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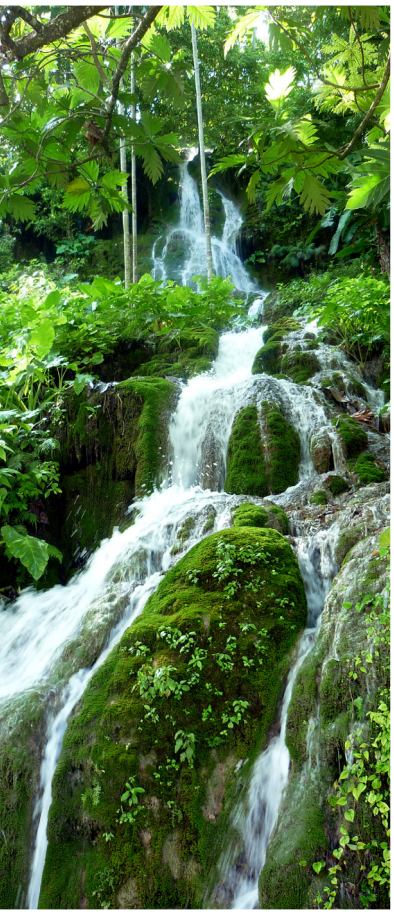


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National groundwater monitoring guide for Timor-Leste

Vulnerability assessment of climate change impacts on groundwater resources in Timor-Leste

Baskaran Sundaram, Luke Wallace and Lindsay Furness

Prepared for the Australian Government Department of Climate Change and Energy Efficiency **July 2012**

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PREPARED FOR THE AUSTRALIAN GOVERNMENT DEPARTMENT OF CLIMATE CHANGE AND ENERGY EFFICIENCY

BY GEOSCIENCE AUSTRALIA

June 2012

by

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Contents

Understanding Groundwater

WHAT IS GROUNDWATER?

Groundwater is water stored beneath the ground in gaps and cracks in the rocks. These gaps and cracks that occur in the rocks are referred to as pores and fractures. Groundwater is a vast resource which greatly exceeds the amount of water in rivers and lakes, both around the world and in Timor-Leste. The rocks in which groundwater is stored and flows through are called aquifers. These aquifers typically consist of gravel, sand, limestone or fractured rocks.

GROUNDWATER IN TIMOR-LESTE

Groundwater is likely to be found beneath most land in Timor-Leste, however, the groundwater resources will be unevenly distributed and will vary in quality and quantity. In Timor-Leste groundwater occur in three principal aquifer types: sedimentary intergranular aquifers; fissured aquifers of karst formations within limestone rocks; and rocks with localised flow comprised of fractured rocks and clay sediments.

GROUNDWATER AS A RESOURCE

The people of Timor-Leste rely on groundwater during the dry season when most surface water dries up. In Timor-Leste, groundwater is used as a source of drinking water for urban and rural communities, as well as for industrial and agricultural activities. Rural villages may have one or two groundwater wells which service the entire community, while others get their water solely from natural groundwater springs. Groundwater is also an important part of natural ecosystems, flowing into wetlands, rivers and lakes.

GROUNDWATER EXTRACTION EFFECTS ON WATER AVAILABILITY AND QUALITY

Groundwater is increasingly being seen as an alternative source to surface water supplies in recent years in Timor-Leste due to prolonged drought periods. However, when groundwater extraction exceeds the average long-term recharge rates from rainfall, groundwater levels will steadily decline and impact on aquifer yields and quality. For example:

- Lower yields mean less water is available for domestic water supply, stock drinking water, irrigation and other uses;
- Springs, streams and rivers that are fed by groundwater may partially or completely dry up, causing adverse ecological effects;
- A reduction in river flows may be insufficient for dilution of discharged wastewater, resulting in greater surface water pollution;
- An increased threat of saltwater intrusion into fresh groundwater supplies in coastal regions; and
- Deterioration of groundwater quality.

GROUNDWATER RECHARGE

Ground water recharge is the infiltration of surface water or rainwater into an aquifer. The great majority of aquifers in Timor-Leste are generally recharged by direct infiltration of rainwater or by leakage from rivers and lakes. This type of recharge is generally widespread where permeable rocks are exposed, but in karst areas, the recharge is mostly through karst features and is localised. An accurate estimation of recharge remains one of the biggest challenges for groundwater managers.

GROUNDWATER MOVEMENT

Aquifers are not only a storage pool for groundwater in Timor-Leste, but also act as a pathway for water movement underground. Groundwater moves from an aquifer's recharge areas until it reaches a discharge zone, an area where the water table intersects the land surface.

In general, groundwater moves very slowly and only if sufficient pressure is available to force it through the spaces within the porous aquifer materials. Groundwater moves from high to low water levels - the direction of the flow normally follows the topography of the land surface. High flow rates in aquifers are in the order of metres per day and are dependent on the type of aquifer material, but can be as low as meters per year. It may take years, decades or even centuries for water to flow through some aquifers. However in sedimentary aquifers comprising very porous materials (coarse gravel) or fractured rock with large openings (fractured basalt) flow rates are relatively high. In some cases water may reside underground only a few days or weeks before reaching the discharge zone. Groundwater can naturally discharge into streams, springs, wetlands or oceans.

GROUNDWATER CONTAMINATION

Contamination of groundwater may be associated with specific point sources or may occur over a wide area (non-point source). The sources of groundwater contamination in Timor-Leste are numerous and diverse, including improper: disposal of wastes; use and storage of chemicals; installation and maintenance of septic tanks; positioning of landfills; wastewater or urban runoff; and located storage waterways and lagoons used by industry. Contaminants can be extremely hard to remediate, with pollution often resulting in permanent damage to the aquifer. It is better to prevent groundwater contamination than subsequently spend significant resources to clean it up.

Groundwater Bore Drilling

The simplest way to access groundwater is to dig a well. Wells can be dug manually to reach the shallow water table. However, if an aquifer is deeper than a few metres, a borehole needs to be drilled. Choosing a site for bore construction requires local hydrogeological knowledge, a skilled driller and specialised equipment. All groundwater bores should be drilled, cased and equipped properly. Some of the drilling methods described in this section have been adapted from Sundaram et al. (2009).

DRILLING METHODS

Drilling methods are many and varied, ranging from digging with hand tools to high speed drilling with sophisticated equipment. Contamination of the borehole and its surrounds needs to be avoided during drilling and construction of the bore. Water contaminants such as lubricants, oil, grease, solvents, coatings and corrodible materials may affect the suitability of the bore for groundwater monitoring, especially when monitoring for contaminants.

There are many methods used to drill monitoring bores. When drilling a monitoring bore, a lithological log (and preferably a stratigraphic interpretation) should be made by an experienced person able to identify the important features. The most commonly used drilling methods are briefly described below.

Auger drilling

Auger drilling works on the simple mechanical clearing of a hole as it is drilled. Auger drilling eliminates the need for a drilling fluid (liquid or air) and hence reduces the potential influences from an introduced fluid. However, auger drilling has a high potential for smearing material such as clay or contaminants along the hole, thus affecting groundwater flow paths or increasing contaminant concentrations.

