Series G: General Guidelines

G3

BEST PRACTICE GUIDELINE

Water Monitoring Systems

Best Practice Guidelines for Water Resource Protection in the South African Mining Industry

DIRECTORATE: RESOURCE PROTECTION & WASTE

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DOCUMENT INDEX

This document is the third in a series of the following General aspects Best Practice Guideline documents:

BPG G1: Storm Water Management

BPG G2: Water and Salt Balances

BPG G3: Water Monitoring Systems

BPG G4: Impact Prediction

ACKOWLEDGE-MENTS

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Since 1999 a number of steering committee meetings and stakeholder workshops were held at various stages of the development and drafting of this series of Best Practice Guidelines for Water Resource Protection in the South African Mining Industry.

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APPROVALS

This document is approved by the Department of Water Affairs and Forestry

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PREFACE

Water is typically the prime environmental medium (besides air) that is affected by mining activities. Mining adversely affects water quality and poses a significant risk to South Africa's water resources. Mining operations can further substantially alter the hydrological and topographical characteristics of the mining areas and subsequently affect the surface runoff, soil moisture, evapo-transpiration and groundwater behaviour. Failure to manage impacts on water resources (surface and groundwater) in an acceptable manner throughout the life-of-mine and post-closure, on both a local and regional scale, will result in the mining industry finding it increasingly difficult to obtain community and government support for existing and future projects. Consequently, sound management practices to prevent or minimise water pollution are fundamental for mining operations to be sustainable.

Pro-active management of environmental impacts is required from the outset of mining activities. Internationally, principles of sustainable environmental management have developed rapidly in the past few years. Locally the Department of Water Affairs and Forestry (DWAF) and the mining industry have made major strides together in developing principles and approaches for the effective management of water within the industry. This has largely been achieved through the establishment of joint structures where problems have been discussed and addressed through co-operation.

The Bill of Rights in the Constitution of the Republic of South Africa, 1996 (Act 108 of 1996) enshrines the concept of sustainability; specifying rights regarding the environment, water, access to information and just administrative action. These rights and other requirements are further legislated through the National Water Act (NWA), 1998 (Act 36 of 1998). The latter is the primary statute providing the legal basis for water management in South Africa and has to ensure ecological integrity, economic growth and social equity when managing and using water. Use of water for mining and related activities is also regulated through regulations that were updated after the promulgation of the NWA (Government Notice No. GN704 dated 4 June 1999).

The NWA introduced the concept of Integrated Water Resource Management (IWRM), comprising all aspects of the water resource, including water quality, water quantity and the aquatic ecosystem quality (quality of the aquatic biota and in-stream and riparian habitat). The IWRM approach provides for both resource directed and source directed measures. Resource directed measures aim to protect and manage the receiving environment. Examples of resource directed actions are the formulation of resource quality objectives and the development of associated strategies to ensure ongoing attainment of these objectives; catchment management strategies and the establishment of catchment management agencies (CMAs) to implement these strategies.

On the other hand, source directed measures aim to control the impacts at source through the identification and implementation of pollution prevention, water reuse and water treatment mechanisms.

he integration of resource and source directed measures forms the basis of the *hierarchy of decision-taking* aimed at protecting the resource from waste impacts. This hierarchy is based on a *precautionary approach* and the following order of priority for mine water and waste management decisions and/or actions is applicable:

RESOURCE PROTECTION AND WASTE MANAGEMENT HIERARCHY

Step 1: Pollution Prevention

↓

Step 2: Minimisation of Impacts
Water reuse and reclamation
Water treatment

↓

Step 3: Discharge or disposal of waste and/or waste water
Site specific risk based approach
Polluter pays principle

The documentation describing Water Resource Protection and Waste Management in South Africa is being developed at a number of different levels, as described and illustrated in the schematic diagram below page.

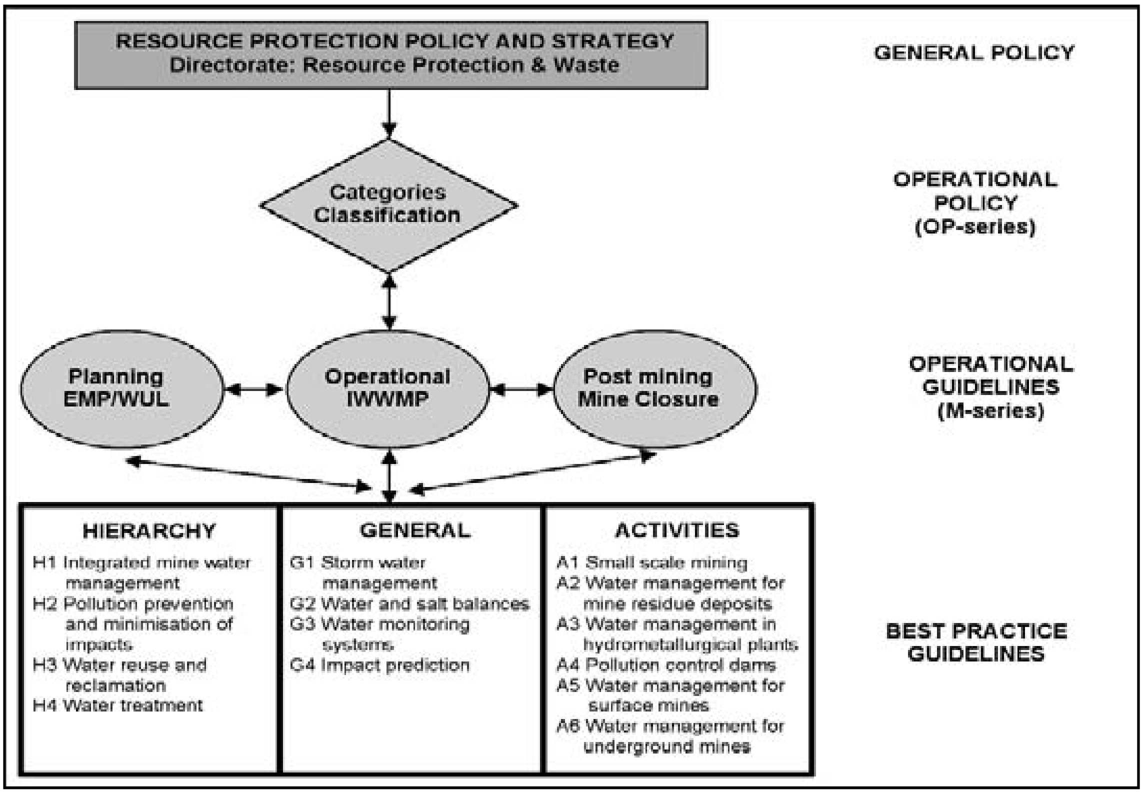
The overall Resource Protection and Waste Management Policy sets out the interpretation of policy and legal principles as well as functional and organisational arrangements for resource protection and waste management in South Africa.

