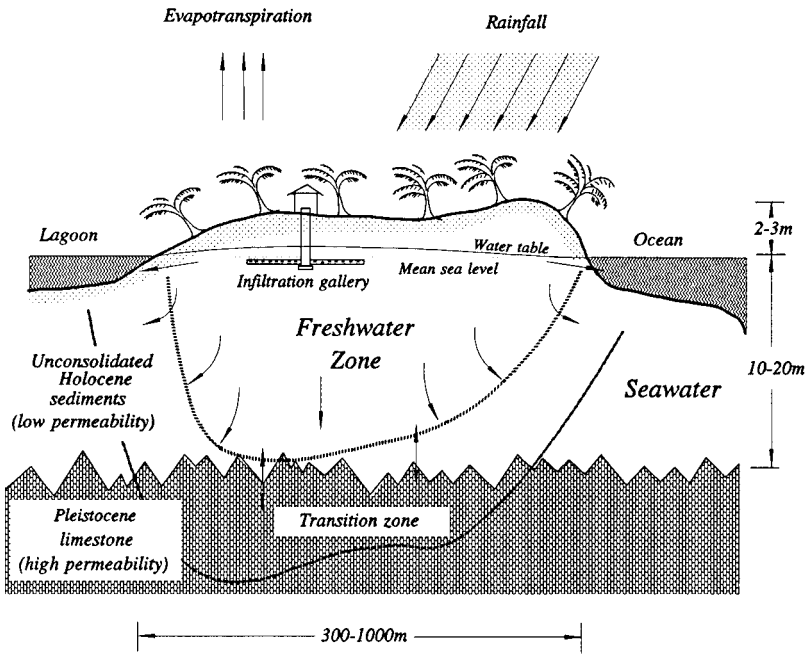


Figure 2: Schematic diagram of an infiltration gallery taking water from a freshwater layer (lens) overlying seawater on an island.

3.4.5 Colour

Colour may be due to dissolved iron, manganese or natural organic substances (humic substances). A colour greater than 15 TCU (true colour units) can be detected by the consumer. The presence of excessive colour increases the amount of disinfectant required. Disinfectants can subsequently produce trihalomethane by-products in the water which may have adverse health effects.

Colour determination is most easily made by comparing the colour of the water with calibrated glass discs. The discs are supplied by various suppliers (e.g. Lovibond).

3.4.6 Fluoride

Fluoride may occur naturally in water or it may be added to water by a water utility or water provider in controlled amounts. High levels are only likely to be found in water supplies from groundwater in active volcanic areas. Fluoride in water can be both good or bad, depending on the levels of concentration. Research has shown that a concentration of about 1mg/L of fluoride in drinking water reduces tooth decay. When drinking water contains excessive flouride above 2mg/L, it causes "endemic dental fluorsis". Sometimes called "Colorado Brown Stain , it appears as a dark brown spotting of the teeth or causes them to become chalky white. Above 4mg/L, it can cause crippling skeletal fluorosis, a serious bone disorder.

Fluoride may be measured using simple testing kits (e.g. HACH) or fluoride sensitive electrodes (e.g. HACH, Orion).

3.4.7 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. For example, dead coral is essentially calcium carbonate ($CaCO_3$) so freshwater flowing through old coral rock (e.g. on a coral atoll) will dissolve calcium and carbonate ions. The amount of ions dissolved depends on the rock type, the time the water is in contact with the rock, and characteristics of the water (e.g. pH). The major ion content is related to the conductivity with the more major ions present, the higher the conductivity.

Moderate amounts of hardness is not undesirable because of the protective coating it produces on exposed metal surfaces. Excessive “hard” water, however, will cause a hard, chalky scale (boiler scale) to form when water is heated. Water heaters are especially affected by hardness. The boiler scale will accumulate on the heating elements, reducing their heating capacity, and eventually causing them to burn out. Vegetables cooked in “hard” water may be tough and more soap is needed for washing activities using “hard” water. Despite all the operational problems it causes, “hard” water is generally not considered to be a health hazard unless the water is so “hard” it tastes salty.

Hardness may be measured using simple testing kits (e.g. HACH) but titrimetric and flame atomic absorption spectroscopy methods are more accurate.

3.4.8 Metals (e.g. Al, As, Cd, Cr, Hg, Pb, Zn)

Heavy metals may be toxic to humans or aquatic organisms depending on their concentration in the water. The waste products of industrial activities such as mining, factory discharges to air and water, and urban runoff can contain significant levels of metals which may enter water sources directly or indirectly (Stumm and Morgan, 1996). Once metals are in a reticulated system, corrosion of metal pipes and tanks can also occur under certain conditions (low pH and hardness) releasing metals (e.g. Cadmium (Cd) and Lead (Pb)) into the water supply (Gray, 1994). Even if no sources of anthropogenic contamination exist there is potential for natural levels of metals to be harmful to human health. This was highlighted recently in Bangladesh where natural levels of Arsenic (As) in groundwater (associated with a particular rock type) were found to be causing harmful effects on the population (e.g. Anawara et al., 2002). Unfortunately, this problem arose because the groundwater was extracted for drinking without a detailed chemical investigation. Certain metals may also be associated with certain industrial activities (e.g. Mercury (Hg) and Arsenic (As) in gold mining).

Great care is needed when sampling and analysing for metals in water, in order not to contaminate the sample with dust or other metallic-containing materials. Acid-washed (e.g. soaked in 10% nitric acid (HNO_3) for a week) sample containers must be used in order to avoid contamination. Special clean laboratory facilities are needed for very low level analyses.

Aluminium
Aluminium (Al) is one of the most common elements in the earths crust, and occurs in a large variety of minerals in almost all geological environments. High concentrations of aluminium are likely to occur in all geological environments where the pH is less than 4 or greater than 10.

Aluminium salts are used extensively in water treatment for removal of colour and turbidity. Some natural waters also contain significant amount of colloidal and dissolved aluminium (ANZECC 1992). The filtered water could contain high levels of aluminium if there is a process failure. Aluminium can cause health problems for kidney dialysis patients.

Copper
Copper (Cu) is both an essential and beneficial element for plant and animal life. It rarely occurs in high levels in water supplies, and therefore it is generally not considered to be a health hazard. The WHO guideline value for copper (2 mg/L) is based on levels which cause taste and laundry staining problems.

Iron & Manganese
Iron (Fe) and Manganese (Mn) are naturally occurring metallic elements that closely resemble each other in the way they react in water. Small amount 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 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.