Auger drilling is generally used in soils and soft rock for relatively shallow bores. It is possible to insert the casing into the centre of a hollow flight auger before it is removed from the hole. This does require a large diameter borehole, but can be particularly useful in sandy ground.

Rotary air drilling

Rotary air drilling uses a rotating drill bit combined with circulating air that clears the drill cuttings, blowing them to the surface. The major advantage of rotary air drilling is that groundwater-bearing formations tend to be easily identified when encountered. The disadvantage of rotary air drilling is the potential for oxidation, volatilisation and precipitation of substances of interest. The introduction of high pressure air may also disturb flow paths and hydrochemical profiles in some aquifers.

Rotary mud drilling

Rotary mud drilling works on the same principle as rotary air drilling except that liquid is used as a circulation medium. Mud additives are used to support an open hole and prevent cave-in in soft and unconsolidated formations. The use of liquid may influence the formation, and hence groundwater samples, in the following ways:

- drilling fluids may enter the aquifer and mix with groundwater;
- clay particles or other chemical products in the drilling mud may physically or chemically alter the groundwater properties;
- mud may restrict or block groundwater flow paths; and
- Care should be taken to properly develop the hole post-drilling to ensure mud has been flushed from the screened interval.

Cable tool drilling

Cable tool drilling involves lifting and dropping a string of drilling rods with a bit at the base that cuts the hole with each blow. The cuttings are retrieved by removing the drilling rods and collected using a bailer. Cable tool drilling is slow and can compact aquifer material around the hole.

Direct push technology

Direct push (DP) technologies are an alternative method to conventional drilling techniques for sampling groundwater and installing monitoring bores in unconsolidated materials such as clay, silt, sand, and gravel. They are appropriate for sampling in the saturated zone and to depths of around 20 m. Typically, a truck mounted mechanical hammer or hydraulic rig is used to push a string of steel hollow rods or a drive casing to the desired depth with a sacrificial tip. The rod assembly is disengaged from the tip and the sampling screen exposed. By directly pushing the sampler, the soil is displaced and helps to form an annular seal above the sampling zone. Direct push technologies are generally faster to install and more economical for high density sampling. They produce little or no cuttings during installation. DP installed groundwater bores are not appropriate for high volume sampling, are not recommended when telescoped bores are required to prevent migration of contaminants below confining layers, and may not penetrate hard bands, bedrock and some unconfined layers.

Sonic drilling

Sonic drilling is a relatively new technique, where a high frequency vibration is combined with rotation to advance the drill stem. The core barrel is retrieved and the sample vibrated into a plastic sleeve or core trays. The advantage of this technique is relatively continuous and undisturbed geological samples, without the use of drilling fluids or other potential contaminants.

Vibro coring

Vibro coring is used whenever soil conditions are unsuited to gravity corers or where greater penetration of the seabed is necessary. Standard size vibro coring equipment will produce 86 mm diameter core samples to a maximum depth of 6 m. In coarse aggregates larger diameters up to 150 mm can be obtained. This method is used widely throughout the geotechnical investigation industry and can be deployed in water depths up to 1000 m.

BORE CONSTRUCTION

Groundwater bores need to be constructed to a high standard to ensure ongoing and reliable data is obtained over the life of the bore. When constructing a bore (see Figure 1), the casing material will be determined by the required bore depth and monitoring requirements, including the type of contaminants to be monitored. The following materials should be considered, based on what is to be monitored:

- PVC, stainless steel and fibreglass are suitable for monitoring most organic substances.
- PVC or fibreglass is suitable for monitoring most inorganic substances, particularly in corrosive waters.

The bore casing for a monitoring bore should have mechanical joints to avoid contamination by solvents such as PVC solvent cleaner and cement. Organic-based lubricants (such as hydrocarbons) should not be used on casing joints, drilling rods or equipment if sampling for organics is required.

A gravel pack may be used to avoid siltation when fine-grained aquifers are encountered. The bore annulus should be carefully and evenly filled to a level approximately one metre above the screened interval with a graded gravel pack. Screen and gravel pack intervals should not be installed across different geological units or water-bearing zones.

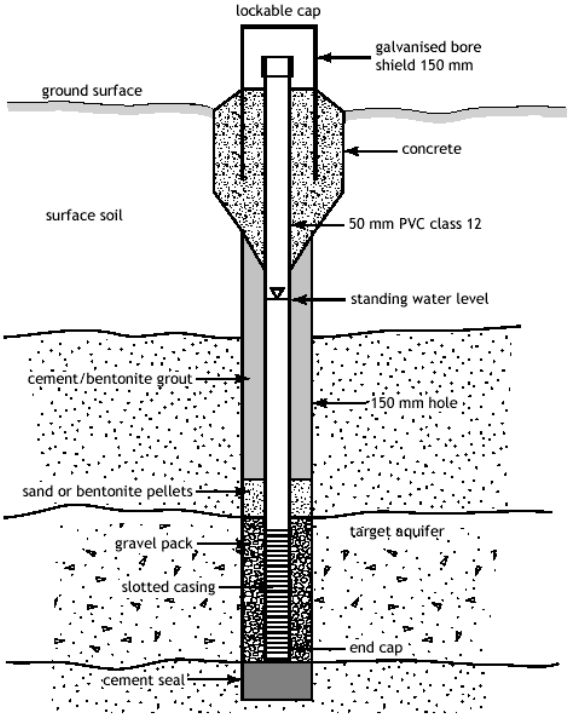

Figure 1: *A typical water monitoring bore (adapted from ARMCANZ, 2003)*

A cement or bentonite seal at least one metre thick should be placed on top of the graded gravel pack to prevent water movement from the surface or between aquifers. A bentonite seal may be constructed using pellets inserted slowly down the annulus.

Bores **must** be constructed to avoid cross-contamination of aquifers. Particular care needs to be taken when positioning the screen as it can provide a pathway between aquifers. All bores should be capped with a lockable cap to prevent ingress of surface water, dust or other foreign matter and to avoid tampering.

The bore should be clearly labelled with the bore name or ID number.
Additional information on bore construction requirements and standards can be obtained from the document *Minimum construction requirements for water bores in Australia* (ARMCANZ, 2003).

