5. Water Sampling and Flow Measurement

5.1 *Introduction*

Water monitoring can be a very expensive and time consuming exercise and therefore the monitoring plan must be well designed before the program is implemented. Suggested planning steps are shown in Table 5.1

In addition to these key steps, specific requirements of the National Water Quality Management Strategy need to be considered and the ANZECC (1992) guideline documents also need to be reviewed.

5.2 *Principles and Purpose of Monitoring*

The key issues that must be addressed before the commencement of sampling and flow monitoring are listed below.

1. **Reasons for monitoring** - The objectives and purpose of the monitoring program must be established. Monitoring programs are usually implemented for compliance with an operating licence, to meet company or corporate policy requirements, for project design input data or for a baseline survey. Data from monitoring will also provide valuable feedback and corroboration of design data adopted. The program should meet the defined objectives.
2. **Trained field staff** - Personnel who collect meteorologic, hydrologic and water quality data should be skilled in hydrography, field flow measurement techniques and the fundamentals of water chemistry. The increased use of electronic field data also requires field personnel to be skilled in the use of data loggers, portable computers and associated software. Standard and uniform sampling and preservation procedures need to be used. If this expertise is unavailable within the organisation, consideration should be given to using a reputable and experienced consultant.
3. **Execution of the program** - The type of sample collection (eg. automatic or manual grab sampling), frequency, number of monitoring sites and phase (exploration, feasibility, construction, operation, decommissioning and after site closure) of the project should be identified within the initial planning stage.
4. **Budget** - Sufficient financial resources must be assigned to meet the objectives of the program, or else the program needs to be modified. Ideally, staff and financial resources allocated to a monitoring program should complement the scope of the program, and the sensitivity of the local environment. In circumstances where financial resources are limited, it is better to:

- ensure that the samples collected are representative in both time and space;
- restrict sample collection to key locations (including controls); and
- review previously collected data to ensure unwarranted analyses are not requested.

Finally, when allocating and revising financial resources, all the associated costs need to be incorporated. Expenses that are frequently neglected include:

- sample storage costs (ice for field storage, temporary refrigeration);
- sample transport costs to the laboratory;

TABLE 5.1: **Key Planning Steps for Water Monitoring**

The Key Planning Steps

1. Identify the potential receiving waters and their beneficial uses.
2. Outline the site resources (personnel, financial) which are available for the monitoring program.
3. Locate and review the presence of any existing data, environmental audits and reports.
4. Identify all Local, State and Commonwealth statutory requirements which must be met by the operation.
5. Select a reputable laboratory which can advise on sampling methodology, containers, preservation and storage, etc.
6. Using a site plan, identify the physical and chemical properties of all likely point and non-point sources of pollution, the network and the catchment partitioning.
7. Design and implement a “screening” monitoring program to identify all sources and types of contaminants (eg. suspended solids, zinc, phosphates, E. coli) from each location. The screening program should include all surface waters, groundwater, industrial and domestic discharges, receiving waters etc. Control or background sites should also be identified and sampled. This program should be undertaken during dry and wet weather periods and the results reviewed in detail to identify contaminants which should or should not be analysed for a specific location.
8. Identify all monitoring sites which require flow measuring facilities (if contaminant loadings are required for water balance data, for catchment yield characterisation and rainfall/runoff parameters). Ensure a proper program is in place for physical measurement of flows for calibration and for validation of all recorded data.
9. Design and implement a calibration, quality control and quality assurance program with appropriate control sites, blank and duplicate samples, etc., and ensure detection limits are appropriate.
10. Ensure rainfall guages (and climate stations as appropriate) are in place for catchment rainfall/runoff characterisation.
11. Implement a site-wide sampling program and review the data once they are available. Parameters that have been measured below the detection limit can be sampled less frequently.
12. Review all results against statutory requirements.
13. Design an appropriate computerised database management system so that results can be managed and retrieved with ease.

- consumable costs (sample bottles, acid rinsing of sample bottles, labels, coolers, field clothing);
- costs associated with calibrating streamflow data, which requires qualified personnel manually undertaking a program of streamflow gauging; and
- database development, data analysis costs (eg. computer facilities and employees’ time) and implementation of an appropriate data management system.