Operational policies describe the rules applicable to different categories and aspects relating to waste discharge and disposal activities. Such activities from the mining sector are categorised and classified, based on their potential risks to the water environment.

Operational Guidelines contain the requirements for specific documents e.g. licence application reports.

Best Practice Guidelines (BPG's) define and document best practices for water and waste management.

Schematic Diagram of the Mining Sector Resource Protection and Waste Management Strategy



The DWAF has developed a series of Best Practice Guidelines (BPGs) for mines in line with International Principles and Approaches towards sustainability. The series of BPGs have been grouped as outlined below:

BEST PRACTICE GUIDELINES dealing with aspects of DWAF's water management HIERARCHY are prefaced with the letter H. The topics that are covered in these guidelines include:

- H1. Integrated Mine Water Management
- H2. Pollution Prevention and Minimisation of Impacts
- H3. Water Reuse and Reclamation
- H4. Water Treatment

BEST PRACTICE GUIDELINES dealing with GENERAL water management strategies, techniques and tools, which could be applied cross-sectoral and always prefaced by the letter G. The topics that are covered in these guidelines include:

- G1. Storm Water Management
- G2. Water and Salt Balances
- G3. Water Monitoring Systems
- G4. Impact Prediction

BEST PRACTICE GUIDELINES dealing with specific mining ACTIVITIES or ASPECTS and always prefaced by the letter A. These guidelines address the prevention and management of impacts from:

- A1 Small-scale Mining
- A2 Water Management for Mine Residue Deposits
- A3. Water Management in Hydrometallurgical Plants
- A4 Pollution Control Dams
- A5 Water Management for Surface Mines
- A6 Water Management for Underground Mines

The development of the guidelines is an inclusive consultative process that incorporates the input from a wide range of experts, including specialists within and outside the mining industry and government. The process of identifying which BPGs to prepare, who should participate in the preparation and consultative processes, and the approval of the BPGs was managed by a Project Steering Committee (PSC) with representation by key role-players.

The BPGs will perform the following functions within the hierarchy of decision making:

- Utilisation by the mining sector as input for compiling water use licence applications (and other legally required documents such as EMPs, EIAs, closure plans, etc.) and for drafting licence conditions.
- Serve as a uniform basis for negotiations through the licensing process prescribed by the NWA.
- Used specifically by DWAF personnel as a basis for negotiation with the mining industry, and likewise by the mining industry as a guideline as to what the DWAF considers as best practice in resource protection and waste management.
- Inform Interested and Affected Parties on good practice at mines.

The information contained in the BPGs will be transferred through a structured knowledge transfer process, which includes the following steps:

- Workshops in key mining regions open to all interested parties, including representatives from the mining industry, government and the public.
- Provision of material to mining industry training groups for inclusion into standard employee training programmes.
- Provision of material to tertiary education institutions for inclusion into existing training programmes.
- Provision of electronic BPGs on the DWAF Internet web page.

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FIGURES

TABLES

1 INTRODUCTION AND OBJECTIVES OF THIS BEST PRACTICE GUIDELINE

Accurate and reliable data forms a key component of many environmental management actions. Some of these actions may receive more focus from government officials, whilst others may be more important for the mine personnel. Water monitoring is a legal requirement and can be used in negotiations with authorities for permits etc. The most common environmental management actions require data and thus the objectives of water monitoring include the following:

- Development of environmental and water management plans based on impact and incident monitoring (facilitate in decision-making, serve as early warning to indicate remedial measures or that actions are required in certain areas) for the mine and region.
- Generation of baseline/background data before project implementation.
- Identification of sources of pollution and extent of pollution (legal implications or liabilities associated with the risks of contamination moving off site).
- Monitoring of water usage by different users (control of cost and maximizing of water reuse).
- Calibration and verification of various prediction and assessment models (planning for decommissioning and closure with regards to financial provision and required actions).
- Identification and design of appropriate water treatment technology.
- Control of unit processes such as water treatment plants or process plants (through process control loops).
- Evaluation and auditing of the success of implemented management actions (ISO 14000, compliance monitoring).
- Assessment of compliance with set standards and legislation (EMPs, water use licenses).
- Assessment of impact on receiving water environment.

Without reliable measurement of water quality and quantity, the above functions cannot be undertaken - hence the saying that "one cannot manage that which one cannot measure". This Best Practice Guideline (BPG) has been developed to assist in this process by addressing the following objectives:

- To provide clear guidelines on how to design an effective monitoring programme that meets defined management needs.
- To provide guidelines on how to implement a monitoring programme such that the acquired data is reliable and supportive of the defined management needs.
- To provide guidelines on how to interpret, manage and report the data obtained from implemented monitoring programmes.