SHALLOW PIEZOMETER INSTALLATION

Equipment

The equipment you will need to install a piezometer (Figure 2) includes:

- auger (extendable to 5 m) with a 100 mm tip
- bucket of gravel or sand, with the typical grainsize dependent on the aquifer lithology
- bentonite pellets (pre-soaked)
- premixed concrete
- a capped galvanised or clay pipe (large enough to case the piezometer above the ground)
- extra PVC pipe and extension joint
- hacksaw

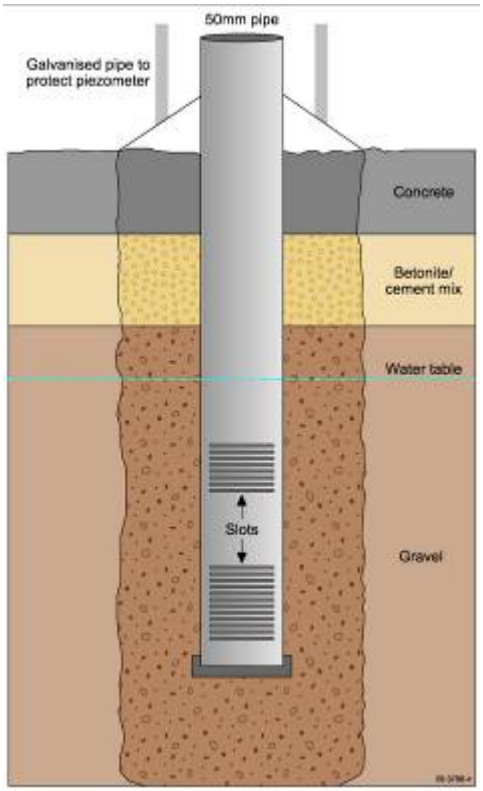

Figure 2: *Cross section of a piezometer*

Procedure

1. Use the auger to dig a hole to the length of the prepared piezometer. The depth should be at least equal to, but preferably greater than, the depth to the water table.
2. Put a small amount of gravel pack at the bottom of the hole. Place the piezometer in the centre of the hole, ensuring that it extends at least 100 mm above the ground.
3. Fill around the pipe with the remaining gravel pack, to within 400 mm of the surface.
4. Fill the next 300 mm with a concrete/bentonite slurry, and the remainder with a concrete mix. Slope the concrete so surface water flows away, reducing the likelihood of contamination of the piezometer with surface water.
5. Place a larger diameter casing (typically PVC or galvanised iron) over the top of the piezometer to reduce the likelihood of damage.
6. Quite often when drilling or augering holes, particularly in clay formations, the bore wall can become smeared. To ensure the through-flow of groundwater it is recommended that the fully constructed bore is pumped or bailed for a period immediately after construction and before it is used for monitoring. This will remove debris and fine material from the annulus.

Groundwater Monitoring

WHAT IS GROUNDWATER MONITORING?

Groundwater monitoring is a means of gathering information about the condition of the aquifer. Groundwater monitoring provides information about groundwater availability and quality and it is an integral part of water management. Ideally groundwater level and quality monitoring should be carried out regularly in all areas where groundwater resources are extracted for variety of uses.

GROUNDWATER MONITORING - OBJECTIVES

The main objectives of groundwater monitoring include:

- establishing the baseline quality of groundwater occurring naturally in aquifers and assessing the impact of human activities on groundwater quality
- documenting any change in groundwater storage over time
- assessing and predicting the response of hydrologic systems to natural climatic variations and over pumping

Existing bores in a study area largely define the potential sites for groundwater sampling, however natural features (such as springs) can also be used for groundwater access. It is a common practice to sample surface water bodies and rainfall to integrate with the groundwater chemistry.

FREQUENCY AND DURATION OF GROUNDWATER MONITORING

If the monitoring is for a basic groundwater resource assessment it is recommended quarterly sampling for groundwater levels, half-yearly sampling for basic quality indicators (eg. electrical conductivity (EC) and temperature (T)) and as-need basis for other quality parameters (Table 1). Collection of long-term (one or more decades) water level data is recommended for better understanding issues associated with groundwater availability and sustainability (USGS, 2001).

Table 1: Indicative monitoring frequency for various groundwater monitoring purposes (adapted from Timms et al. 2009).

PURPOSE FOR MONITORING	GROUNDWATER LEVEL	GROUNDWATER QUALITY INDICATOR (EG. EC, T)	GROUNDWATER QUALITY PARAMETERS**
Basic Resource Monitoring	Quarterly	Half-yearly	As required
Resource Monitoring at Sensitive Sites *(eg. Significant Drawdown, Well Head Protection Zone, Risk of Groundwater Quality Impacts)*	Daily	Monthly	Quarterly
Recharge Processes & Rainfall Response	Daily or Hourly	Monthly or Hourly	As required
Measure Aquifer Confinement and Specific Storage	Hourly or 15 minute*	-	-
Point Source Contamination – Potential Impacts^	Quarterly	Quarterly	Half-yearly
Diffuse Source Contamination – Potential Impacts	Half-yearly	Half-yearly	Annual

* Including barometric pressure measurement at the bore site, ^ Depending on Groundwater Quality Protection Level. ** Selection of appropriate water quality parameters for testing depends on the purpose of monitoring, possible contaminants and constraints on the cost of analyses.

Groundwater Level Monitoring

GROUNDWATER LEVEL MONITORING

Groundwater levels are affected by natural climatic variations as well as by a range of specific uses, such as human consumption, industrial and agricultural activities. It is of vital importance to monitor groundwater levels regularly within the aquifers as it helps to manage the groundwater resources properly. Some of the groundwater level monitoring methods described in this section has been adapted from Sundaram et al. (2009).

GROUNDWATER LEVEL MONITORING METHODS

The total depth and depth to the water level should be measured within the bore before any purging and sampling. Groundwater level measurements can provide information on lateral and vertical head distribution and hydraulic gradients within individual aquifers and between aquifers in layered aquifer systems. Long-term groundwater level measurement provides information on the temporal trends in groundwater levels (and therefore flow direction and rates) due to the effects of drought, high rainfall events and groundwater pumping.

Measuring total depth of the bore

When monitoring unequipped bores the first parameter to be measured is the total depth (TD) of the bore. When monitoring a bore that has pumping equipment permanently installed and does not provide access to the bore casing, the TD cannot be measured. Total depth should be obtained from the owner or custodian of the bore and noted on the Bore Information Sheet (Appendix 2). Note that all depth measurements are conventionally taken from the top of the casing or bore shield (at a marked point, such as the padlocking point). Hence, the height above the ground surface of this reference point should also be measured.

Over time, the base of the monitoring bores can silt up, and this can occur to the top of the slotted/screened interval. Comparing the measured total depth reading with the depth documented at the time of construction can be useful to determine the status of the bore.

Equipment

Total bore depth can be measured using a weight attached to a tape measure. Use a tape measure that is at least as long as the deepest bore to be measured. To avoid mistakes in depth measurements use quite a heavy weight that can easily reach the bottom of the bore.

Procedure

1. Lower the weight into the casing until it reaches the bottom of the hole – as this happens the tape will become slack.
2. Lift and drop the tape several times to ‘feel’ the bottom of the bore.
3. Remember to add the length of the weight onto the tape measurement (if this has not been accounted for)
4. Subtract the height of the casing above the ground level from the measurement.
5. Record the result as total depth (in metres) of the bore on the Bore Information Sheet.
6. Clean the tape before using it again.

Measuring depth to water table

The depth to the water level in the bore is also called depth to groundwater or the standing water level (SWL). Methods and instruments used to collect and record groundwater levels can vary substantially. The more common instruments are fox whistle, plopper and tape measure, electrical tape, pressure transducer and pressure gauge.

Depth to water table should be measured and recorded before every sampling event. Water level cannot be measured in production bores that have permanently installed pumping equipment as there is no direct access to the bore casing. These bores cannot be used for water level monitoring. Some production bores may, however, have additional casing of small diameter that was installed specifically for the purpose of water level monitoring. This casing will run alongside the main bore casing used for water extraction.