5.3 *Compliance Monitoring*

In the past, licence and discharge criteria varied frequently between the States. Recently, a more uniform approach has been taken with a move towards the ANZECC Water Quality Guidelines (1992)[1], which consider both discharge limits and receiving water quality. This document should be reviewed in order to understand the existing national approach to water quality management in Australia.

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1 Under revision 1997-98.

5.3.1 AMBIENT, POINT SOURCE AND NON-POINT SOURCE POLLUTION

Ambient concentrations generally refer to natural or background levels of water quality parameters within a receiving water. It is important to determine if the background values reflect actual natural conditions or a natural system which may have been modified over the past two centuries.

Discharge or point source criteria refer to the concentration of a contaminant or parameter at the point of discharge (eg. an outfall from a wastewater treatment plant). The criteria may specify a mean value and a higher level not to be exceeded at a given frequency.

Non-point source pollution refers to a diffuse source rather than a single discharge point, eg. unconfined stormwater runoff from a minesite, workshop and maintenance areas. Contaminants from diffuse sources may be measured as a concentration (eg. Mg/L), but usually contaminant loading data (eg. kg/ha/yr) are required and both quality and quantity data must be collected.

5.3.2 MIXING ZONES

When assessing compliance with receiving water quality guidelines, the “mixing zone” of the waterbody must also be considered. This is a region of the receiving water at which elevated levels of a contaminant can be present due to a discharge source, before dilution to an acceptable level.

ANZECC (1992) defines a “mixing zone” as an explicitly defined area around an effluent discharge where certain environmental values are not protected.

All relevant mixing zones, both within and outside a lease area, should be clearly identified. Monitoring programs and interpretation of data need to consider that these areas exist.

Control strategies should ensure that the area of a mixing zone is limited in order that the value of the waterbody is not prejudiced.

5.4 *Data Collection - Quality*

The resources allocated to environmental data collection will depend on the phase of the mining operation (ie. exploration, construction, operating, closure).

- Baseline studies and associated monitoring programs should be implemented at prospective sites prior to the commencement of any major earthworks or infrastructure development.
- The resource evaluation and feasibility phases usually involve the collection of meteorological and hydrological data, if no long-term data exist for the local region. Long-term time series data will improve techniques for optimising tailings dam design, surface drainage works, water supply and flood mitigation.
- The construction phase generally involves expanding the monitoring program as staff and financial resources increase. A target monitoring program during construction is often necessary to measure the impacts of the construction activities. It also allows fine tuning of initial “screening” programs prior to full-scale operation.
- The operational phase will normally involve frequent monitoring of all point source (eg. sewage effluent, potable water, process and tailings dam water), non-point source (eg. stormwater from the plant area, landfill leachate) and receiving water quality and quantities (waterbodies within and adjacent to the mine and mineral processing lease).
- The decommissioning phase and the extent and duration of monitoring will depend on the nature of the operation and the requirements outlined in the mine decommissioning plan, agreements and licences.

5.4.1 MONITORING DESIGN

Initially both a statistical evaluation of the monitoring design and a review of the procedures and techniques to be adopted should be undertaken. Once a preliminary plan is prepared, the logistics (eg. staff and financial resources) need to be reviewed.

Development of the statistical design and validation of the sampling program, analytical methods and final data set need to be undertaken by personnel with appropriate expertise. The use of blank samples, unidentified duplicate samples and inter-laboratory testing should be incorporated as key components of the monitoring program.

Electronically collected hydrological data from streams and rivers should also be validated using appropriate statistical procedures and manual gauging methods during low, medium and high flow flood events. Electronically collected rainfall data should be validated similarly.

5.4.2 IDENTIFICATION OF KEY MONITORING PARAMETERS

The monitoring parameters selected (physical, chemical and biological) will depend on the ore being mined at the operation, the process technology and chemistry, the geographical location and the beneficial environmental uses which need to be protected. It is important to identify all the key monitoring parameters early in the program in order to avoid possible delays at some later stage of the development.