As the collection of data is driven by the requirements of environmental and water management actions, this BPG will also contain cross-references to other BPGs that depend on monitoring programmes for the provision of data. This BPG will not evaluate or recommend specific types of monitoring equipment or monitoring/analytical services provided by different suppliers. Although no specific legislation is addressed in this guideline, it is important that any applicable legislation should be taken into consideration during the development of the monitoring programme.

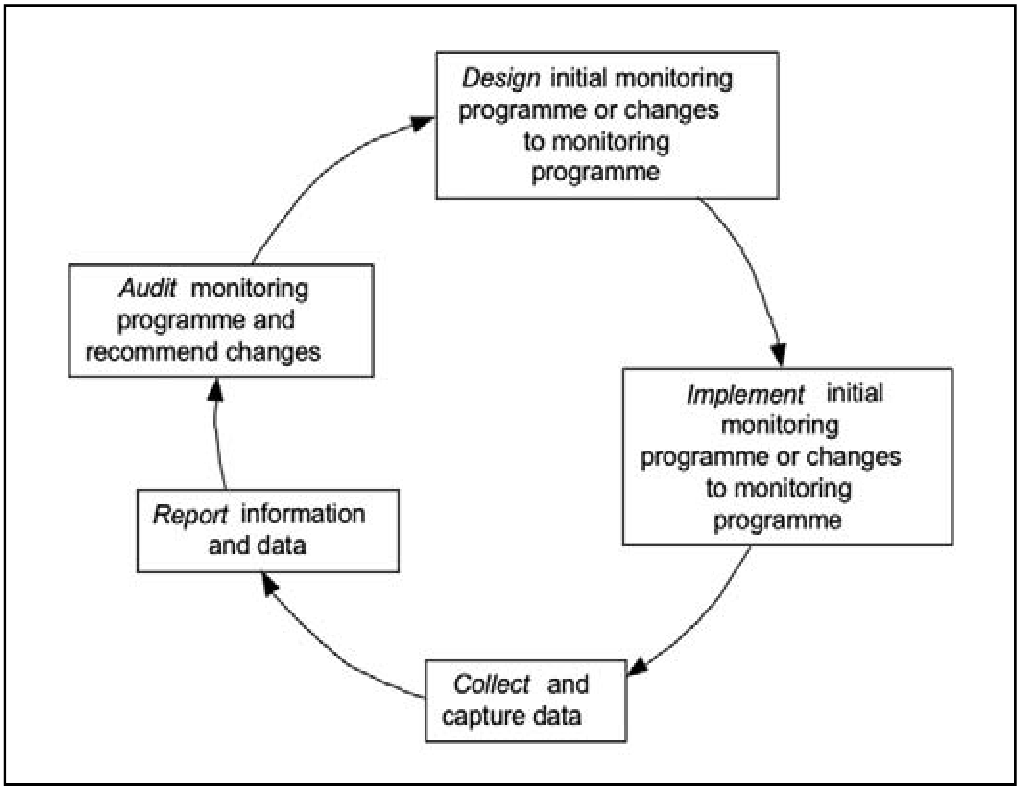
2 GENERAL PRINCIPLES OF WATER MONITORING SYSTEMS

Monitoring on a mine consists of various components as illustrated by the overall monitoring process (Figure 2.1). It must be recognized and understood that the successful development and implementation of an appropriate, accurate and reliable monitoring programme requires that a defined structured procedure be followed. Furthermore, it is important that this is done by a suitably qualified person.

As discussed in Chapter 1, monitoring programmes can be developed to support various management actions that have different primary objectives. The detailed features of monitoring programmes tend to be very site-specific. As a result, there is no single uniform procedure that can be followed when defining and implementing a monitoring programme. However, there are a number of general principles that need to be followed when developing these site-specific monitoring programmes to ensure that the data and information that are collected are appropriate and reliable:

- Interested and affected parties should be consulted at the appropriate time during the development of the monitoring programme. The monitoring programme should be able to address their concerns and provide answers to their questions.
- The objectives of the management actions that drive the monitoring programme must be clearly defined, together with the data and information requirements that support these objectives.

Figure 2.1: Monitoring process



- A detailed design of the monitoring programme must be undertaken. This should define the location of all monitoring points (indicated on a map), the type of data to be collected, as well as the data collection (protocol/procedure/methodology, frequency of monitoring and parameters determined, quality control and assurance), management (database and assessment) and reporting procedures.
- The monitoring programme should be implemented according to the detailed design. The implemented programme should be able to deliver the data and information that are required to achieve the objectives of the programme.
- The results from the monitoring programme should be representative of the actual situation. This requires that the monitoring programme should cover the relevant area in sufficient detail with a sufficient amount of appropriate monitoring points. It also requires that the sampling and monitoring should be undertaken according to procedures that will ensure representative samples and data.
- To ensure that the monitoring programme functions properly, an operating and maintenance programme should be developed and implemented.
- A well-defined data management system is required to ensure that data is used optimally and is accessible to all the relevant users.
- The monitoring programme must include quality control measures and audits to ensure that the collected data are meeting the defined objectives.

Each of these above-mentioned principles is fairly broadly stated and requires logical and progressive consideration by means of different technical steps as set out in Chapter 3 of this BPG.

A monitoring programme is a dynamic system that should change as the mine and water management needs change. The data requirements differ at each of the life cycle phases of a mine and should be taken into consideration when a water monitoring system is developed and managed. A monitoring system that is developed for the planning phase will for example focus on gathering background and baseline data. The focus of the monitoring system will then change for example to compliance monitoring when the mine is in operation. During the closure phase the monitoring system will also have to collect data that can be used to verify simulated predictions by models that predict long-term impacts.