Zinc
Zinc (Zn) is a naturally occurring element. Although it is commonly found in rocks and minerals, zinc is seldom found naturally in well waters in more than trace amounts. The principal cause of zinc in drinking water is the corrosion of galvanised pipes. At the levels normally found in drinking water, zinc is not a health hazard. At above 3 mg/L zinc could give water an undesirable astringent taste.

Chromium
Chromium (Cr) is a metal found in natural deposits as ores containing other elements. The greatest use of chromium is in metal alloys such as stainless steel; protective coatings on metal; magnetic tapes; and pigments for paints, cement, paper, rubber, composition floor covering and other materials. Its soluble forms are used in wood preservatives.

Short-term effect of chromium is that it causes skin irritation or ulceration when people are exposed to it at level above 0.1ppm for relatively short periods of time. Chromium also has the potential to cause damage to liver, kidney circulatory and nerve tissues and skin irritation from a lifetime exposure at levels above 0.1ppm.

Metals in drinking water are sometimes measured using simple testing kits (e.g. HACH kits for Aluminium, Iron, Manganese, Copper) but these are often not sensitive enough to determine if certain metal concentrations (e.g. Lead and Cadmium) are below WHO guidelines. If this is the case equipment such as flame and graphite furnace atomic absorption spectrometers are needed. However this equipment is relatively expensive to purchase and maintain.

3.4.9 Hydrogen Sulphide

Hydrogen sulphide (H_2S) can be present in underground water and, under anaerobic conditions, in surface waters. The most sensitive effect of sulphides are the “rotten egg” odour and sulphur taste it gives to water. Sulphide may also lead to the growth of sulphur oxidising bacterial slimes that can deposit on piping and fixtures. H_2S odour could be eliminated from water by aeration or chlorination

Hydrogen sulphide may be measured using simple testing kits (e.g. HACH)

3.4.10 Nutrients (e.g. ammonia and nitrate)

There are several different chemical compounds which are termed 'nutrients', most containing one of the elements nitrogen, phosphorous or silica. In water, they provide nutrients for the primary producers (plants) such as phytoplankton, algae and seaweeds. If however nutrients reach high levels in water supplies exposed to light, algal problems may arise which might make water treatment more difficult.

Ammonia (NH_4^+)
Ammonia enters surface waters and ground waters from decomposition of nitrogenous organic matter (e.g. domestic waste) and effluents from industries. Ammonia in the amount present in natural or polluted waters is not physiologically damaging (ANZECC, 1992). However, the presence of ammonia in water supplies may indicate recent sewage pollution and should be addressed as a matter of priority. High ammonia levels could give rise to consumer complaints due to odour and taste problems. Groundwater supplies generally have low ammonia concentrations due to binding/adsorption) by the soil particles.

Nitrate (NO_3^-) *and Nitrite (NO_2^-)*

Nitrate pollution may occur from discharge of human and animal waste, and fertiliser runoff or seepage into groundwater. At very high levels in drinking water, nitrate and nitrite may impact human health, particularly for infants. Infants less than 6 months of age may develop a condition called methemoglobinemia (blue baby syndrome), which causes a bluish color 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.

This problem occurs because human infants have bacteria in their digestive systems that convert nitrate to nitrite, a very toxic substance. When nitrites are absorbed into the blood, they make the hemoglobin (red oxygen-carrying blood pigment) incapable of releasing the oxygen, and the condition known as methemoglobinemia occurs. Consuming water from a source containing 10 or less mg/l nitrate-nitrogen provides assurance that methemoglobinemia should not result from drinking water.

Therefore, the monitoring of nitrate is recommended in many drinking water supplies and in particular those which are located in rural/agricultural areas where the water supply is from a borehole or a well. In these circumstances, regular monitoring is recommended to ensure early warning of increases or when nitrate releases are highly seasonal in nature.

High nitrate levels from agricultural sources may also indicate that there may 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.

Nutrients in drinking water may be quickly and simply measured using kits or test strips (e.g. HACH & Marck). Although these kits are not as sensitive as other methods, they are usually sufficient to determine if nutrient levels exceed WHO guidelines. For lower nutrient levels possibly found in surface waters, a spectrophotometer, chemical reagents and some specialist equipment (e.g. nitrate reducing column) may be necessary.

3.4.11 Pesticides

Pesticides (herbicides, insecticides) are often applied in agricultural areas to control pests or weeds which destroy or damage crops. Some of the pesticides can make their way into surface water and groundwater supplies and can be toxic to human health and aquatic organisms at relatively low concentrations. If pesticide contamination is suspected it is important that a survey is carried out to identify what pesticides are used in the area and to find out application rates and time of application.

Pesticide analysis is difficult and expensive and requires specialist equipment (e.g. gas chromatographs) and extensive training. Routine analysis of pesticides is only performed in a few of the better-equipped Pacific Island Country laboratories. If a pesticide contamination risk has been identified, representative samples of water and food from these areas can, if necessary, be preserved and sent to an external laboratory for analysis.

3.4.12 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 range is from 0 (acidic) to 14 (basic) but most natural water types have pH in the range 5-9. Rainwater typically has a pH around 5.5-6.5 while river water pH is typically higher than this (pH 6-8) but is variable as it is dependent on the type of rock present in the surrounding catchment areas. The pH of 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. If mining operations are present upstream of the sample site, it is recommended that the pH is regularly monitored as acid-mine drainage may affect the health of aquatic organisms. A water with a pH > 8.5 could indicate that the water is hard. 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 alkali 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.

pH in drinking and other freshwaters is best measured using calibrated glass electrodes. However, indicator kits or litmus paper can give a crude estimation of pH (based on colour determination).

3.4.13 Radionuclides

Some radionuclides are naturally occurring at low levels however some have been introduced into the environment through the testing of nuclear weapons. At high exposure levels they can cause serious negative effects on human and ecosystem health. The risk of radionuclides being at harmful levels in drinking water or surface water is generally small for most Pacific Island nations. However, for some, which have been subjected in the past to nuclear testing this, could be a concern.

Radionuclides are measured using instruments that are able to *count* the amount of radioactive particles emitted from a sample. These instruments are expensive and require specialist training to use. If a risk is identified and in-country measurement is not possible it is recommended that samples are sent overseas for analysis.

3.4.14 Turbidity and Suspended Solids

Turbidity and suspended solids measurements indicate how many suspended particles are present in a water sample. These particles may include soil material, such as clay, silt, organic (e.g. plant) material and micro-organisms. In drinking water, high turbidity is a problem for several reasons:

- It protects micro-organisms from chlorine and other disinfectants.
- It acts as a food source for micro-organisms, allowing them to survive and multiply in the water distribution system.
- It interferes with the maintenance of a chlorine residual.
- People think the water is unsafe for drinking if it is not clear.