5.4.3 INITIAL SCREENING PROGRAM

Prior to commencing a full-scale monitoring program, it is worthwhile undertaking an initial screening survey at all potential monitoring locations within the project area to determine which parameters are relevant, significant and measurable above analytical detection limits. This should be done in conjunction with the statutory authorities concerned and the analytical laboratory. Multi-element screening of water samples for total and dissolved contaminants on a selected number of samples is a cost-effective technique to identify parameters which should be incorporated into the site monitoring program. Results from the initial screening program should be compared with guideline values such as those published by ANZECC (1992) and NHMRC (1994). Locating best positioned flow monitoring stations, relative to the monitoring locations required, can also be assessed as part of the initial screening program.

5.4.4 SAMPLING LOCATIONS

The selection of suitable sampling sites within and surrounding a mining operation should be based on the potential for a specific area, process or activity to have an environmental impact.

Selection criteria for sampling and control sites are shown in Table 5.2

It should be noted that the conditions required for an acceptable control site for biological monitoring programs are generally more stringent and complex than a control location for chemical monitoring programs.

Sufficient samples should be collected to quantify accurately the concentrations and behaviour of a compound from the time it is discharged through to the point where it can no longer be detected above ambient concentrations.

5.4.5 SAMPLING FREQUENCY

The frequency interval selected for the collection of samples for a water monitoring program will depend on the following factors:

- statutory and licence conditions (eg. weekly, monthly);
- size and geographic location of the mining operation;
- distance and ease of access to sample locations;
- variability of natural and seasonal conditions;
- availability of staff resources to collect samples and process data; and
- type of analysis.

TABLE 5.2: **Selection Criteria for Establishing Sampling Sites**

Sample Sites	*Control Sites*
The selection of sampling sites within and outside the project area should reflect the: • beneficial uses requiring protection; • geographic location and the area potentially impacted by the operation; • the nature of the operation and the type of ore/minerals/metal produced; • conditions of the licence agreement; • access to sampling sites (all weather if required); and • budget and analytical constraints. An overview of the "typical" monitoring sites that should be sampled at an operation are: • within or adjacent to areas of beneficial use; • the discharge point for industrial or domestic waste streams prior to entering receiving waters; • monitoring of receiving waters upstream and downstream of the discharge point or property boundary, if a mixing zone is identified in licence conditions; • monitoring of all impounded water including tailings dams, retention pond water, seepage ponds; • monitoring of groundwater downstream from contaminated sites, eg. dirty water ponds, hazardous waste sites; and • below the confluence point of major tributaries within the region.	Control sampling sites are an essential component of any water monitoring program. The location and number of control sites selected will depend on: • the geographic and topographic location of the operation; • the spatial coverage of the proposed monitoring program; and • financial constraints. It is essential that control and routinely monitored sites: • are in similar locations, preferably in the same catchment; • are not influenced by past or current mining operations or other human influences; • have similar geochemical conditions, ie. either carbonate systems or organic systems; and • have similar meteorological and hydrological conditions.

5.4.6 SAMPLING TECHNIQUES AND DESIGN

There are numerous methods by which a representative sample can be collected, with the final technique selected primarily dependent on the type of waterbody or waste stream requiring assessment. It is particularly important that the procedures used, and any changes to these, be thoroughly documented, and all persons using them are adequately trained in their use.

Surface Water Sampling

Sample collection of surface waters (sewage effluent, stormwater, tailings dams, streams and estuaries) can range from simple grab sampling techniques through to sophisticated automatic samplers, which have the capacity to collect both discrete or composite samples over a specified period.

When surface sampling techniques are to be used the following should be considered.

- The sample containers used must be appropriate for the chemical parameter being measured (eg. acid washed high density polyethylene for trace metals, organic solvent rinsed glass bottle with teflon lid for organic compounds).
- Before filling, rinse the sample bottle out three times with the water being collected, unless the bottle contains a preservative. Ensure clean hands are used as dirty hands may contaminate the sample (eg. cigarette smoke or residual ash will contaminate low level nutrient and metal samples). For trace metal samples, prevention of contamination is paramount, and special techniques such as the use of non-powdered latex gloves are required.
- Avoid contamination of the sample and disturbance of the waterbody being sampled.
- Exclude air from the sample containers.
- Appropriate sample preservation techniques must be implemented immediately after sample collection (eg. filtration and addition of AR grade HNO_3 for dissolved trace metals, temporary storage at 4^0C for nutrients).

Note that sample holding times vary between 3 hours and 28 days for different parameters being analysed.

- Ensure the laboratory and the analytical techniques used are NATA (National Association of Testing Authorities) registered.