Effective water monitoring systems on a mine consist of the following components:

- Surface and ground water quality monitoring system.
- Surface and ground water flow monitoring system.
- Biomonitoring.
- Data and information management system.

These different systems can be constructed and developed in different ways, using different measurement and monitoring techniques and different data storage, interpretation and presentation techniques. These different options are discussed in Chapter 4 of this guideline.

The application of the principles and the stepwise procedure to develop a monitoring programme is presented in a practical example in Chapter 5.

3 PRACTICAL STEPS AND CONSIDERATIONS

The process of developing and implementing a successful monitoring programme can be divided into 4 primary phases as shown in Figure 3.1. The process follows a logical sequence from designing the monitoring programme, through implementation and managing the programme to auditing the programme. The process is, however, a continuous process where recommendations from the auditing need to be incorporated by repeating the process from Phase 1, namely the design aspects of the monitoring programme. When a monitoring programme is developed, it is important to be familiar with and to understand the whole process as discussed in this chapter, before the process is started. It is also important that the entire process from Phase 1 to Phase 4 should be executed to develop a complete monitoring programme.

Risk assessment needs to be built into any monitoring programme and it is important to determine the risk of water being polluted from different sources and its associated impact. Considering this before the design of the monitoring system will ensure that the monitoring system is adequate. Issues to consider in the risk assessment include:

- Potential or actual water use
- Aquifer or catchment vulnerability
- Toxicity of chemicals
- Potential for seepage or releases
- Quantities and frequency of release to the environment (point and non-point).
- Management measures in place to minimize risk.

There are various alternative methods available for water quality and flow monitoring, as well as biomonitoring. These alternatives, together with aspects that need to be considered when taking samples, will be discussed in Chapter 4. Besides the alternatives for monitoring, there are also various methods available to manage data and information, which will also be addressed in Chapter 4.

Phase 1: Design the Monitoring Programme

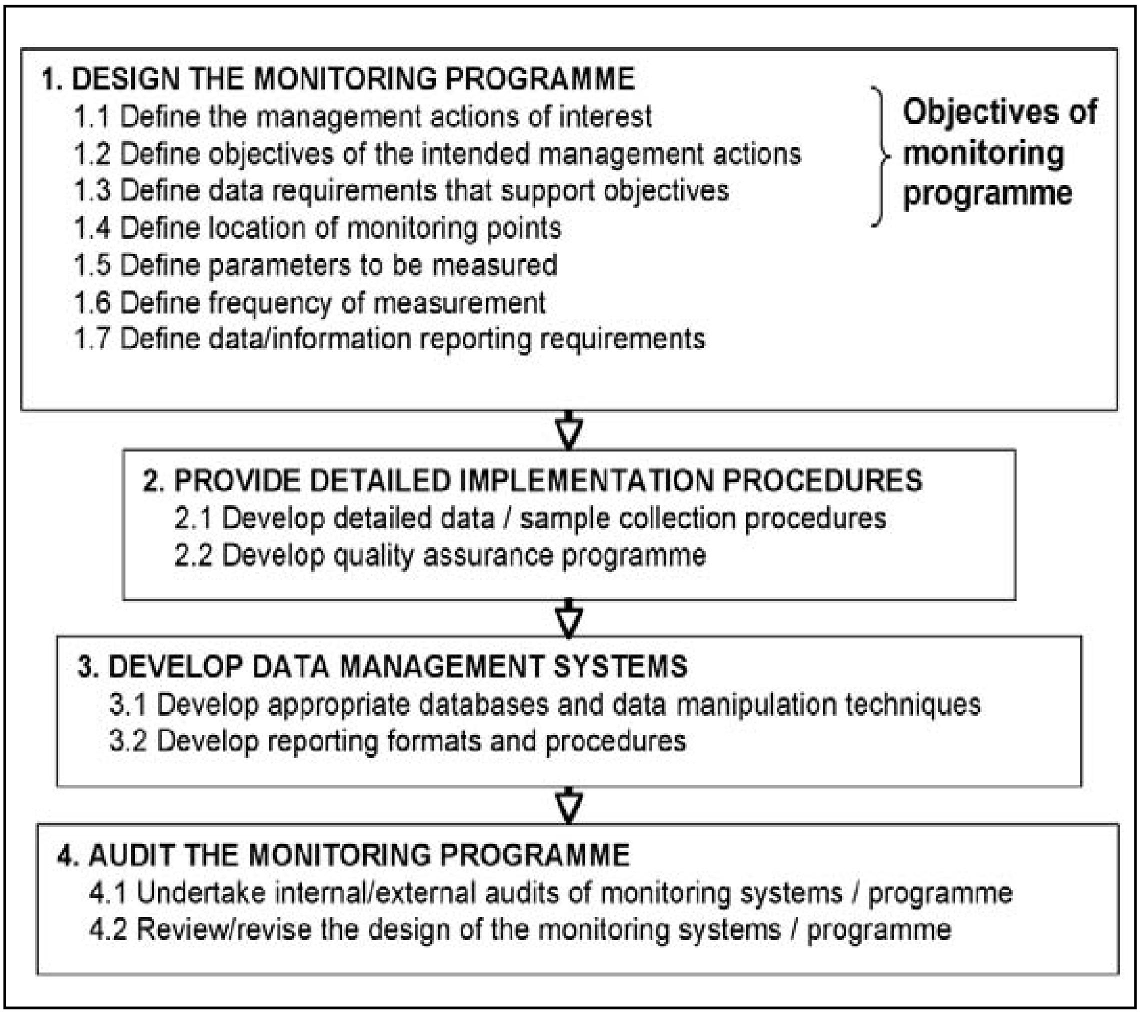
The diversity of climates, ecosystems, land uses and topography influences the design of a monitoring programme. Social factors have also become important elements in environmental management based on the Constitution of South Africa. The monitoring programme designed will thus be very site-specific and will need to consider regional physical and social factors. As indicated in Figure 3.1, this phase has been subdivided into seven steps, each of which is discussed in more detail below.