Water level measurement using a water level meter

There is a wide range of water level meters and interface meters available on the market. The water level meter uses a probe attached to a permanently marked polyethylene tape, fitted on a reel (Figure 3). The probe detects the presence of a conductive liquid between its two electrodes and is powered by a standard 9 volt battery. When contact is made with water, the circuit is closed, sending a signal back to the reel. This activates a buzzer and a light. The water level is then determined by taking a reading directly from the tape, at the top of the bore casing or borehole. Use of a tape guide gives extra accuracy and protects the tape.

Figure 3 : *Water level meter*

Groundwater Sampling and Quality Monitoring

GROUNDWATER SAMPLING

A representative groundwater sample can be collected from the existing bore fields. It is necessary to remove the stagnant water from the bore casing before a sample is taken. This is called purging. It is recommended that at least three casing volumes of water should be removed before sampling. Usually pumping of the bore is continued even after three casing volumes have been removed until such time as the pH, EC and temperature of the discharge water are observed to stabilise. Only then is the obtained sample considered to be representative of groundwater residing in the aquifer surrounding the bore screen. Some of the groundwater sampling and analysis methods described in this section have been adapted from Waterwatch (2005) and Sundaram et al. (2009).

GROUNDWATER QUALITY MONITORING

Groundwater quality monitoring can be done for a variety of purposes. Some of them include:

- understanding the current status of water quality in the aquifer;
- determining suitability for specific uses;
- detecting long-term trends in groundwater quality;
- detecting suspected contamination; and
- preventing and/or remediation of salt water intrusion in coastal aquifers.

Depending on the purpose of the monitoring, a variety of parameters can be tested. Parameters such as pH, electrical conductivity (EC), temperature, dissolved oxygen (DO), redox potential (Eh) and alkalinity should be measured in the field. The field parameters can be reliably measured using a multiparameter meter—usually with an electrode for each parameter (Figure 4). It is crucial to calibrate the meter accurately before using it, and regularly during use against known standards and according to standard operating procedures. Calibration procedures vary between meters and between manufacturers so it is important to follow the instructions supplied with the equipment.

Figure 4: *Testing of field measurements using multiparametre metres*

Most electrodes are calibrated using standard solutions. When calibrating a meter, record on a standard sheet the date, temperature and calibration readings. This will keep a record of the performance of each meter and provide evidence that quality procedures are being used. Appendix 4 provides an example of a field calibration record sheet.

FIELD TESTING PARAMETERS

pH

A pH meter measures pH and temperature, and adjusts the reading according to the temperature of the sample (as pH varies with temperature). Groundwater pH is a fundamental property that describes the acidity and alkalinity.

Equipment

The equipment you will need for this method includes:

- pH meter
- sample bottle
- deionised water
- calibration solutions and containers

Calibration

Meters must be calibrated with buffer solutions before each sampling trip and periodically during sampling, e.g. every tenth sample, to check if the meter has drifted off calibration. Your check on the calibration standard should be within ±0.1 pH units of the buffer used. If you are using a two-point calibration meter, use buffer solutions at 4.01 and 7.00 for instance. If you are using a three-point calibration meter, use buffer solutions at 4.01, 7.00 and 10.01 for instance. A buffer solution of pH 4.01 will last 3 months, but a solution of pH 7.00 will last 6 months if stored in a cool dark place.

Procedure

1. Rinse the electrode well with deionised water.
2. Place the electrode in the sample. Wait 2–3 minutes for the reading to stabilise but be aware that some change will occur as pH reacts with carbon dioxide dissolving from the air.
3. Record the result on the Bore Information and Field Analyses Sheet (refer Appendix 2).
4. Within the laboratory, periodically measure the pH of the calibration solution to test accuracy. If it has drifted, recalibrate the electrode using a new buffer solution

Maintenance

Always follow manufacturer's recommendations. If not available, rinse the electrode well with deionised water, replace cap with 3M Potassium Chloride solution when finished.

Electrical Conductivity

Electrical conductivity (EC) is an indirect measure of water salinity, and one of the most common and convenient methods used to test water.

Equipment

The equipment you will need for this method includes:

- electrical conductivity meter
- operating manual for the meter and probe
- calibration solution
- deionised water

Calibration

Use a conductivity calibration solution (usually potassium chloride) to calibrate the meter to the range you will need. For example, a 0.01 molar potassium chloride solution has a conductivity of 1413 µS/cm, and a 0.001 molar potassium chloride solution has a conductivity of 147 µS/cm.

To prepare a 0.01 molar conductivity solution, dissolve 0.7456 g of potassium chloride (that has been dried overnight at 105°C) in deionised water and dilute to 1 L (this can be stored for 6 months). To prepare a 0.001 molar solution, use 0.0746 g of potassium chloride (this can be stored for 3 months). Store solutions in a dry, dark and cool room.

If your EC meter does not have an inbuilt temperature probe (i.e. no automatic temperature compensation) make sure your calibration solution is brought to a temperature of 25°C before calibration, otherwise significant errors can result. For example, if the meter is calibrated using a solution at 15°C, it will give erroneous sample readings that are 20% too high.

Tip a small volume of calibration solution into a small clean container for use when calibrating the meter. Discard used solution (do not return it to the bottle). Do not immerse the EC probe in the stock solution container. Rinse the electrodes with deionised water.

Procedure

1. Before testing the samples, calibrate your meter.
2. On site, rinse the electrode in deionised water.
3. Dip the electrode into the sample and, if necessary, select the appropriate conductivity range.
4. Do not immerse the probe too far (some probes/meters are not waterproof above a certain point).
5. Move the electrode slowly in a circle for one minute until the digital readout stabilises or continually jumps between two numbers.
6. Record the results in a Bore Information and Field Analyses Sheet (refer Appendix 2).
7. Rinse the electrode with deionised water.

Maintenance

Rinse the electrode with deionised water. Dry the electrode by carefully dabbing (not rubbing or wiping) it with a paper towel; replace the cap and place the meter back in your kit. The electrode needs to be kept clean and dry.

To ensure accurate readings, you should periodically clean the electrode with methylated spirits. Put it into a beaker with enough methylated spirits to just cover it, and leave it to stand for 15–20 minutes. Remove the electrode and dab it with a soft tissue soaked in methylated spirits. Finally rinse it thoroughly with distilled water.

Temperature

Equipment

The equipment you will need for this method is a glass thermometer or a digital meter. Before using a glass thermometer, check the glass for cracks and check the alcohol or mercury column for breaks.

Procedure

1. Place the thermometer a few centimetres into the water sample as soon as it has been collected.
2. Wait one minute, until the reading is stable.
3. Read the temperature to the nearest 0.5°C while the thermometer bulb, or temperature probe, is still immersed in the water; make sure you take the reading as close as possible to eye level.
4. Record your results on a Bore Information and Field Analyses Sheet (Appendix 2).