Variations in sampling and preservation techniques, storage times prior to analysis and the analytical methods chosen all contribute to incompatibility of data. Considerable time and effort should be allocated to ensure that the samples collected, and the results obtained, are of a consistent high quality.

To facilitate the collection of high quality samples and data interpretation, field log sheets need to be completed at the time of sample collection. Examples of field record data sheets are presented in Fact Sheet No. 1.

The reader is strongly recommended to review published guidelines and texts for the collection and preservation of samples prior to designing and implementing a monitoring program. Examples of such documents are provided in the references section of this handbook.

5.4.7 SAMPLE TRANSPORTATION

The remote location of most Australian mining operations means that samples may need to travel considerable distances to the laboratory at which the analysis will be performed.

Water samples should be freighted in portable “coolers” containing ice, as many parameters require storage at 4^0C prior to analysis. Samples should be placed in designated “coolers” to allow the separation of low-level control samples from high level effluent samples.

Some parameters (for example alkalinity) require analysis within 3 to 24 hours of sample collection and so, it is recommended that these analyses be performed at the mining operation using properly calibrated instrumentation and clean conditions. Others, such as pH, EC and temperature should be measured in the field. The remaining samples should be rapidly transported to the allocated laboratory if possible by same-day or overnight transport.

Appropriate chain-of-custody forms must also be dispatched with the samples, clearly identifying all sample details and the required analysis.

5.4.8 SAMPLE ANALYSIS

The selection of a laboratory is an important decision in the design phase of the program. It is preferable that the laboratory and the methods used for a specific analysis are NATA registered. NATA registration means that the laboratory has been inspected by personnel from the governing authority; the analytical method has passed stringent quality control procedures and the method has been used in inter-laboratory quality control programs. The results of these interlaboratory quality control programs should be requested prior to commissioning long-term work to a specific laboratory.

The inclusion of duplicate and blank samples within all sample batches sent to a laboratory is recommended. Feedback should be provided to the laboratory to identify and remedy problem areas in the analysis.

As a guide, the QAQC component of monitoring and analysis should account for at least 10-15% of the effort (and cost) of the monitoring program.

It is essential that all aspects of a QA/QC program are discussed with the selected laboratory once the site screening program is complete and prior to the implementation of a long-term site-wide monitoring program.

5.4.9 DATA MANAGEMENT

Data management is an important component of any environmental monitoring program, as vast amounts of data can be generated within short periods. Data management should be incorporated into the initial planning stages of the program in order that the database may be used to meet the initial objectives of the monitoring program.

The use of spreadsheets for data storage and management is often insufficient for most long-term environmental monitoring programs. A relational database is more applicable due to its capacity to store and easily process vast quantities of data. It also has the advantage of rapidly retrieving information for a specific purpose, such as reporting to government authorities. In most cases, existing hydrologic, water quality and meteorological data which are stored in a spreadsheet or ASCII format can be imported easily to a central relational database.

A relational database linked to a geographic information system (GIS) provides a particularly powerful tool for the management and interpretation of data. For example, geographic trends, such as downstream dilution of groundwater contaminants, are easily identified and readily appreciated by management when presented visually.

5.4.10 LABORATORY, PILOT PLANT AND LEACH TESTS

In some circumstances, laboratory bench scale tests can increase the knowledge about the behaviour and removal of a pollutant within a treatment plant, sedimentation dam or tailings dam.

Pilot plant and laboratory studies can often be more closely and easily monitored than full-scale field studies, as samples can be collected more frequently and the time, travel and cost of collecting samples is significantly less. Examples include the use of leach columns to test the acid generation potential and leachability of tailings, waste rock and other materials stored in bulk.

Where laboratory and pilot plant tests are conducted, it is important that findings and conclusions based on these studies are verified in the field under full-scale natural conditions.

5.5 *Data Collection - Quantity*

When considering the data measuring systems for the volumetric water parameters such as rainfall, evaporation, and stream flow, the specified use of the data is the primary consideration in selecting the appropriate recording system. The following is an overview of appropriate recording systems and controls for various climate and water-related parameters and the various circumstances when each may be utilised.

5.5.1 RAINFALL READING

There are two methods of recording data.