Step 1.1 Define the Management Actions of Interest

Monitoring programmes are very site-specific and need to be tailored to meet a specific set of needs or expectations. A clear understanding of the practices (technologies, processes) and procedures at the site is important before a monitoring programme can be established. The first step in ensuring that an appropriate monitoring programme is developed, is to clearly understand and define the management action that the monitoring programme is intended to support and how the data collected will be used in the decision-making process. The reasons for acquiring accurate and reliable data (listed in Chapter 1), for example the development of environmental and water management plans, identification of sources of pollution and assessment of compliance with set standards, are also examples of typical management actions that require the support of a monitoring programme.

Each of the management actions has unique objectives and monitoring requirements, and these will be discussed in the subsequent steps.

Figure 3.1: Procedure to develop a monitoring programme



Step 1.2 Define Objectives of the Intended Management Actions

The objectives that the intended management action aims to meet, need to be clearly defined in order to ensure that appropriate data are collected. It is recommended that the objectives be specific, measurable, implementable/ feasible and that they adhere to the principles discussed in Chapter 2. For example, the objectives of the first management action listed in Chapter 1 above, i.e. the development of environmental and water management plans, could be as follows:

- Identify all point and diffuse pollution sources on the mine.
- Identify and quantify all uses of water on the mine.
- Determine the water quality required for the water uses on the mine.
- Develop water and salt balances for different water circuits.
- Develop a mine catchment model (hydrology and water quality) that can simulate impacts of the mine and effects of management strategies.
- Develop and implement appropriate water reclamation strategies.

As another example, the technical objectives of the sixth management action listed in Chapter 1 above, i.e. the identification and design of appropriate water treatment technology, could be as follows:

- Identify current and future water uses and determine water quality and quantity requirements for these.

- Define historical, current and future quality and quantity of the water to be treated.
- Define critical water quality/quantity parameters for the water treatment options under consideration (in terms of absolute values and variability).
- Identify appropriate water treatment options.

Step 1.3 Define Data Requirements that Support Objectives

Once the objectives of the intended management action have been clearly defined, an action plan that details the practical steps that will be followed to meet the objectives must be defined. This process should clearly identify the data requirements associated with these practical steps. An example is shown below for the first objective of management action 1 of Step 1.2 above, i.e. identify all significant point and diffuse pollution sources on the mine (this example is extended in the practical example in Chapter 5).

Objective: Identify all significant point and diffuse pollution sources on the mine

Practical steps:

1.3.1 Identify all known potential point and diffuse sources of pollution (e.g. residue deposits, domestic waste dumps, point discharges, sewage treatment plants, beneficiation plants, mine shaft areas, etc.)

1.3.2 Define key indicators of pollution for each source (e.g. sulphate, conductivity for residue deposits, nitrogen and phosphorus for sewage plants, cyanide for an active gold mine slimes dam, etc.)

1.3.3 Have a suitably qualified person evaluate groundwater qualities and quantities from existing boreholes in the vicinity of the potential pollution sources.

1.3.4 Divide mine into sub-catchments on the basis of stream confluences, known pollution points, abstraction points and mine boundaries.

1.3.5 Collect flow data, together with key water quality indicator data at the upstream and downstream points of key sub-catchments.

1.3.6 Establish whether the calculated added or subtracted pollution load can be accounted for by known quantified sources or abstraction points. If not, undertake a river profiling exercise in order to locate diffuse sources of pollution or unknown point sources of pollution or water abstraction points (this may require drilling, digging of test pits or trenches, sampling of surface soils).

1.3.7 Develop water and salt balances for the different sub-catchments, sources, units or whole mine area (see *BPG G2 - Water and Salt Balances*).

1.3.8 Establish whether there will be any long-term changes to the point and diffuse sources. For example, if the source contains sulphide minerals or other acid generating minerals that are geochemically unstable, then the nature of the pollution will change with time and this will need to be predicted using appropriate techniques and additional monitoring programmes will be required (as described in *BPG G4 – Impact Prediction*).

In this example, steps 1.3.2; 1.3.3; 1.3.5; 1.3.6 and 1.3.8 all contribute towards defining the data requirements.

At this stage in the development of the monitoring programme, it should be determined whether there are any other monitoring programmes that are being developed or existing on the mine (and probably in the region/catchment). If there are any overlaps between the different systems, these systems should be integrated (catchment management strategy). The integration of the different monitoring programmes should aim to optimize the cost, operation, maintenance and management of the different systems.

Steps 1.1 to 1.3 combined will assist in determining the objectives of the monitoring programme. These steps address the "why should one monitor" question.

Step 1.4 Define Location of Monitoring Points

This step addresses the "where" to monitor question. It is important to be aware of the aspects that are addressed in Sections 4.1 and 4.2 on auditing the monitoring programme when Steps 1.4 – 1.6 are undertaken.