Maintenance

After use, rinse the thermometer or meter probe with clean water, dry it and return it to its protective container. Keep the thermometer free from dirt and other contaminants. Make sure the glass does not get scratched or cracked.

Dissolved oxygen

Dissolved oxygen (DO) is a measure of the quantity of oxygen present in water. Groundwater, in general, will have low dissolved oxygen content where there is a lack of direct contact with air or where the existing oxygen has been utilised in chemical and microbiological processes.

Equipment

The equipment you will need for this method includes:

- dissolved oxygen meter and probe (electrode)
- operating manual for the meter and probe
- spare membranes and electrolyte solution for the probe
- spare batteries for the meter

Calibration

The DO probe is generally calibrated in a special sleeve containing a water-saturated sponge before each sampling trip and periodically during sampling, e.g. every tenth sample or every day, to check if the meter has drifted off calibration.

Procedure

1. Turn the meter on and allow 15 minutes for the meter to reach equilibrium before calibrating.
2. Calibrate the meter before each use, according to the manufacturer's instructions.
3. Place the probe in the flow cell.
4. Set the meter to measure temperature and allow the temperature reading to stabilise. Record temperature reading on a water quality results sheet.
5. Switch the meter to read 'dissolved oxygen'. Record your results on a Bore Information and Field Analyses Sheet (refer Appendix 2).
6. Re-test water to obtain a field replicate result.

Redox Potential (Eh)

Redox potential (Eh) is a measure of the oxidising/reducing conditions of the groundwater system. This information can be useful in interpreting metal species in solutions and the possible corrosive effects of groundwater on metal pipes (Lloyd and Heathcote, 1995). Redox is measured in units of millivolts (mV) and is usually reported as relative to the standard hydrogen electrode (SHE). High Eh (>400 mV) indicates a strong oxidising tendency of groundwater whereas low Eh (<400 mV) indicates a strong reducing tendency of groundwater.

Equipment

The equipment you will need for this method includes:

- redox meter and probe (electrode)
- operating manual for the meter and probe
- extra batteries for the meter

Calibration

Be sure to calibrate the meter according to the manufacturer's instructions, before each use.

Procedure

1. Turn the meter on and allow 15 minutes for the meter to reach equilibrium before calibrating.
2. Calibrate the meter before each use, according to the manufacturer's instructions.
3. Place the probe in the sample container.
4. Switch the meter to read 'redox' in relative mV (SHE). Record your results on a Bore Information and Field Analyses Sheet (refer Appendix 2). Note that some redox probes will not report redox in SHE and the measured ORP needs to be added to the voltage of the reference system (typically ~200 mV), which is also dependent on temperature. Refer to operators manual.
5. Re-test water to obtain a field replicate result.

Alkalinity using alkalinity titrator

Digital Titrator is a precision dispensing device fitted with compact cartridges that contain concentrated titrants (Figure 5). Accurate titrations are made without the bulk and fragility of conventional burettes. A main drive screw in the digital titrator controls a plunger which forces the concentrated titrant from a titration cartridge in a carefully regulated flow through the delivery tube.

The titrator body is constructed of precision-molded, heavy-duty, chemical- and impact-resistant acetal plastic. Accuracy of this method is rated at ± 1%.

Figure 5: *Digital titrator for measuring alkalinity*

The alkalinity titrator is preferable to a standard burette dispenser for several reasons:

- smaller, faster unit to use in the field. No glass parts.
- accurate to ±1%
- virtually no exposure to acid, with small volumes of concentrated acid released directly into the sample via a sealed delivery tube.
- digital unit 'automatically' accounts for acid delivered with a simple factor to convert to alkalinity in mg/L.
- interchangeable sealed acid cartridges and multiple titration methods available.

Equipment and reagents

The equipment and reagents you will need for this method includes:

- digital titrator
- titration catridge
- alkalinity reagent set
- erlenmeyer flask 250 ml
- graduated cylinder
- pipette

Procedure

1. Select the sample volume and Sulfuric Acid (H_2SO_4) Titration Cartridge corresponding to the expected alkalinity concentration as mg/L calcium carbonate ($CaCO_3$).
2. Insert a clean delivery tube into the titration cartridge. Attach the cartridge to the titrator body.
3. Turn the delivery knob to eject a few drops of titrant. Reset the counter to zero and wipe the tip.
4. Use a graduated cylinder or pipet to measure the sample volume.
5. Transfer the sample into a clean 250-mL Erlenmeyer flask. Dilute if necessary.
6. Add the contents of one Phenolphthalein Indicator Powder Pillow and swirl to mix. If the solution turns pink, titrate to a colourless end point.

7. Place the delivery tube tip into the solution and swirl the flask while titrating with sulfuric acid. Record the number of digits required.
8. Calculate: Digits Required x Digit Multiplier = mg/L $CaCO_3$ Phenolphthalein Alkalinity.
9. Add the contents of one Bromcresol Green-Methyl Red Indicator Powder Pillow to the flask and swirl to mix.
10. Continue the titration with sulfuric acid to a light greenish blue-gray (pH 5.1), a light violet-gray (pH 4.8), or a light pink (pH 4.5) colour, as required by the sample composition.
11. Calculate: Total Digits Required x Digit Multiplier = mg/L as $CaCO_3$ Total Alkalinity.

Further details on the alkalinity measurement using digital titrator can be obtained from http://www.hach.com/fmmimghach?/CODE%3A1690008_24ED-210509%7C1

HYDROCHEMICAL SAMPLING

Filtration of groundwater samples

It is recommended to filter groundwater samples in the field to preserve certain parameters (cation, anion, and some isotopes) during the delay between sampling and analysis. There are various methods and equipment available for field filtration, from simple syringe systems to more automated pump operated (positive) pressure or vacuum (negative pressure) systems. In general 0.45 µm filters have been used for filtering groundwater samples in the field.

Syringe filters

There are range of disposable filters and syringes available on the market that can be readily be used for filtering groundwater samples in the field (Figure 6).

***Figure 6*:** *Syringe filter*

The sample should be drawn into the syringe directly from the sampling beaker. The syringe should be rinsed with the sample three times with the rinses discarded. A volume of water is then drawn into the syringe before a 0.45-µm filter is attached to the syringe. The sample can then be pushed through the filter and the filtrate retained in a clean container, itself rinsed three times with the filtered sample. Care should be taken to ensure that the filters are changed as they have a tendency to clog. Excessive force may rupture filters or affect the properties of the sample.

SAMPLING PROCEDURE AND SAMPLE PREPARATION

Collect and prepare samples for major chemistry, trace elements, nutrients and isotopes according to Table 2 below.

Anions

Most anions in groundwater (Cl^-, SO_4^{2-}, F^-, Br^-, NO_3^- and PO_4^{3-}) can be analysed using ion chromatography. Some anions (F^-, I^-) can be analysed by ion specific electrode (ISE) techniques. Bicarbonate (HCO_3^-) is determined by alkalinity titration in the field.

Major and minor cations

Major (Na, K, Ca and Mg) and minor (Fe, Si, B, Ba, Li, Sr, Al, Cu, Mn and Zn) cations in groundwater can be analysed by either inductively coupled plasma-atomic emission spectrometry (ICP-AES), or inductively coupled plasma-mass spectrometry (ICP-MS) or ICP-optical emission spectrometry (ICP-OES). Analyse U, Pb and V using ICP-MS.