Filtration, settling or the addition of coagulant chemicals can reduce high levels of turbidity in drinking water.

Turbidity is measured by shining light through the sample and measuring how much light is adsorbed and scattered by the suspended particles rather than transmitted through the sample. The measuring instrument is called a nephelometer and the readings are expressed as nephelometric turbidity units (NTU).

Suspended solids are determined by filtering a measured volume of a water sample through a pre-weighed filter (e.g. 1.2 μm pore size, Whatman GF/C). The filter is then dried and re-weighed to determine the weight of suspended solids per volume of water (typically in mg/L).

4. COASTAL AND SURFACE WATER (NON-DRINKING) QUALITY MONITORING

Monitoring coastal water quality is also very important in the Pacific Islands, particularly for enclosed lagoons and coral reef areas. Poor water quality in some areas has led to degradation of important fishing and tourism resources. Major problems are present with regard to sewage disposal (Naidu et al. 1989; Mosley and Aalbersberg 2003). Water used for primary contact activities, such as swimming, bathing and other direct water contacts should be sufficiently free from faecal contamination, pathogenic organisms and other hazards such as toxic chemicals. Also water used for secondary contact activities such as boating and fishing should be safe to use (ANZECC 1992).

Data on coastal water quality in Pacific Island Countries is very limited which is a concern. A regional water quality survey (Naidu et al. 1989) noted that "*a disappointing feature of this project has been the inability of local government authorities to commit the resources necessary to establish significant on-site monitoring programmes. The value of time-series data cannot be over-emphasised. If local authorities are to take serious action to control the quality of coastal waters then the regular production of data using local recurrent resources is essential so that changes can be detected and action taken before the problems become so severe that either they cannot be resolved or the costs are prohibitive. This is particularly important for the fragile (Pacific Island) coastal environments on which so many people depend for their livelihood and source of food*".

Maintaining freshwater (river and creek) quality is also important to protect aquatic organisms (e.g. fish and shellfish) and the people that eat them. It is also important as rivers are a major source of pollution to the coastal environment. Not clearing vegetation on river banks and mangrove forests will help prevent the amount of sediments and pollutants washing into rivers and reaching the coastal reef environment.

4.1 Selection of sites and frequency of sampling

Samples should be taken from locations which are considered representative of the area or problem you are interested in. Multiple samples are required in most cases. Samples should also be taken at locations not obviously affected by a particular water quality problem. For instance this could be at a similar site upcurrent or some distance away, or perhaps out in the open ocean or channel entrance. The purpose of taking samples at these 'background' locations is that you may be able to prove that levels at the polluted site are elevated above 'natural' levels. If a pipe discharge is present, samples can be taken at intervals on a transect leading from upcurrent to downcurrent from the discharge point. Using this approach the effect of the discharge on water quality should be apparent.

The levels of contaminants at coastal water sites may change with different tide, swell, wind, rainfall and seasonal patterns. Therefore it is important to note these conditions at the time of sampling and try to undertake measurements at different times of the year. Coastal water samples are often collected near the low-tide time as this will be when there is least dilution of any contaminants present. As noted in the 'drinking/fresh water quality section' there are also a number of staff and budgetary requirements to consider. A boat and divers may be necessary which will add to costs.

In areas where toxic chemicals or oil are released in large quantities into the aquatic environment, immediate monitoring should be undertaken and closely linked with an emergencies warning procedure which should function to alert water suppliers, surveillance agencies and health bodies of the problem. Where it is not possible to monitor the chemical in question, in-country representative samples should be taken and preserved for future analysis overseas. Photos should be taken of the contaminated areas for future reference.

4.2 Coastal Water Guidelines

Water quality guidelines are used as a reference to determine whether a potential risk to human health or aquatic ecosystem is present. The Australia and New Zealand Conservation Council provide comprehensive guidelines on water quality (ANZECC 2000) and recreational microbiological water quality guidelines are also available on the internet. Any guideline used must be appropriate for the local situation, especially with regard to protection of coral reef ecosystems. ANZECC (2000) provide some values for coastal water trigger values of various parameters, appropriate for the protection of coral reefs (see Table 3).

Table 3: ANZECC (2000) guidelines for inshore marine waters. Levels above these values may lead to adverse effects on the ecosystem.

Total N mg/L	NH_4 mg/L	NO_3,NO_2 mg/L	Total P mg/L	PO_4 mg/L	PH
<0.1	0.001-0.010[a]	0.002-0.008[a]	<0.015	0.005	8-8.4

a. values typical in clear coral reef dominated areas.

4.3 Surface (river and creek) water quality guidelines

Water quality guidelines that can be used to ensure protection of freshwater aquatic organisms have not been developed specifically for the tropical Pacific islands. However the ANZECC (2000) guidelines may be used to estimate contaminant levels which may be harmful to aquatic organisms.

4.4 Description of coastal and surface water quality parameters

The following parameters are considered some of the most essential to measure for the purpose of assessing coastal and surface water quality in the Pacific.

4.4.1 Suspended Solids, Turbidity and Clarity (Transparency)

Inputs from river, industrial, and sewage may cause high turbidity/suspended solids levels, as will activities (e.g. dredging, removal of mangroves) that cause re-suspension of fine sediments from the sea or river bed. Suspended material in the water reduces water clarity which is the maximum distance at which objects can be viewed and related to level of light penetration in the water body. Reduction in clarity will result in a reduction of photosynthesis and hence primary production, with possible deleterious effect on

phytoplankton, and bottom dwelling plants and animals. High turbidity also makes swimming and diving more dangerous due to the reduced visibility.



Figure 3: Highly turbid creek flowing out through a mangrove area.

Coral reefs close to the shoreline and/or large rivers are very vulnerable to high sediment/turbidity levels. The sediment smothers the tiny coral animals, reducing light levels and eventually killing the coral.