The location of the required monitoring points is also logically derived from the process of defining the practical steps needed to satisfy the objectives. For the example shown in Step 1.3 above, Steps 1.3.1; 1.3.4; 1.3.5 and 1.3.6 all contribute towards defining the location of monitoring points. For other management actions, such as the second-last action listed in Chapter 1, i.e.

assessment of compliance with set standards (EMPs, water use licenses), a somewhat different process would be developed in Step 1.3 and it may be desirable to define different types of monitoring points depending on the nature and type of data required. Key monitoring points (e.g. compliance monitoring points) could, for example, require continuous monitoring stations and the location of such stations is largely dictated by geotechnical factors such as local topography and soil conditions. In some cases, the location of key monitoring points could be defined by the authorities on the basis of catchment management plans. A suitably qualified person is required to define the locations of groundwater monitoring points, for example monitoring boreholes can not be placed at random, but should be placed at the most suitable location to collect the required data accurately, considering groundwater flow directions, depth of groundwater table, pollution source localities, pollution plumes etc. A monitoring borehole that is not placed at the correct location or that is too shallow may indicate incorrect water quality or flow, which can lead to inaccurate assessments and wrong decisions.

The location of the monitoring points should be clearly indicated on a map in such a way that it can be found by a person not familiar with the exact point (GPS referencing, GIS based map or based on infrastructure such as roads, bridges, rivers, etc., indicated on the map). Monitoring points could be registered on the DWAF water monitoring system database (check with DWAF on the procedure for this).

Step 1.5 Define Parameters to be Measured

This step addresses the "what" to monitor question. Based on the data requirements defined in Step 1.3, it will be possible to identify the parameters that should be measured. For example the key indicators of pollution could comprise specific parameters, like cyanide, sulphate or ammonia; assessment models that could be used could require specific input parameters, like pH, temperature and BOD (biological oxygen demand); and the development of water and salt balances could require specific parameters, like non-conservative salts. The reserve determination done for a water use license application may also require a mine to monitor for specific parameters. In certain instances, it may be valuable to only monitor key indicators at certain positions such as EC (electrical conductivity) and only when this indicator parameter shows significant change would it be required to analyze water in more detail by monitoring more parameters.

It is important to identify all the necessary parameters at this stage to minimize knowledge gaps when modeling and interpretation are undertaken. A lack of important data at a later stage in the process may cause considerable delays and additional finances in order to collect this data or may not practically be possible since the data is required for the same period in time for which other parameters were determined. For example, in-situ redox potential and temperature may be required with sulphide, pH, EC and other measurements. Besides the identification of the parameters, it is also important to identify the correct state of the parameter, e.g. dissolved or total iron; free or total cyanide; ammonia, nitrate or total nitrogen.

A phased monitoring programme can be implemented where a wide variety of tests are undertaken in the initial phase to identify water quality parameters specifically significant to the mining operations. In the follow-up phase only parameters of specific interest can be monitored. Based on the outcome of the identification of parameters to be measured and Step 1.4 above, a schedule should be prepared that clearly identifies the parameters that need to be measured at each monitoring point - including water quality variables, biomonitoring variables and flow. This is best done in a tabular format, as indicated in Example 1 below. It is recommended that the list of parameters be rationalized (see example 1 below). This will simplify the monitoring parameters and reduce the risk of confusion and errors during implementation of the monitoring programme. It is generally advised that no more than 4 or 5 different combinations of parameters be developed. If each identified monitoring point has a unique set of parameters that must be measured, a high risk exists that there will be confusion at some stage during the monitoring programme in labeling or analyzing the sample.

When rationalising the list of parameters to be measured, it is also important to give some thought to the quality assurance programme (Step 2.2). For example, it may be necessary to expand the set of parameters to be measured to support the calculation of ionic balances at key monitoring points. It is also important to ensure that the data requirements of any model that will be used, are met.

As indicated in Chapter 2, the monitoring programme needs to adapt and change according to the requirements of the different phases during the mine's life-cycle. One of the components that will most likely change during the life cycle of the mine is the parameters to be measured. It should thus be reviewed regularly, as indicated in Phase 4, and changed when it is required.

Climatic data will be important for surface water monitoring and although the Weather Services has a network of monitoring stations, it might be to the advantage of the mine to establish its own weather monitoring station. Variables such as rainfall, evaporation, temperature, humidity, wind direction and wind speed can be monitored. Rainfall, particularly can vary over short distances and has a significant impact on surface water monitoring and should therefore be considered when assessing surface water monitoring data.

Example 1: Rationalising parameters to be measured

Six monitoring points have been identified for a monitoring programme at a hypothetical mine. The parameters that are to be measured at each of the monitoring points are indicated in Table 3.1. To prevent confusion, it is important to indicate the parameters correctly, e.g. not only to indicate "nitrogen", but to indicate whether it is measured as "ammonia", "Kjeldahl nitrogen" or "nitrate".

When the parameters of the sampling points are rationalized, they can be combined as indicated in Table 3.2.

Table 3.1: Sampling points and identified parameters

SAMPLING POINTS					
1	2	3	4	5	6
Ca	Ca	Ca	Ca	Ca	Ca
Na	Na	Na	Na	Na	Na
Cl	Cl	Cl	Cl	Cl	Cl
SO_4	SO_4	SO_4	SO_4	SO_4	SO_4
pH	pH	pH	pH	pH	pH
EC	EC	EC	EC	EC	EC
TDS	TDS	TDS	TDS	TDS	TDS
Temp.	Temp.	Temp.	Temp.	Temp.	Temp.
Al	Al		K		NH_3
Cu	CN				NH_4
Fe	Cu				NO_2
Hg	Fe				NO_3
Mg	Hg				PO_4
Mn	Mn				BOD
Ni	Pb				COD
Pb					E.coli
Zn					Total coli

Table 3.2: Lists of rationalized parameters

A	B	C
Ca	Ca	Ca
Na	Na	Na
Cl	Cl	Cl
SO_4	SO_4	SO_4
pH	pH	pH
EC	EC	EC
TDS	TDS	TDS
Temp.	Temp.	Temp.
Al	K	NH_3
CN		NH_4
Cu		NO_2
Fe		NO_3
Hg		PO_4
Mg		BOD
Mn		COD
Ni		E.coli
Pb		Total coli
Zn		

The parameters to be monitored at each of the sampling points are thus:

Sampling Point	List of Parameters to be Sampled
1 and 2	A
3, 4 and 5	B
6	C

Rationalising the parameters into three lists has the implication that analyses for more parameters might be required for some sampling points than initially identified. This can be seen, for example, when the identified parameters at sampling point 2 are compared to list A, which is the rationalized list of parameters to be analyzed at sampling point 2. If the identified parameters were not rationalized, it would require that samples from each of the six sampling points be analyzed for the six different combinations of parameters. The higher the number of sampling points that are involved, the higher the risk of confusion that can occur during the sample labeling and analyzing process.