- Manual recording of rainfall collectors, eg. a standard rain gauge, on a daily basis. These data are useful for general interpretation of rainfall trends and long-term water balance analyses. The data can also be used to verify automatic recording rain gauges.
- Automatic recording rain gauges, which have a calibrated tipping bucket gauge with associated electronic data recording logger. The advantage with the automatic system is its ability to record the time sequencing of rainfall events. These data are valuable for characterising the storm intensities for an area and for the establishment of the rainfall runoff response at the site.

An automatic recording system is relatively inexpensive to install, with power from localised battery or solar panels. These systems can manually download data to a computer or can be connected to a telemetry system for data capture remote from the site of installation.

5.5.2 FLOW RECORDING

Flow recording in existing streams and waterways and future waste streams or diversion works is essential for comprehensive characterisation of the site hydrology and water management plan.

The critical areas where flow recording instrumentation is either required or desirable for developing site specific characteristics are:

- at licensed discharge locations from the site;
- at stormwater discharge locations around the site;
- on existing streams both upstream and downstream of the site; and
- selected catchments where flow monitoring will provide useful design data.

The selection of flow monitoring systems will depend on the characteristics of the monitoring location. These normally range from constructing hydraulically rated controls in streams, pipe monitoring systems and manually flow rating the streams. Regardless of the type of hydraulic control structure it is imperative that the following basic rules be followed in establishing the flow recording system.

1. Select the monitoring location that will maximise the reliability of data recovery for the range of flows that will occur. This may require construction of hydraulic control devices such as a flume or v-notch weir. Where natural controls are selected they must be robust.
2. Select the appropriate flow depth recording hardware for the monitoring location. Typical flow depth recording sensors include pressure gauges, sonic systems, float gauges and capacitance probes.
3. It is essential that flow monitoring stations be rated for flow and height. This may be undertaken using a hydraulic structure that has a pre-determined rating relationship. Where natural controls are used, it is critical that the flows are rated by physically measuring the flows through the control and relating this directly to monitored flow heights at the station. It is not sufficient to rate a flow monitoring station using only theoretical and analytical hydraulic relationships that require subjective assessments of coefficients (eg. Mannings equation).
4. Few chances occur to collect time related data, and therefore it is critical that both reliable and appropriate monitoring equipment be installed. As vital development and strategic decisions depend upon the values recorded at these stations, the hardware monitoring and recording equipment must be of a high calibre. The following questions help with the selection of suitable instrumentation:

- Will the equipment be intact and record throughout extreme events?
- Is the site accessible during flow periods for manual flow recording (for rating relationship)?

- How often can loggers be downloaded and is a telemetry system required?
- What is the potential for vandalism or damage by animals or large trees?
- Have rainguages been installed at appropriate locations for characterising the rainfall/runoff response?
- Do personnel responsible for collecting the data and maintaining the station have the required levels of expertise?

5. Measured and recorded data must be validated to ensure the data is correctly presenting the conditions being measured.

The validation must take place as soon as possible after it is collected and should check:

- that the data recorded are realistic;
- any malfunctions in instrument recording; and
- the calibration data.

Validation processes involve processing the raw data into physical outputs (height and flow), checking compliance against similarly recorded data, verifying where the data fall within the calibration limits and scanning the data for anomalies and unrealistic outputs.

For the installation and operation of flow monitoring systems, reference should be made to the Australian Standard 3778 - "Measurement of water flow in open channels" and all its associated sub-sections. Care must be taken that specific requirements for the location of the system and measuring devices are followed, otherwise inaccurate monitoring data will result.

5.6 Groundwater

5.6.1 GROUNDWATER MAPPING

Groundwater mapping involves the identification and location of groundwater resources. A typical groundwater map contains contour information representing piezometric levels. Groundwater contours should be shown relative to an absolute datum (eg. AHD or a suitable mine datum) rather than relative to ground level, as the ground contours may bear no relation to groundwater levels.