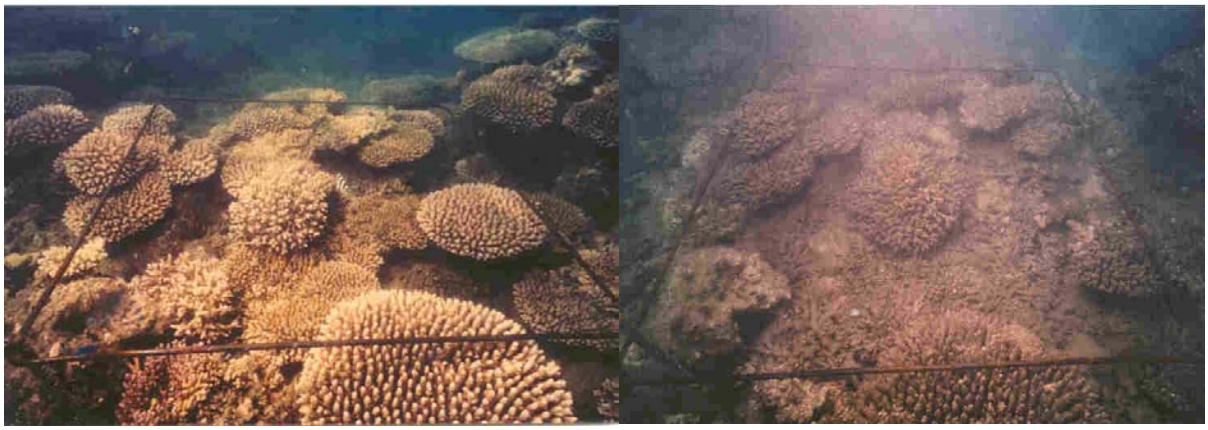


Figure 4: Photos of before (left) and after (right) a sediment discharge has occurred on an area of coral reef. A number of coral species have been killed.

Turbidity and Suspended Solids measurements are performed as detailed in the drinking water section of this report.

Clarity may be estimated using a disk (Secchi) with a 4-6 inch radius that is divided into 4 equal quadrates of alternating black and white colours. It is lowered into water until it can no longer be seen and then lifted back up until it can be seen once again. Averaging the two depths gives the clarity of the water

4.4.2 Salinity/conductivity

In sea/coastal water, a more readily applied measure of the amount of salt in the water is that of salinity which generally ranges from 0.1 (freshwater estuaries) to 35 (open ocean seawater). This scale was originally derived from the fact that open ocean seawater has about 35 g of salt per kg of water. In coastal waters, salinity is often used to trace the mixing of freshwater (including sewage outflows) with seawater. For example, a salinity of 17 would indicate that a sample contained about half freshwater (salinity = 17) and half seawater (salinity = 35). Salinity can also be used to find where a sewage outfall is mixing with the sea and the direction of the effluent plume. However, mixing and dilution of the freshwater may be quite rapid.

In rivers and creeks conductivity or total dissolved solids measurements can be performed as detailed in the drinking water section of this report.

4.4.3 Nutrients (nitrate, phosphate, ammonia)

Nutrients such as nitrate (NO_3^-) and phosphate (PO_4^{-3}) are naturally present in seawater and are essential for growth of phytoplankton and other algae which form the base of the ocean food chain. Nutrient levels in the tropical Pacific Ocean are generally very low, as is productivity. However, coral reefs can maintain high productivity as they are very efficient at recycling nutrients between the coral polyp and the zooxanthellae algae that live in symbiosis with the polyp. Elevated levels of nutrients in coral reef ecosystems have been noted to have several deleterious effects (Goreau and Thacker, 1994; Koop *et al*., 2001). One of the effects noted in several locations is a shift in species dominance from the coral reef building stony (calcified) species to larger non-calcified macro-algae (Goreau and Thacker, 1994; McCook, 1999; Szmant, 2002). The slow growing stony corals, exquisitely adapted for a nutrient deficient environment may be overwhelmed by faster growing macroalgae (e.g. *Sargassum*, *Gracilaria* sp.) which are freed of their nutrient constraints. This can result in mortality and loss of biodiversity of live corals and a loss of settlement sites for coral larvae. The overgrowth of algae may also result in a loss of fish and invertebrate biodiversity as a loss of habitat heterogeneity occurs compared to that presented by the live coral. Overfishing of algal-grazing fishes and invertebrates will also help the establishment of algae on coral reefs (McCook, 1999; Szmant 2002). High levels of phosphorus can also lead to a reduction in structural density of stony corals, causing them to lose their strength and crumble (Kinsey and Davies, 1979).

The major sources of elevated nutrients to coastal waters are typically from human waste and chemicals (e.g. detergents, fertilisers). Research on coral reefs in other locations has found that the levels of nutrients that may be considered healthy for coral reef ecosystems are approximately 1 μmol/L of N as nitrate or ammonia (14 μg/L N) and 0.1 μmol/L of P as orthophosphate and organophosphate (3 μg/L P) (Bell, 1992; Goreau and Thacker, 1994; ANZECC 2000) although there is some debate on this issue as excess nutrients can be taken up by algae and removed from the water (Szmant, 2002). In any case, it is important to note that these levels are much lower than those which would be detrimental to any other aquatic ecosystem (see Table 3). Hence it is extremely important that coral reefs are protected from excess nutrient inputs. Fringing reefs, near to shore, are particularly susceptible to land-based pollution.

At elevated levels in surface water, nutrients may cause algal outbreaks in rivers and lakes. If these algal outbreaks are large, often the algae will eventually die and decompose. The breakdown of this material will reduce the oxygen in the water to a very low level where fish and other organisms will die and foul smelling water will result. This process is termed *eutrophication*.

At the lower nutrient levels typically found in tropical coastal waters, a spectrophotometer, chemical reagents and some specialist equipment (e.g. nitrate reducing column) is likely to be necessary and training required.

At the higher nutrient levels normally found in rivers and creeks, measurements could be performed as detailed in the drinking water section of this report but this would be less accurate.



Figure 5: Photos of algal dominated reefs, an indication of nutrient pollution and overfishing.

4.4.4 Microbiology

Disease causing micro-organisms (pathogens) associated with bathing areas include *salmonellae, shigellae, enteropathogenic Eschorichia Coli, Cysts or Entamoeba histolytica*, *parasite* ova, enteroviruses and infectious hepatitis (ANZECC 1992). Generally the most common types of diseases that have been associated with swimming areas are eye, ear and throat infections, skin diseases and gastrointestinal disorders. Usually the water is tested for faecal coliforms to see the level of bacterial contamination.

Filter-feeding shellfish can bio-accumulate bacteria to dangerous levels as they filter large amounts of water to obtain their food. These should also be periodically tested for faecal coliforms.

Therefore, water used for primary contact activities (swimming, bathing, etc) and for secondary contact activities (boating, fishing, etc) should be safe from bacterial contamination. The ANZECC (1992) guideline recommends that for primary contact activities the water should not have more than 150 faecal coliform/100ml and for secondary contact activities the water should not have more than 1000 faecal coliform/100ml. Similarly the shellfish should not have more than 14 coliform /100ml.