Table 2: Summary of sample preparation for major and minor chemistry, nutrients and isotopes

ANALYTE	CONTAINER	PREPARATION	PRESERVATION
Anions	125+ mL HDPE new bottle	Filter through 0.45 μm membrane filter	Store in a cool place.
Cations	125+ mL HDPE new or acid-rinsed bottle	Filter through 0.45 μm membrane filter	Acidify to pH <2 with ultrapure nitric acid. Store in a cool place.
Trace As, Se, Hg	125 mL brown glass bottle	Filter through 0.45 μm membrane filter	Add a drop of 5% potassium dichromate in 5% ultra pure nitric acid. Store in a cool place.
Dissolved Organic Carbon (DOC)	125 mL PE bottle	Filter through 0.45 μm membrane filter	Refrigerate at 4°C.
Nutrients	125 mL PE bottle	Filter through 0.45 μm HVLP membrane filter	Freeze.
Trace Metals	125+ mL PE bottle	Filter through 0.45 μm HVLP membrane filter	Acidify to < pH 2 with 0.5 mL ultra pure nitric acid. Store in a cool place.
Fluoride & Iodide	125 mL brown glass bottle	Filter through 0.45 μm membrane filter	Refrigerate at 4°C.
Stable Isotopes- Deuterium, Oxygen in water	28 mL glass McCartney Bottle or 15 mL Vacutainers®	None	Store in a cool place.

HDPE: High Density polyethylene; PE: Polyethylene; GF/C: Glass Fibre Filters

Trace metals

A large number of trace elements in groundwater (including Al, Au, As, Be, Sc, Cd, Co, Cu, Cr, Fe, Mo, Pb, Rb, Sr, Th, Ti, U, V, W, Zr and rare earth elements) can be analysed by inductively coupled plasma-mass spectrometry (ICP-MS) or inductively coupled plasma-optical emission spectroscopy (ICP-OES) or inductively coupled plasma-atomic emission spectrometry (ICP-AES) . In some cases a preliminary treatment is necessary to enhance sensitivity (e.g., hydride generation for As, Sb, Se; resin exchange for Pb; collision/reaction cell for Se). Atomic absorption spectrometry (AAS) is an alternative technique for many trace elements. Although it is slower, it can provide information on speciation.

MICROBIOLOGICAL QUALITY OF GROUNDWATER

Measurement of microbiological quality of groundwater is difficult and costly. However, to allow quick and relatively inexpensive detection of faecal contamination in drinking water, faecal indicator bacteria (FIB) are used as surrogates in a number of studies (Plazinska, 2000). The National Health and Medical Research Council (NHMRC, 2003) recommend the use of *E.Coli* as a primary indicator of faecal contamination of drinking water.

Faecal Indicator Bacteria

There are many known waterborne pathogens capable of causing infections when digested even in very small numbers. Most are present in large numbers in human and animal excreta. It is recognised that monitoring for presence of specific pathogens in water (drinking water supplies) is impractical. An indirect approach has been universally adopted where water is examined for indicator bacteria whose presence implies some degree of faecal contamination (NHMRC, 2003).

Method of detection: membrane filtration

This method enables enumeration of microorganisms present in samples of water. A measured volume of samples is filtered through a membrane. The pore size of the membrane is such that the microorganisms are retained on the surface of the membrane. The membrane is then aseptically transferred to a medium (solid or a pad saturated with liquid medium). After incubation at a specific

temperature for a specific length of time growth will occur. Colonies of characteristic morphology and colour are counted and number of organisms per 100 mL calculated. The results are expressed in colony forming units per 100 mL (CFU/100 mL).

Membrane filtration method can be used for enumeration of different groups of microorganisms in water such as faecal indicator organisms (total and thermotolerant coliforms) as well as non-pathogenic hetrotrophic bacteria naturally occurring in waters.

This method:
- Has to be used in laboratory conditions, in clean, preferably sterile environment, sterile growth media, plates, filtration sets, sample bottles are necessary.
- Sample processing has to be conducted by trained personnel
- Collected water samples have to be processed within 4 hours from collection.

Testing groundwater samples for the presence of faecal indicator bacteria, using a membrane filtration method, requires setting up mini field laboratory. At least 3-4 meters of bench space that can be easily cleaned and disinfected, preferably in the clean room not used by others, is required. Prepacked sterile media and Petri plates are available commercially but access to autoclave is necessary for sterilisation of filtration equipment and sample bottles.

Equipment and laboratory consumables
- sterile sample bottles or disposable sterile Whril-pak® bags for sample collection
- portable Bunsen burner
- portable field incubators
- fridge (for media storage)
- low power (20 x) magnification, binocular, wide-field microscope (Millipore) used for scoring colonies on the plates
- vacuum pump
- filtration flask holder or manifold, 1L collection flask
- sterile filtration sets consisting of a funnel and base (1 per sample)
- microbiological media (Millipore)
- petri dishes with absorbent pads (available from Millipore)
- sterile 5 mL pipette tips
- 5 mL automatic pipette
- tweezers
- 0.45um acetate-cellulose sterile filters packed in single envelopes (available from Millipore)
- alcohol

Prepacked sterile liquid media are available from Millipore. These are:
- M-Endo Broth in 2 mL ampoules for enumeration of total coliforms
- m-FC Coliform Broth in 2 mL plastic ampoules for enumeration of thermotolerant (faecal) coliforms

Field procedures – sampling
- Use pre-sterilised plastic bottles for sample collection from bores or surface water.
- Bottles can be substituted by disposable sterile plastic Whril-pak® bags (500mL volume).
- Samples should be stored at 4^{o}C and process within maximum 3 hours after collection.

Filtration
- Pre-sterilised filtration set should used for sample processing.
- Filter three volumes of the sample for each test (faecal or total coliforms): 10, 50 and 100 mL.

- Use 5 mL automatic pipette and a 5 mL sterile plastic tip for the 10 mL volume, and 50 and 100 mL volumes can be carefully poured straight into the graduated filtration funnel.
- Use 0.45 μm grided Millipore filters packed in individual sterile envelopes.
- Place the filters in sterile Petri dishes on top of absorbent pads saturated with appropriate medium (M-Endo or m-FC).

Incubation and scoring

- Incubate plates for enumeration of total coliforms (with M-Endo medium) at 35^{o}C for 24 hours.
- Typical coliform colony is pink to dark red with a metallic surface sheen – only such colonies should be scored.
- Incubate plates for enumeration of faecal coliforms (with M-FC medium) at 44.5^{o}C for 24 hours.
- Typical thermotolerant (faecal) coliform colonies are various shades of blue.
- Score the plates using the Millipore microscope after 24 hours of incubation and record results in the scoring sheet.

Results

- Calculate the results from the plates with the ideal range of 20 – 60 colonies.
- If only one plate is having a count in the ideal range then: CFU/n mL = count/volume filtered x n, where n denotes volume of sample.
- If two or more plates have counts in the ideal range then: CFU/n mL = (count1+count2)/(volume1+volume2) x n.
- Express the results in colony forming units per 1 mL (CFU/1mL).