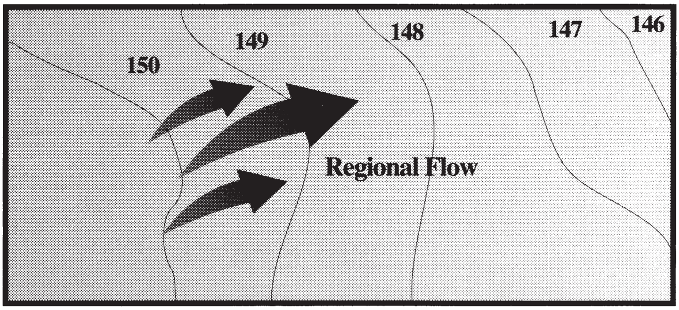
Figure 5.1 shows a typical groundwater surface map.

Groundwater flow is always from a region of high water level or piezometric level to a region of low water level or piezometric level (see Figure 5.1).

The following steps are required to construct a groundwater map.

- Groundwater "borders" should be determined (eg. rivers, lakes, oceans and significant changes in types of soil and rock). Where practical,

FIGURE 5.1: **Typical Groundwater Surface Map**



mapping should include the entire groundwater resource as well as its borders.

- Observation bores or piezometers (see Section 5.6.2) should be installed in a relatively regular grid pattern over the area of interest. Piezometers should be located such that the difference in water levels between adjacent piezometers is less than the planned contour interval of the map.
- Ambient groundwater levels should be measured at regular temporal intervals to identify seasonal fluctuations as well as responses to rainfall and periods of drought. Care should be taken to gather ambient data well before activities such as pumping are commenced.
- Interpolation packages available for computer simulation of contours may be used to generate maps from gathered data. Each map should be a snapshot of groundwater levels for the relevant period of monitoring.

5.6.2 TESTING AND MONITORING

Groundwater testing and monitoring is carried out to establish water quality and changes in quality, and water levels and changes in levels.

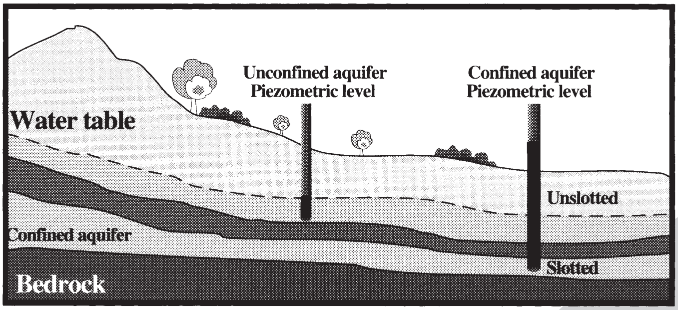
Testing and monitoring should be undertaken for ambient or pre-existing groundwater reserves to establish baseline groundwater characteristics. Testing and monitoring subsequent to events such as pumping, recharge and contaminant leakage can then be used to derive groundwater parameters related to these events. These parameters allow calculation of quantities such as drawdown for various pumping rates, rates of recharge or speed and direction of contaminant flow.

Prior to establishing a groundwater testing program, hydrogeologists and analytical laboratories should be consulted to determine the appropriate testing, sampling and storage methods required for identification of individual compounds in the groundwater. Samples may need to be gathered and stored in non-reactive containers to ensure that they are not contaminated. Special care may be required for biologically active contaminants.

Groundwater levels and quality may be monitored using piezometers. Piezometers extending into unconfined (water table) aquifers show water levels which represent the surrounding water table level. Piezometers extending into confined aquifers show water levels which represent the pressure existing within the aquifer. When there are strong flows within the aquifer, a component of the measured pressure may result from inertial forces as well as static groundwater levels.

Figure 5.2 indicates the water levels given by piezometers in unconfined and confined aquifers.

FIGURE 5.2: **Relationship Between Piezometric Level and Groundwater**



Piezometer Construction

A piezometer is simply an open stilling well into which a probe may be inserted to measure water level or quality, or from which a sample of the groundwater can be collected. Piezometers are primarily made of either PVC (polyvinyl chloride) or ABS (acrylonitrile butadiene styrene).

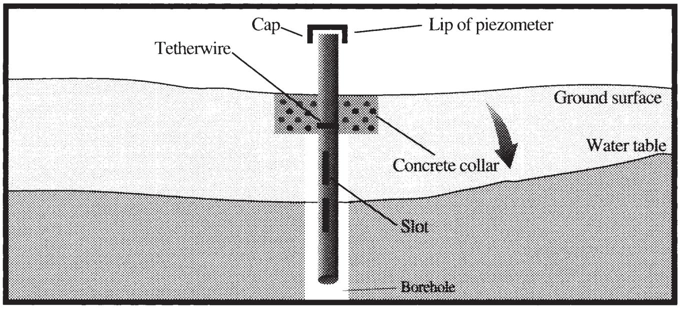
The material chosen for piezometer construction should have strength, rigidity, low maintenance, resistance to galvanic and electrochemical corrosion, resistance to abrasion, high strength-to-weight ratios, partial flexibility and low cost.