4.4.5 Major ions

It is rarely necessary to measure the major ion content of seawater as essentially it is constant. In rivers and creeks, major ion content could be measured if intrusion of saline water is suspected.

4.4.6 Heavy metals

In seawater, it is difficult to accurately analyse for heavy metals without special clean laboratory facilities and specialist equipment and training. However, since most metals readily associate with sediment material, bottom and suspended sediment concentrations are often measured in contamination studies. Sediment concentrations are usually measured using acid digestions and a flame atomic absorption spectrometer or other suitable instrument. For example, see studies by Morrisson et al. (2001) in Laucala Bay, Fiji Islands and Morrison and Brown (2003) in Fanga'uta in Tonga. Urban runoff can also contribute large amounts of heavy metals to the marine environment but unfortunately the impact and quantity of this source has not been well assessed to date in the Pacific.

4.4.7 Oil and Grease

Oil and grease need not be routinely monitored unless industrial or shipping spills or discharges have occurred. Oil is easily visible as a slick on the water surface under calm conditions. If a large spill occurs, it may harm fish and other wildlife and will be unsightly. Oil spill contingency plans and equipment should be present at all ports and oil tanker destinations.

Reasonably simple methods are available to measure total amounts of oil and grease through solvent extraction. If necessary 'fingerprinting' techniques (determining the chemical compounds in oil) may be used to determine the source of the oil but these require specialist equipment and knowledge and are expensive to get analysed.

4.4.8 pH

It is rarely necessary to measure seawater pH for monitoring purposes as it is relatively constant (pH 8.2). Also accurate measurements with an electrode using freshwater pH buffers are not possible.

The pH of rivers and creeks may be simply measured using a pH electrode, ph paper or pH colour comparators.

4.4.9 Dissolved Oxygen

Dissolved Oxygen (DO) is a direct measure of the oxygen dissolved in a water sample. It is generally not measured in coastal waters for water quality monitoring purposes unless a specific effluent discharge is present which may be depleting oxygen (e.g. sewage

discharge, sugar mill, brewery wastes that are high in organic matter). The DO in surface water should be at or near saturation. The saturation value depends on the salinity and water temperature but is generally in the range of 6-9 mg/L. Any reduction in oxygen reduces the physiological efficiency of fish and non-air breathing invertebrates. It has been found that DO concentrations below 5 mg/L is stressful to many freshwater species and therefore DO below 5 mg/L could be detrimental.

A large decline in dissolved oxygen in a water body could indicate high levels of organic based pollution such as sewage discharge and warrants further investigation such as sampling for micro-organisms and nutrients.

Dissolved oxygen is most easily measured using an automatic dissolved oxygen probe.

4.4.10 Pesticides and Organic Contaminants

Pesticides used on land may be washed into the marine environment with potential toxic effects on aquatic organisms. There have been few studies of pesticides and organic contaminants in the coastal environment of the Pacific (e.g. Harrison et al. 1996; Morrison et al. 1996). A regional survey of persistent pollutants noted that there was a very limited data set (UNEP 2002)[1].

An organochlorine compound, tri-butyl-tin (TBT) was formerly widely used in antifouling paints for ships. Concerns about its toxic effect on non-target aquatic organisms led to its ban in many countries. Previous studies in some Pacific Islands showed concerning levels but as TBT is readily broken down in the environment, any toxic effects should be diminishing.

[1] Report currently at website: http://www.chem.unep.ch/pts/regreports/PacificIslands.pdf

5. SOLID AND LIQUID WASTE MANAGEMENT

Many of the causes of poor water quality in the Pacific Islands can be attributed to poor solid and liquid waste management. This section lists some information and suggestions on how to improve this situation.

Development and enforcement of appropriate environmental legislation is a key need for each country if waste discharges are to be controlled.

5.1 Sewage Disposal and Treatment

Disposal of poorly-treated human sewage waste in the Pacific Islands has resulted in serious human and environmental health problems (e.g. typhoid, diarrhoea, dysentery) from contamination of water supplies and modification of the natural environment (e.g. destruction of coral reefs). For municipal treatment systems, it is noted that extensive treatment is necessary to remove pathogens (to protect water supplies) and also to protect coral reef ecosystems (ie. Removal of suspended solids, nitrogen, phosphorus, and pathogens if water is used for swimming/diving). Advanced sewage treatment systems (e.g. tertiary treatment with nutrient removal and UV disinfection) are relatively expensive and are not widely used in the Pacific Islands (e.g. see Institute of Applied Science/JICA 2004 report for Fiji).

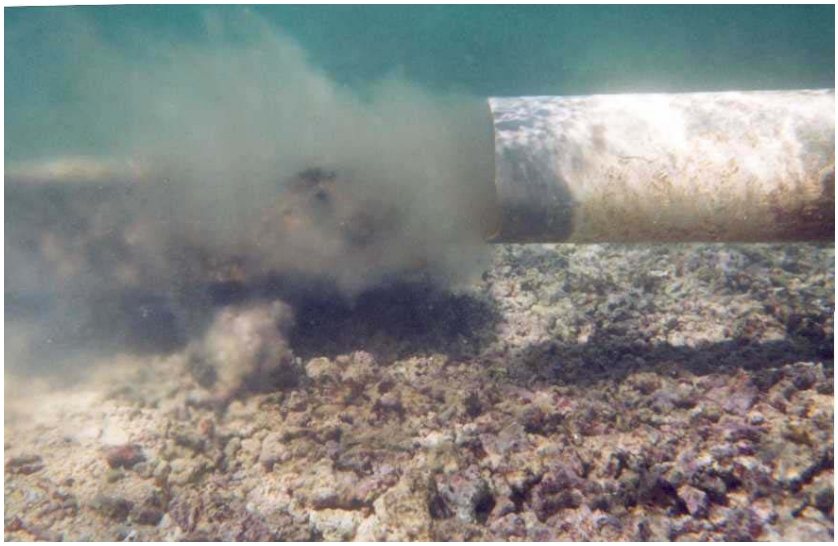


Figure 6: Poorly treated sewage waste discharging on a (now dead) coral reef area.

A useful directory of waste treatment technologies for small island states is provided by UNEP (2002a). Pit latrines are the most basic form of sanitation system and offer very little or no sewage treatment. As the effluent trickles through the soil/sand under the latrine, some removal of organic matter, solids and micro-organisms will occur. However, over time saturation of the soil will occur and any treatment will be negligible. Pit latrines are not recommended, except where population densities are very low. Care should be taken to site latrines away from wells and surface waters (rivers, coastline).