It is also important when defining the parameters to be monitored, to decide on the accuracy and precision in the data required, based on what it would be used for, what the objectives are and how critical data is. This may be different for different determinants. For example, potassium does not influence mining activities nor is it expected to undergo any changes within water going through the process (involved in chemical reactions) nor is it's contribution to the ionic balance considered significant, - therefore the accuracy required for potassium determinations may not be as high as it may be for sulphate which might be used as a primary indicator of pollution.

Step 1.6 Define Frequency of Measurement

This step addresses the “when” to monitor question. Once the location of the monitoring points and the parameters to be measured have been defined, it will be necessary to define the frequency of the measurements. The frequency of measurement is dependent on whether continuous or intermittent (grab sampling) data is required and the following factors will usually influence this decision:

- Importance of the monitoring point (Is it a regulatory compliance monitoring point? Is it necessary to obtain a precise understanding of variability with time? Is it a discharge point?)
- The duration into the future over which data will be required from that point. This should take into account the life of the mine, which includes: planning, construction, operation, decommissioning, closure and post-closure.
- Expected variability in quality or flow at that point (surface points are more variable and can change in minutes whereas groundwater is a slow-moving medium and significant changes in water quality are not expected in days).
- The location of the monitoring point (risk of theft or vandalism).
- The available monitoring budget.

Continuous monitoring systems will, due to their cost, generally only be applied at key monitoring points, e.g. sites that include licensed water use and discharge points. Security of continuous monitoring equipment needs to be considered.

For continuous monitoring points, it is necessary to define the time period over which data must be read, averaged and reported (e.g. 5 minutes, 15 minutes, hourly) while for intermittent monitoring points, the frequency between measurements must be defined (e.g. daily, weekly, monthly, quarterly). The purpose for which the data is being collected, and the expected variability in the measured parameters also influence this decision.

When grab samples are taken, it is important to be aware of any short-term cyclical trends. If grab samples are taken at regular intervals that coincide with peak flows the concentration of contaminants may be relatively low due to dilution and the flow rate will generally be higher. When the data is interpreted it will thus be necessary to understand these short-term cyclical trends.

The requirements of a monitoring programme will change during the life cycle of the mine, as mentioned in Chapter 2 and Step 1.5. Besides the identified parameters, it is also necessary for the frequency of monitoring to adapt to the change in requirements. It is therefore important to review both the parameters to be measured and the frequency of measurement, as indicated in Phase 4, and to change these components according to the needs from the different phases of the mine's life-cycle.

Step 1.7 Define Data/Information Reporting Requirements

Once the data has been collected, it is important to ensure that the data is stored in a suitable database system that is flexible enough to cater for anticipated future requirements and future additions/refinements to the monitoring programme. Suitably qualified persons must be identified to enter the data and appropriate control mechanisms must be defined to ensure that no errors occur. For example, calculating ionic balances to check analyses, and the definition of a data review process that will check for transcription errors and other inconsistencies. Statistical requirements need to be defined and taken into consideration when the data management system is developed. Defining the statistical requirements should be done in consultation with the end users.

The end use of the data and the recipients of the data should also be considered when specifying the database structure and/or outputs. For example, if the data is to be used for water quality modeling or water and salt balances, then the data formats of these applications must be considered when developing the data management systems discussed in Phase 3. DWAF requires reporting on water monitoring and this is set out in the water use authorization.

Phase 2: Provide Detailed Implementation Procedures

Once a detailed monitoring programme has been designed in accordance with the 7 steps discussed in Phase 1 above, it will be necessary to develop a system that will ensure that the monitoring programme is properly implemented. This action has been subdivided into 2 steps as follows:

Step 2.1 Develop detailed data/sample collection procedures

Step 2.2 Develop a quality assurance programme

This phase of the development and implementation of a monitoring programme will need to take account of any existing environmental management systems that may be in place on the mine. Sample collection methodologies and techniques have been discussed in published literature (Van Heerden, 1986; Ward, 1990; Thomas, 1992; Weaver, 1992; Pulles, 1995; Pulles, 1996; Minerals Council of Australia, 1997, Water Research Commission reports) and will not be addressed in this guideline.

Aspects regarding water quality sampling that should also be taken into consideration during this phase are discussed in section 4.1.

Step 2.1 Develop Detailed Data/Sample Collection Procedures

This step addresses the "how" to monitor question. Invariably, a number of different persons with different levels of skills and understanding are involved in the implementation of the monitoring programme. A detailed set of data/sample collection procedures is required to ensure that:

- There is a uniform approach/methodology.
- The programme is properly implemented.
- There is continuity when staff resign, are retrenched or are reassigned to different responsibilities.
- Quality control and assurance measures are included.
- Correct equipment is used.
- Safety measures are adhered to.