Other considerations are:

- piezometers may be installed using a variety of means from hand augers to drilling rigs. In all cases, the piezometer tube is installed after drilling a hole of sufficient diameter and depth;
- the diameter of the piezometer used depends on the type of monitoring or sampling that needs to be carried out. The sizes of probes and sampling devices need to be considered. It is rare to find piezometers of less than 50 mm in diameter, and 100 mm diameter piezometers are common;
- the length of the piezometer needs to be sufficient to measure the maximum possible drawdown;
- when monitoring confined aquifers, the well may need to protrude significantly above ground, in order to measure the standing head of the water. However, if this protrusion becomes impractical, the well may be capped and a pressure transducer installed within it;
- wells should be slotted or screened to facilitate a good connection to the aquifer. Open-bottomed, unslotted wells may be used effectively in granular soils;
- slotted wells often form the cheapest alternative, as slots may be machined by the manufacturer or cut by hand on site. Slots should be cut liberally (either horizontally or vertically) but should be small enough to exclude significant intake of soil. Porous geotextile fabrics may be used to filter out soil particles if required;
- prevention of contamination is critical for the collection of water quality data; the installation of slotted or screened casing will be important. In these instances, a hydrogeologist should be consulted to provide appropriate well designs;
- piezometers should be capped at the surface, preferably with a screw-in cap for ease of removal and re-application;
- a tether wire and concrete collar serve to anchor the piezometer and reduce the risk of slippage in unconsolidated material or accidental movement from outside impact; and
- the lip of the piezometer should be surveyed into the mine datum or Australian Height Datum (AHD), as this is the most convenient point of reference for manual monitoring.

Figure 5.3 shows a typical piezometer installation.

FIGURE 5.3: **Typical Piezometer Installation**



Monitoring

Monitoring of piezometric levels may be performed manually or remotely. Manual devices include:

- dip meters: these comprise an electrical sensor at the end of a graduated wire. Contact with water completes the electrical circuit between sensor and wire, causing a tone to be emitted (see Figure 5.4). The distance between the sensor and the reference point (eg. the lip of the piezometer) may be read off the graduated wire. Dip meters are popular because of the ease and speed of use; and
- graduated transparent piezometers or manometers (when the piezometric level is above ground).

Remote monitoring is carried out using a sensor installed within the piezometer. The sensor may be connected to a central monitoring system or to a data logger which reads, at regular intervals, the voltage output at the sensor. The data logger may be downloaded regularly using a portable computer, or may have removable memory banks which can be replaced and downloaded later. The recorded voltages are then translated into water levels via calibration relationships. Popular sensors include:

- pressure transducers;
- capacitance probes; and
- float levels.

Remote monitoring carries a much higher risk of data contamination or error. A rigorous schedule of equipment maintenance, data verification using manual methods, and frequent calibration checks should be in place.

Groundwater Sampling

Testing of groundwater quality may be carried out using in-situ methods or by the extraction of a representative sample. A range of field equipment exists for measuring such basic parameters as pH and conductivity, using probes which may be lowered into piezometers.

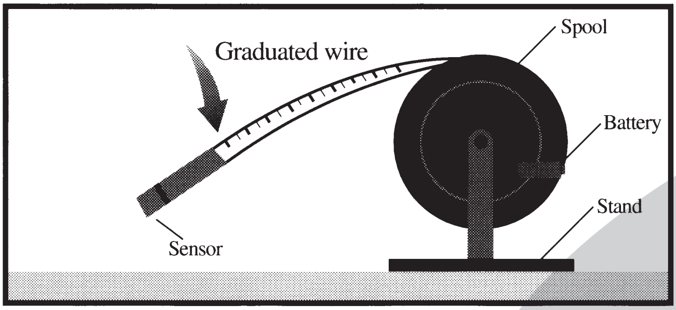
Groundwater samples are normally collected from a piezometer or bore using one of two techniques: a bailer or submersible pump. Submersible pumps powered by a battery or generator are preferred due to the large volumes of water that need to be displaced from a bore prior to the collection of a representative groundwater sample.