Septic tanks are probably the most common form of sanitation technology in the Pacific but these provide very limited treatment of sewage and contamination of groundwater often occurs when septic tanks fail because of poor maintenance (Dillon 1997). When septic tanks become full of sludge, the treatment time in the tank is reduced, the sewage can backflow if the perforated pipe becomes clogged, and continuous (rather than intermittent) seepage of effluent occurs. Septic tanks and pit latrines need to have sludge removed at intervals of between 2-10 years (depending on amount of usage). The sludge must also be disposed of properly and this should not be done in proximity to any water supply well. Sludge can be dried and incorporated with compost and spread (in thin amounts) over garden soils or under forests.



Figure 7: Septic tank poorly sited on a tidal creek.

“Waterless Toilets”, “Dry Sanitation” and “Organic Toilets” are all terms which refer to what is commonly known as Composting Toilets. These systems do not use water to treat or transport human excreta and if appropriately designed conserves precious water resources and avoids disposal of effluent and pollutants into waterways and the general environment. Composting Toilets produce a soil improver that is hygienic to use if the required time and conditions occur (UNEP 2002a). It is however important to include an active awareness campaign of composting toilets to complement the implementation of the system.

The Sanitation Park Project for which the project partners are Fiji School of Medicine, Ministry of Health Fiji, World Health Organisation and SOPAC, have developed a Demonstration Park of various wastewater treatment systems to be used as an education and awareness raising tool and can be visited for a better understanding of how the systems operate, costs of construction and other pieces of information.

For households and small resorts, composting toilets may be the best sanitation system in terms of protecting the environment, but public education must be performed to enable them to be more widely accepted.

5.2 Industrial effluent

Industrial effluents may contain contaminants of concern, such as organic material, heavy metals, oil, paints, solvents and suspended matter. Companies should be required to monitor their effluent regularly and to undertake best management practises as to its disposal. Unfortunately the general lack of willpower, finances, environmental legislation and enforcement in the Pacific Islands has meant that many industries have not developed effective waste treatment and disposal technologies.

5.3 Plastics, litter, solid waste

A serious problem in many Pacific Islands with limited land areas is the disposal of non-biodegradable items (plastics, rubber, metal). This is a complex problem, related to the industrialisation of many countries resulting in the increased use, import and manufacture of these items.



Figure 8: Litter poorly disposed off or washed up on a beach.

Some practical options to reduce waste are described in Table 4. Public education activities are also very important in order to ensure correct disposal of plastic and other solid wastes.

Table 4: Practical options to reduce solid waste.

Solid Waste Type	Options
Plastic	Recycle and/or shred for use in low-grade plastic materials Deposits for drink and other containers to encourage return of items and cover recycling costs Discourage use where possible Levy imports to recover recycling costs
Glass	Collect and recycle Deposits for drink and other containers to encourage return of items and cover recycling costs Crush and use for construction sand
Vegetation, organic material	Compost
Paper	Recycle
Batteries	Remove and recycle lead
Tyres	Shred and use as fuel source
Oil	Recycle, use as fuel source
Metals (e.g. cars, refrigerators)	Crush and recycle scrap metal Levy imports to recover recycling costs

The South Pacific Regional Environment Programme (SPREP) has further information related to solid waste[2].



Figure 9: Collection for recycling.

[2] Website: www.sprep.org.ws

6. GENERAL SAMPLING, ANALYSIS AND LABORATORY NOTES

6.1 Sampling Methods

Sampling is a vital part of studying the quality of water. A major source of error in the whole process of obtaining water quality information often occurs during sampling. Poor management decisions based upon incorrect data may result if sampling is performed in a careless and thoughtless manner. Obtaining good results will depend on a great extent upon the following factors:

1. Ensuring that the sample taken is truly representative of the water under consideration.
2. Using proper sampling technique (eg use of acid washed bottles for heavy metal testing, sterilised bottles for microbiological testing).
3. Protecting and preserving the samples until they are analysed.



Figure 10: Tap is left open to flush the system before collecting sample.

The sample bottle should be labelled with an identifying number or code. At the time of sampling this should be written down along with other information such as the date, time, location, and weather. For coastal water samples it is advantageous to take GPS measurements that can be plotted on a map or used to return to the same site in the future. Also for coastal water samples it is important to note the time and heights of the high and low tides and sea information.

6.2 Sampling from a tap

A. *Samples for Chemical and Physical Analytes*

1. Remove any attachments e.g. hoses, cloths etc from the tap.
2. Carefully clean the mouth of the tap with a clean cloth or tissue to remove any dirt or grease.
3. Open the tap and leave running for at least one minute or long enough to flush the system before taking a sample. *Note:* Take sample as close as possible to the

source of the supply or to the main reticulated pipe. This lessens the influence of the distribution system on the sample.

4. Rinse the sampling bottles at least three times with the tap water to be sampled and then fill sample container slowly with a gentle stream to avoid turbulence and air bubbles.

B. *Collecting samples for bacteriological testing*

Make bacteriological examinations on samples collected at representative points throughout the distribution system. Select the frequency of sampling (see section4.1*)* and the location of sampling points to ensure accurate determination of bacteriological quality of the treated water supply, which may be controlled in part by the known quality of the untreated water and thus by the need for treatment (APHA, 1998). Only properly sterilised bottles should be used for collecting samples. Bottles could be sterilised by cleaning them properly with detergent and then rinsing with distilled water followed by autoclaving at 121^{o}C for 15 minutes. Pressure Cooker could be used for bottle sterilisation if autoclave is not available. Keep sampling bottles closed until it is to be filled.

1. Remove any attachments e.g. hoses, cloths etc from the tap.
2. Carefully clean the mouth of the tap with a clean cloth or tissue to remove any dirt or grease. *Tap nozzles are often flamed to remove bacteria before sample collection so just the drinking water supply itself is tested. A conventional cigarette lighter may be used for this purpose for about 30 seconds.*
3. Open the tap and leave running for at least one minute or long enough to flush the system before taking a sample
4. Wash your hands thoroughly. Remove cap from the sampling bottle and fill container without rinsing, replace cap immediately. Note: (a) when sample is collected, leave ample air space in the bottle (at least 2.5cm) to facilitate mixing by shaking, before examination. (b) sodium thiosulphate is added to sample bottles for testing bacteria on chlorinated supplies, this neutralises the chlorine so bacteria levels reflect the time of sampling

6.3 Sampling from a lake, river, ocean and other surface waters

In all cases, it is vital to obtain a sample which is representative of the main body of water. For example, when sampling from a river do not sample the quiet or stagnant areas near the bank as these do not represent the main body of water. It is also vital not to introduce external contamination into the sample

Where there is easy and safe access it may be possible to take samples by hand dipping of the sample bottle.