Additional information on the membrane filtration method can be obtained from Plazinska (2000, 2003).

Method of detection: presence and absence tests

Presence/absence tests (P-A) provide qualitative information on the presence or absence of microorganisms in the test sample. When compared with other detection techniques, the P-A test for coliforms has been found a more sensitive method and requiring significantly less effort and expense.

This method:

- Can be used in field conditions
- Can be performed by personnel with minimal training.
- Can be performed with minimal preparation time

The Colilert test for detection of coliforms and *E.coli* uses the principle of *'defined substrate technology'*: substrates (chromogenes and fluorogenes) that produce colour and fluorescence upon cleavage by specific enzyme. It is based on detection of the beta-galactosidase enzyme which caltalyses the breakdown of lactose to galactose and glucose (characteristic of family Enterobacteriaceae). The assay is based on biochemical reaction in which beta-galactosidase cleaves the substrate (ONPG) to produce yellow nitrophenol (Manafi et al. 1991).

The detection of E.coli is based on detection of beta-glucoronidase activity (the substrate is hydrolysed by beta-glucoronidase to produce an end-product which fluoresces when irradiated with long-wave UV light).

Colilert is US EPA approved and is included in Standard Methods for Examination of Water and Wastewater. It is used in over 90% of all US State laboratories (APHA, 1995).

Equipment and laboratory consumables

- sterile sample bottles or disposable sterile Whril-pak® bags for sample collection
- when sterile equipment for sample collection is not available, sample can be collected directly to the 100 mL incubation vessel
- portable field incubator
- hand-held UV lamp
- sterile 100 mL sample vessels
- pre-packed dehydrated media with appropriate substrates

Field procedures: sampling and incubation

- Collect water samples into sterile bottles or bags (as described above). If sterile bottles are not available collect directly into incubation vessel.
- Collect only one 100 mL sample and incubate the sample.
- Sample vessels have 100 mL volume mark on the side of the bottle, so there is no need for additional sterile measuring equipment.
- Add dehydrated Colilert reagent in pre-measured satchet to the sample.
- Incubate sample at 35^{o}C for 24 hours.

Results

- Examine samples after 24 hours - development of yellow colour indicates presence of coliforms.
- Examine samples under long-wave UV light using a small hand-held lamp − fluorescence of the sample indicates a positive test for *E.coli*.

Water Quality Guidelines

The Australian water quality guidelines for drinking water (ADWG, 2004) and irrigation, livestock watering and aquatic ecosystems (ANZECC/ARMCANZ, 2000) are summarised in Table 3. The guidelines place specific thresholds on the quality of water that is intended for specific uses. The goal of groundwater protection is to protect the groundwater resources of the nation so that these resources can support their identified beneficial uses and values in an economically, socially, and environmentally sustainable and acceptable manner.

Guideline values have been determined for those chemical components that are considered to have significant potential to harm human health at concentrations above the specified limits. Guideline values should not be exceeded in public water supplies. It should also be noted that exceeding the guideline values may not always be a matter for immediate concern, but rather a trigger for follow-up action.

Table 3: Australian Guidelines for Drinking Water[a], Livestock[b] and Irrigation Water[b]

PARAMETER	DRINKING WATER (mg/L)		LIVESTOCK WATERING	IRRIGATION LTV[D]	IRRIGATION STV[E]
	HEALTH	AESTHETIC	(mg/L)	(mg/L)	(mg/L)
Thermotolerant coliforms	0 CFU/100 mL	-	100 CFU/100 mL	<10-10000 CFU/100 mL	
Aluminium	NAD	0.2	5.0	5.0	20
Antimony	0.003	-	-	-	-
Arsenic	0.007	-	0.5-5[c]	0.1	2
Barium	0.7	-	-	-	-
Beryllium	NAD	NAD	-	0.1	0.5
Boron	4	-	5.0	0.5	Crop dependent
Calcium	-	-	1000	-	-
Cadmium	0.002	-	0.01	0.01	0.05
Chloride	-	250	-	Crop dependent	Crop dependent
Chromium (as VI)	0.05	-	1.0	0.1	1
Cobalt	-	-	1.0	0.05	0.1
Copper	2	1	0.4 (sheep) 1 (cattle) 5 (pigs/poultry)	0.2	5
Fluoride	1.5	-	2.0	1.0	2.0
Iodide	0.1	-	-	-	-
Iron	-	0.3	-	0.2	10
Lead	0.01	-	0.1	2	5
Lithium	-	-	-	2.5 (0.075 on citrus)	
Magnesium	-	-	-	-	-
Manganese	0.5	0.1	-	0.2	10
Mercury	0.001	-	0.002	0.002	0.002
Molybdenum	0.05	-	0.15	0.01	0.05
Nickel	0.02	-	1.0	0.2	2
Selenium	0.01	-	0.02	0.02	0.05
Silver	0.1	-	-	-	-
Sodium	-	180	-	Crop dependent	Crop dependent
Uranium	0.02	-	0.2	0.01	0.1
Vanadium	-	-	-	0.1	0.5
Zinc	-	3.0	20.0	2	5
Ammonia (as N)	-	0.41	-	-	-
Nitrite (as N)	0.9	-	9.12	-	-
Nitrate (as N)	11.3	-	90.3	-	-
pH	-	6.5-8.5	-	6-8.5	
Sulfate	500	250	1000	-	-
TDS	-	500	Stock dependent	Site specific	Site specific

[a] From *Australian Drinking Water Guidelines*, National Water Quality Management Strategy, NHMRC/NRMMC, 2004.

[b] From *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*, ANZECC/ARMCANZ, 2000.

[c] May be tolerated if not provided as a food additive and natural levels in the diet are low.

[d] LTV denotes long-term trigger value, the maximum concentration of contaminant in the irrigation water that can be tolerated assuming 100 years of irrigation, based on irrigation loading assumptions.

[e] STV denotes short-term trigger value, the maximum concentration of contaminant in the irrigation water which can be tolerated for a shorter period of time (20 years), assuming the same maximum annual irrigation loading to soil as for the LTV.

NAD denotes No Available Data.

Quality Assurance/Quality Control

Quality Assurance/Quality Control (QA/QC) is a set of operating principles that is adopted to help produce data that is of known, consistent and defensible quality. The QA/QC process is used to check the accuracy and precision of field sampling procedures and laboratory analyses and is done by taking duplicate, spike and equipment blank samples. The QA/QC procedures described in this section have been developed through the Australian groundwater quality assessment project (Please et al. 1996; Watkins et al. 1998).

QUALITY ASSURANCE

Quality assurance (QA) is the policies, procedures and actions established to provide and maintain a degree of confidence in data integrity and accuracy. For a sampling program to successfully meet its objectives, a rigorous and thorough program of checks, comparisons and communication must be implemented. In order to achieve consistent data collection, a QA system must be followed.