In addition to these two methods, groundwater samples may also be collected from sample valves located near above-ground pumps on water supply bores.

When groundwater samples are to be collected, the following should be considered:

- the piezometer or bore needs to be purged prior to sample collection. This technique must be used in order to obtain a representative

FIGURE 5.4: **Diagram of a Piezometer Dip Meter**



groundwater or aquifer sample. In the absence of extensive pumping, the sample collected will merely represent water held in the bore or piezometer which has been exposed to atmospheric conditions. Extensive pumping also reduces cross contamination of the sampling equipment between bores. Typically, three times the volume of water held in the piezometer or bore needs to be removed prior to sampling;

- if a bailer is used then extensive bailing of water held in the bore must be undertaken prior to sample collection. Most bailers only have about one litre capacity and consequently manual bailing of a bore can be a time consuming procedure. If sufficient funds are available, disposable bailers should be considered to eliminate the risk of sample contamination between bores; and
- appropriate sample containers, rinsing procedures and preservation techniques must be used, as for surface waters.

5.6.3 GROUNDWATER PARAMETERS

Physical and chemical parameters are of interest when attempting to characterise and model aquifers in order to simulate various scenarios. Groundwater parameters are best obtained by stressing the aquifer and observing the response induced. These stresses are typically obtained by pumping water out of the aquifer or pumping water into the aquifer via bores.

A large range of pump tests and analytical methods exist for this purpose. Advice from qualified hydrogeologists should be sought to determine:

- which parameters are of interest;
- cost-effective methods of obtaining this data; and
- the applicability of these methods to site-specific conditions.

5.6.4 PREDICTION OF GROUNDWATER CHARACTERISTICS AND RESPONSES

Prediction of aquifer responses to various scenarios allows “what if ... ?” questions to be answered. Predictive modelling may be carried out using analytical models (simplified equations) or, more recently, numerical models which use the technically rigorous and complex physics of groundwater flow. Numerical models have developed significantly in the last two decades and their popularity has increased. A brief discussion of the types of numerical models is presented in Fact Sheet No.12, and advantages and disadvantages of using numerical models are summarised in Table 5.3.

Predictive modelling in groundwater now enjoys widespread use and offers significant benefits in assessing groundwater-related issues. An increasing environmental focus in the mining industry and the recognition of groundwater as a fragile natural resource has seen the expanding use of groundwater models. Models simulating contaminant transport in groundwater and root-zone behaviour are now widely available.

Predictive modelling should always be used with a questioning attitude, and a rigorous process of calibration, verification and sensitivity analysis should be an integral part of any modelling program.

5.7 *Review of Monitoring Data*

For a vast majority of existing monitoring programs, insufficient time is spent actually reviewing and analysing the data. Regular screening of data can detect problems in sampling and analytical techniques as well as in hydrographic data recording systems.

TABLE 5.3: **Advantages and Disadvantages of Using Numerical Models**

Primary Advantages	***Primary Disadvantages***
• Ability to run complex and lengthy calculations in increasingly short times as computers evolve rapidly; • a low level of labour intensity during simulations; • high capacity for testing the sensitivity to groundwater parameters; • the development of increasingly visual outputs, which allow the lay person to understand the answers proposed by the models; and • flexibility in assessing a range of scenarios quickly and easily.	• Initially high level of labour intensity during setting up a numerical model; • development of a 'black box' mentality which results in the widespread use of models without understanding of concepts and limitations; • a tendency among the public to perceive models as infallible and acceptance of results as the literal truth; and • high capacity for misunderstanding or misuse of models because of their complexity.

A review of the data set can establish seasonal trends and will detect analyses that are unwarranted (ie. those continually below the detection limit). Sites with data that do not fluctuate to any degree can be sampled less frequently to reduce costs.

Regular review will also forewarn management of any impending changes which may effect the sites ability to obtain or discharge water or any breaches in compliance with statutory obligations. Presentation of data in a graphical format allows easy scanning of large numbers of results and identification of trends in the data.