1. Grasp the sample bottle firmly and dip the open mouth of the cup into the water. (In areas where there is a current flow (i.e. rivers) the sample should be taken against the current flow).
2. Submerge the bottle to a depth of about 10cm below the surface and scoop up the water sample.
3. Cap the bottle.

6.4 Sampling from a well or borehole

1. The sample bottle should be attached to a cable or placed in a sampling device and lowered into the well. Care should be taken not to allow the bottle to touch the walls.
2. Submerge the cup to a depth of about 30 cm. If pump is used to draw water from the well, let the pump run long enough to draw fresh groundwater into the system and collect the sample from the tap near the well.
3. Lift the sample cup carefully and close the cap.

6.5 Filtration, preservation and storage of samples

It is extremely important that samples are appropriately treated and stored following sampling. Different chemical parameters have different requirements for preservation (Table 5).

For *microbiological analysis* it is particularly important that samples are analysed immediately or stored in ice/refrigeration until analysis to stop the organisms multiplying during transport. Even with refrigeration, analysis should be performed within 6 hours and certainly no longer than 24 hours. The subsequent examination then will indicate more accurately the true microbial content of the water at the time of sampling.

Some parameters such as *pH, temperature, chlorine residual, dissolved oxygen and turbidity* should be measured on site or as soon as possible to avoid possible changes in their levels during transport.

For *nutrients*, if a delay between sampling and analysis is inevitable it is best to filter the samples in the field and place samples on ice/refrigeration. The nutrient levels may decrease if this is not performed, as any plankton and micro-organisms present may continue to use them. This is especially important in coastal water samples where nutrient levels are low so large changes may occur in a short space of time. A simple filtration device consisting of a 50-100 mL plastic syringe, and a plastic filter holder (e.g. Swinnex type from Gelman Sciences) to fit a 47 mm glass fibre filter (1.2 µm pore size, GF/C) is satisfactory.



Figure 11: Filtering seawater samples to be tested for nutrients.

Table 5. Sampling and Preservation of samples according to measurement parameter (Source: APHA 1998).

Measurement	Vol. Req. (ml)	Container (note 1)	Preservative	Holding Time
Physical				
Color	50	P,G	Cool, 4 deg. C	48 Hrs.
Conductance	100	P,G	Cool, 4 deg. C	28 Days
Hardness	100	P,G	HNO3 - pH below 2	6 Mos.
pH	25	P,G	None Req.	Analyze Immediately
Temperature	1000	P,G	None Req.	Analyze Immediately
Turbidity	100	P,G	Cool, 4 deg. C	48 Hrs.
Metals				
Dissolved	200	P,G	Filter on site, HNO3 - pH below 2	6 Mos.
Suspended	200		Filter on site	6 Mos.
Total	100	P,G	HNO3 - pH below 2	6 Mos.
Chromium	200	P,G	Cool, 4 deg. C	24 Hrs.
Mercury				
Dissolved	100	P,G	Filter, HNO3 - pH below 2	28 Days
Total	100	P,G	HNO3 - pH below 2	28 Days
Inorganics, Non-Metallics				
Acidity	100	P,G	Cool, 4 deg. C	14 Days
Alkalinity	100	P,G	Cool, 4 deg. C	14 Days
Chloride	50	P,G	None Req.	28 Days
Chlorine	200	P,G	None Req.	Analyze Immediately
Cyanides	500	P,G	Cool, 4 deg. C, NaOH - pH over 12 0.6g ascorbic acid	14 Days
Fluoride	300	P,G	None Req.	28 Days
Nitrogen				
Ammonia	400	P,G	Cool, 4 deg. C, H2SO4 - pH below 2	28 Days
Kjeldahl, Total	500	P,G	Cool, 4 deg. C, H2SO4 - pH below 2	28 Days
Nitrate + Nitrite	100	P,G	Cool, 4 deg. C, H2SO4 - pH below 2	28 Days
Nitrate	100	P,G	Cool, 4 deg. C,	48 Hrs.
Nitrite	50	P,G	Cool, 4 deg. C,	48 Hrs.
Dissolved Oxygen				
Probe	300	G bottle + top	None Req.	Analyze Immediately
Winkler	300	G bottle + top	Fix on site and store	8 Hours
Phosphorus				
Ortho-P, dissolved	50	P,G	Filter on site, Cool, 4 deg. C	48 Hrs.
Total	50	P,G	Cool, 4 deg. C, H2SO4 - pH below 2	28 Days
Total, dissolved	50	P,G	Filter on site, Cool, 4 deg. C, H2SO4 - pH below 2	24 Hrs.
Silica	50	P only	Cool, 4 deg. C	28 Days
Sulfate	50	P,G	Cool, 4 deg. C	28 Days
Sulfide	500	P,G	Cool, 4 deg. C, add 2 ml zinc acetate plus NaOH - pH over 9	7 Days
Organics				
BOD	1000	P,G	Cool, 4 deg. C	48 Hrs.
COD	50	P,G	Cool, 4 deg. C, H2SO4 - pH below 2	28 Days
Oil & Grease	1000	G only	Cool, 4 deg. C, H2SO4 - pH below 2	28 Days
MBAS	250	P,G	Cool, 4 deg. C	48 Hrs.

1.Plastic (P) or Glass (G). For metals, polyethylene with a polypropylene cap (no liner) is preferred.

7. ANALYSIS METHODS AND METHOD DOCUMENTATION

Simple standard operating procedures (SOPs) should be written for each parameter being analysed outlining the analysis and instrument procedures step by step. A copy of each SOP should be laminated and placed in the laboratory. The APHA "Standard Methods for the Examination of Water and Wastewater" provides several accepted methods which can be used to develop a SOP for a particular laboratory.

7.1 Method Detection Limits and Quality Control Procedures

Method detection limits (MDLs) should be determined for each analytical method. The MDL can be determined by preparing a low-level standard or spiked sample near to where you think the MDL is. Analyse seven portions of this solution, calculate the standard deviation of the results, and multiply by 3.14:

MDL Calculation (for 7 analyses) = Standard Deviation x 3.14

The calculated MDL should be no more than 5 times less than the mean of the analytical results. Otherwise a lower standard should be prepared and the process repeated until a suitable result is obtained.

A system of quality control (QC) procedures is critical to maintain and improve the accuracy, precision and reliability of the data produced in water quality analysis. QC schemes should be implemented in each laboratory to ensure that appropriate sampling and analysis procedures are followed, laboratory and field equipment is regularly checked and calibrated, and staff adequately trained and supervised.