To keep errors in field sampling to a level acceptable to the data user, a QA program should be implemented from the sampling program design stage through to delivery at the laboratory. During these stages, QA should include peer review, training, standardised field procedures, submission of quality control (blank) samples, sample container and field equipment checks, sample transport processes and traceability, and continuous review and improvement of the field sampling plan.

QUALITY CONTROL

Quality control (QC) is a sample or procedure intended to verify performance characteristics of a system. Water sampling QC should focus on ensuring that the results obtained by analysing samples represent the groundwater as it was when the sample was collected. That is, if there is any significant change in, or contamination of, the sample due to containers, handling and transportation, it will be picked up by QC.

The type and number of QC samples collected should be based on data quality objectives. The required confidence in results will be reflected in the number of QC samples; more QC samples will provide a greater degree of confidence in the results. The most common types of QC samples are blanks, spikes and duplicates; their purpose and the minimum requirements are summarised below.

Blanks

A blank is a portion of deionised water that is carried through all or part of the sampling and analytical process and is designed to provide an indication of contamination. It is important that the volume used for blanks be the same as the samples. The various types of blanks include:

Method blanks: A sample of deionised water is carried through the entire sampling and analytical process.

Trip blanks: These blanks are used to monitor potential contamination during shipping and storage. These blanks are sent from the laboratory with empty bottles and remain with other samples throughout the sampling trip but are not opened in the field.

Field and equipment blanks: These blanks are taken under field conditions and include filtration and addition of preservatives, as appropriate.

Duplicate Samples

These are taken to test for analytical precision in the laboratory and put through the same filtering, storage and analysis processes.

One in every 10 - 15 sites should be sampled in triplicate to provide the following set of samples:

- Original
- Duplicate
- Spiked Duplicate

One sample is split, or three samples bottled in immediate succession and each is given its own identification number.

Duplicate samples, prepared about every ten samples, can be used to monitor reproducibility of sampling and analysis. Calculate the relative percentage differences (RPDs) to observe the variation in duplicates, as follows (Nielsen, 1991):

$$\text{Relative Percentage Difference (\%)} = \frac{\text{concentration } S_A - \text{concentration } S_B}{\text{average concentration of } S_A + S_B} \times 100$$

where S_A denotes Sample A; S_B denotes the duplicate, sample B; units will be consistent within a calculation.

Spiked Duplicate Samples

These are taken to test the accuracy of the analytical process and to detect any degradation or chemical alteration of the sample from the point of collection to analysis. Known amounts of a number of elements of interest can be added to a sample. The spiking solutions are taken into the field and added during the sampling process, usually when a duplicate sample is taken.

The sample to be spiked should be filtered in the same way as the original and duplicate. 5 L of filtered sample will be sufficient for the spiked samples. This should be kept cool until required. Keep all spiking solutions refrigerated until required.

Rinse all glassware in 5 % HCl + 3 rinses in de-ionised water after each spiking procedure.

Note that in some cases the volume of spiked sample submitted for analysis is less than the usual sample volume. This is necessary to minimise the use of expensive spiking solutions. Sampling personnel should ensure that adequate supplies of these sample bottles are stocked.

Anion-Cation Balance

The accuracy of the laboratory analysis can be readily checked by looking at the anion-cation balance. Since water is neutrally charged, the sum of anions should equal the sum of cations. The anion-cation balance is normally expressed as a percentage.

$$\text{Ion balance} = (\sum C - \sum A)/(\sum C + \sum A)/100$$

Where, $\sum C$ is the sum of cations and $\sum A$ is the sum of anions

If the anion-cation balance is >5% that indicates an error in analysis and the results should not be relied on for subsequent interpretation.

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Appendix 1: Field Equipment Checklist

EQUIPMENT LIST	CHECK	EQUIPMENT LIST	
Purging/sampling equipment		**Kit bag/tool box**	
Water level probe and batteries		Tape (gaffa, masking)	
Water quality meters		Disposable gloves	
Standards to calibrate the water quality meter		Tools—spanner/shifter/ Stillson wrench/screw drivers	
Pump, tubing		Paper towel	
Folding table and chairs		Disinfectant wipes	
Generator		Garbage bags	
Bailers & cord		Ziplock bags for samples	
Sample bottles		Leather gloves	
Labels for samples		Spare pump motors	
Eskies & ice		**Safety equipment**	
Decontamination		First-aid kit	
Buckets		Sunscreen	
Demineralised water		Drinking water	
Detergent solution		Mobile phone	
Sponges, scrubbing brush		PPE — wide-brimmed hat	
Plastic groundsheet		— wet weather gear	
Documentation		— steel-capped boots	
Sampling plan		— sunglasses	
Map of bore locations		— work pants	
Site plans		— long-sleeved cotton shirts for hot weather	
Bore records		**Miscellaneous**	
Field notebook		Calculator	
Chain of Custody		Digital camera & batteries/charger	
Pens & textus		Bore key	
MSDS		GPS & batteries	
		Business/ID cards	

Appendix 2: Bore Information and Field Analyses Sheet

FIELD ID	**DATUM USED:**
	Alt =
	S =
Sample ID / **Date**	**E =**

Measured T.D. (m)		
Measured W.L. (m)		
Casing Height (m)		
Radius of bore (m)		
Slots/Screen @ (m)		
Pump Depth (m)		
Pump Time On		
Pump Time Off		
Pumping Time (min)		
Average Flow Rate (L/min) (from Flow rate conversion chart)		
Reduced T.D.(m)		Measured T.D. - Casing height
Reduced W.L.(m)		Measured W.L. - Casing height
Water column (m)		Reduced T.D. - Reduced W.L.
Approximate casing volume (L)		3.1416 x radius^2 x water column x 1000
Approximate vol. removed (L)		Pumping time x Average flow rate

Field analyses:

TIME	FLOW RATE (L/MIN)	PH	TEMP ^{0}C	D.O. (MG/L)	REDOX MV	EC µS/CM

Comments **Redox probe correction factor to apply to above Redox values = mV**

APPENDIX 3: CHAIN OF CUSTODY RECORD

Project Name		Laboratory contact	
Name and address of organisation		Telephone	
Project contact		Contract/Project/Job No.	
Telephone			

SAMPLE ID	SAMPLE LOCATION	SAMPLE TYPE (WATER, SOIL, SEDIMENT)	SAMPLE PRESERVATION	SAMPLING		NO. OF CONTAINERS	ANALYSIS REQUESTED	COMMENTS
				DATE	TIME			
Sampled by:			Signature					

SAMPLE RELINQUISHED BY:					SAMPLE RECEIVED BY:				
NAME AND ORGANISATION	SIGNATURE	DATE	TIME	SAMPLE CONDITION	NAME AND ORGANISATION	SIGNATURE	DATE	TIME	Sample condition

APPENDIX 4: FIELD PARAMETER CALIBRATION RECORDS

DATE	pH STANDARD 1 (4.0)	pH READING	pH STANDARD 2 (7)	EC STANDARD 1 ( )	EC READING	EC STANDARD 2 ( )	EC READING	DO STANDARD	DO READING	TEMP (^{0}C)	DO MEMBRANE CHANGE DATE	Signature