During the chemical analysis of samples, the accuracy, precision, and reliability of analytical results should be monitored:

- **Accuracy** is getting the right result. Regular calibration and checking of instruments against known standards is essential. For example, at the start of conductivity analysis the meter should be checked against a known standard and re-calibrated if necessary. Accuracy can also be assessed by regularly analysing appropriate certified reference materials which are available from several organisations (e.g. NIST and NRCC). In addition, a laboratory can participate in 'blind' analysis schemes (e.g. FAPAS) where a central laboratory provides samples to participating laboratories in which the concentration of chemical constituents is not known by the participating laboratories. The correct results are then collated and the performance of the laboratory assessed against the other participating laboratories.
- **Precision** is getting the same result in repeat analyses. Analysing the same sample several times can be used to assess precision. The individual values obtained should generally be within 10% of the mean value.
- **Reliability** is repeatability getting the right result. Reliability can be assessed by how well a laboratory can consistently produce accurate and precise results.

Good laboratory practices and regular maintenance and checking of equipment are essential to getting accurate, precise and reliable results.

7.2 Methods Used for Expressing Concentrations of Solutions

Since quantitative analysis requires measured quantities of chemical reagents of known strength, the methods used for preparing and using reagents should be understood. Solids and liquids of known degrees of purity may generally be purchased from suppliers. When an aqueous solution of a solid is required as a reagent, its strength must be accurately determined by means of chemical analysis. There are several methods of expressing concentration of a solution.

Several units are used in the water quality literature and may be somewhat confusing:

Typical units used in water are:

μ (micro) = 10^{-6} = 0.000001
m (milli) = 10^{-3} = 0.001

L = dm^3 = kg (in freshwater)
mL = cm^3 = g (in freshwater)

The following units are commonly used for freshwater:

mg/L = mg/dm^3 = mg/kg = ppm (parts per million)
μg/L = $\mu g/dm^3$ = μg/kg = ppb (parts per billion)
moles/L = M

Generally, it is considered best to express the concentration of something in water on a weight per volume basis (e.g. mg/L, μg/L). Molarity (M) and molality (N) are also used sometimes in methods for solution concentrations and in reporting results.

To calculate the amount of a compound needed to produce a certain concentration in moles (M):

First you need to find the atomic/molecular weight of the compound you are using to prepare the solution. To do this go to a periodic table or look at Tables of Atomic Weight (e.g. in front of APHA standard methods book) and look up the atomic weight for individual elements in your compound (e.g. for NaOH: Na = 23, O = 16, H=1). If more than one atom is present in the element formula multiply the atomic weight of that element by the number present in the compound (e.g. for Na_2CO_3 we would multiply the atomic weight of Na by 2 and the atomic weight of O by 3). Sum to find the total atomic weight of the compound (e.g. NaOH = 40, Na_2CO_3 = 106). Weigh the amount of the compound required to produce the concentration required.

For example, to prepare a 1M NaOH solution, weigh out 40 g NaOH and add water to a total volume of 1L. To prepare a 0.25 M NaOH solution, weigh out 10 g and dilute to 1 L. Depending on the amount of solution required smaller volumes may be prepared, e.g. For a 1M NaOH solution you could dilute 4 g to 100 mL instead of 40 g to 1 L.

Preparing acid solutions to a concentration expressed in *M* and *N* is slightly different. Table 6 gives preparation of diluted acid solutions expressed in N and more information could be found inside the front cover of the APHA standard methods book.

Table 6: Preparation of Acid solutions from Concentrated Reagent

Desired Component	HCl	H_2SO_4	HNO_3
Specific gravity (20/4^{0}C) of ACS grade concentrated acid	1.174-1.189	1.834-1.836	1.409-1.418
% of active ingredient in concentrated reagent	36-37	96-98	69-70
Normality of concentrated reagent	11-12	36	15-16
Vol (ml) of concentrated reagent to prepare 1 L of:			
18N solution			
6N solution	-	500(1+1)	-
1 N solution	500(1+1)[1]	167(1+1)	380
0.1N solution	83(1+11)	28	64
	8.3	2.8	6.4

Converting from other units to molar (M) units

To convert to molar concentrations from more commonly used concentrations (e.g. mg/L, µg/L) is relatively straightforward. Just divide by the molar mass of the element or compound in question.

For example a nitrogen concentration in form of nitrate (NO_3-N) of 14 µg/L can be converted to molar units by dividing by the molar mass of nitrogen (14) giving a result of 1 µM.

7.3 Reporting of Results

Results should be reported in the correct units and values less than the detection limit should be reported as <detection limit or if this has been determined properly a value can be specified (e.g. <1 µg/L)

7.4 Dilution of Solutions

It is often necessary to perform dilutions of samples that are too concentrated for a particular method and also when preparing standard solutions. Dilutions are performed using high purity water that is demonstrated to be undetectable for the parameter you are measuring (e.g. bacteria, copper). Sample concentrations are then corrected for the dilution.

For example: to do a 10 times dilution of a sample or standard:

Pipette 10 mL of the sample/standard into a 100 mL volumetric flask. Add pure water to make up to the 100 mL mark.

The dilution factor (DF) is calculated by dividing the total diluted solution volume by the volume taken of your undiluted solution.

For the above example, DF = 100 mL/10 mL = 10

[1] the *a*+*b* system means *a* volume of the concentrated reagent and *b* volume of distilled water to form the required solution

The concentration measured in your diluted sample is then multiplied by the dilution factor to give the actual sample concentration.

For the above example, say we found 20 colonies of bacteria in the 100 mL of the diluted sample, we would multiply this by the DF of 10 to get a reported level of bacteria of 200 colonies per 100 mL of sample.

7.5 Safety in the Laboratory

- Safety of personnel in the laboratory should be made a priority.
- Eye-glasses should be worn at all times, and are essential when using dangerous chemicals such as acids.
- Gloves should be used when handling hazardous chemicals or samples.
- An exhaust fume cupboard should be used for chemicals such as acids which give off poisonous fumes.
- Never add water to a concentrated acid solution. Acid can be added to water slowly.
- A safety shower and preferably also an eye wash station should be present in the laboratory. If chemicals are spilled on eyes, skin or clothing, immediately wash with large quantities of water.
- A microbiological safety cabinet should be used during processing of water samples for bacteria content. Face masks could also be worn to protect the lab personnel from breathing in potentially harmful bacteria.
- A fire extinguisher should be present in the laboratory.
- A first aid kit should be present in the laboratory.
- MSDS (Material Safety Data Sheet) should be available for all chemicals used by the laboratory.

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