These procedures should be developed in a format that makes them easy to understand and suitable for use in training. Typical issues that should be covered in these procedures include the following:

- Safety procedures and precautions.
- A practical checklist that indicates all the necessary aspects that should be considered/remembered when collecting samples, e.g. the necessary sampling equipment, sample record sheets, labels, sampling bottles, etc.
- The parameters and the required accuracy of parameters to be measured (see Step 2.2).
- Definition of the appropriate measurement technique at each monitoring point.
- Cleaning and calibration procedures for continuous monitoring and field instruments.
- Data downloading protocols for data loggers on continuous monitoring stations.
- Sampling procedures to ensure representative sampling and elimination of sample contamination during collection.
- Preservation of samples, depending on analyses to be performed. Details regarding preservation should be obtained from the laboratory that will do the analysis.
- Identification and chain of custody of samples.
- Development of data sheets (describing site conditions, name of sampler and relevant observations) that should accompany the sampling report.

The fourth issue listed above, i.e. definition of the appropriate measurement technique at each monitoring point, should be based on the information collected in Step 1 and needs to address:

- Frequency
- Sampling procedure (as discussed in this section)
- Analytical techniques
- Detection limits
- Required precision
- Quality monitoring instruments to be used
- Flow measurement technique to be used

The detailed procedures should be produced in a format that allows updating as and when required and should be incorporated into in-house staff training programmes.

The establishment of monitoring points will also be included during this phase. This may include the drilling and equipping of boreholes and the installation of measuring mechanisms within streams, e.g. weirs.

Step 2.2 Develop Quality Assurance Programme

The value of data and the reliability of assessments made using the data are totally dependent on the accuracy and reliability of the collected data. A decision should be made as to what percentage change in data represents an acceptable change. Order of magnitude changes between two time-related data sets is not acceptable and the analyses have to either be repeated if an analytical error is suspected or the cause of the change needs to be established.

A vital part of the data collection process is the analysis of the samples and it is recommended that reliable, accredited laboratories be used that have internal and external quality assurance programmes. It is also necessary to define the acceptable detection limits for each parameter and to confirm that the laboratory is capable of achieving this and that it is using the appropriate analytical techniques. For example, if a parameter is being measured for which a regulatory compliance standard of 10 µg/l has been set, then it is inappropriate to receive an analysis report from the laboratory reporting the parameter as being less than 50 µg/l. It is recommended that a suitably qualified person defines the required detection limits, as it can be very costly to install measurement systems for a high degree of accuracy that may not be required.

To ensure the integrity of the collected data, it is important that the monitoring programme incorporates a quality assurance programme that covers the following issues:

- Training and testing of personnel.
- Regular audits of actual performance of personnel.
- The development and documentation of standard sample collection and preservation techniques.
- Blank samples such as field blanks – distilled water sample accompanying sampler on field trip to detect any contamination or environmental factors that may impact on samples.
- Taking of duplicate samples for submission to different laboratories or sending spiked samples to laboratories.
- Use of standard reference samples.
- Proper specification of detection limits for all monitoring parameters.
- Regular comparison and calibration of all handheld and field measurements with laboratory measurements.

- Verification of data integrity through consistency checks, ionic balances, and identification, confirmation and rejection of outliers.
- Integration of the monitoring system into existing management systems such as ISO 9000 and/or ISO 14001.
- Review of entered data to ensure absence of data manipulation and transcription errors.
- Archiving and backup of databases.
- Regular reviews and checks of the data management system.

Such a quality assurance programme must be developed at the outset and be integrated into the whole monitoring system.

Phase 3: Develop Data Management Systems

Step 1.7 requires that the end use of the collected data be clearly defined in order that appropriate data management systems can be developed. This process can be divided into the following 2 steps:

Step 3.1 Develop appropriate databases and data anipulation techniques.

Step 3.2 Develop reporting formats and procedures.

Although this process actually starts in Phase 1 (Steps 1.1, 1.2, and 1.7) by defining the objectives and end uses of the data collection programme, it is necessary to translate these requirements into the products described in Steps 3.1 and 3.2 below.

Step 3.1 Develop Appropriate Databases and Data Manipulation Techniques

Due to the increasing complexity of environmental and water management functions on mines, it is recommended that a thorough data review process be undertaken to clearly and completely define the data collection requirements at the mine. Data review and manipulation should assess trends in the short-, medium- and long-term and recognize environmental changes and their causes. This process should lead to the clear definition of the following aspects:

- End users of information and use to which the information will be put.
- Modeling techniques, including the formats of input and output data that will make use of the data. Modeling will produce new data, which will also require a clear definition.
- Reporting requirements (see Step 3.2).

In defining these requirements, it is important to not only consider the current requirements but to also anticipate and define future requirements. It is important that databases be developed with sufficient inherent flexibility to accommodate future changes without the need to scrap existing databases - thereby running the risk of losing historical data.

Various software programmes are available that have a database and spreadsheet function. These programmes can be used to manage, manipulate, store and view the data. Geographic Information Systems (GIS) can also be used to perform the same functions as these programmes. Different types of GIS systems are available from the very simple through to the highly complex. The different types of information management systems are discussed in more detail in Chapter 4.

Manipulation of data should include statistical evaluations, median values can be calculated to assess general conditions, upper and lower limits or considering hydrological cycles can be used to assess seasonal variations and extreme conditions. Statistically calculated values can be compared to standards or objectives set and to assess compliance under different conditions. The uncertainty and variation (standard deviation) should be assessed relative to the amount of datasets.

Step 3.2 Develop Reporting Formats and Procedures

Different persons will use data and information for different purposes and any good data management and reporting system must be capable of accommodating these different requirements. For example, senior management may require a simple summary report that only shows compliance or deviation from defined set objectives/points, together with simple graphics showing historical trends. Senior management would typically also not receive detailed datasets but rather the results of some interpretation of the data, for example, from a water and salt balance.

On the other hand, the environmental or water manager will probably need to see and review the data in some detail in order to identify reasons for observed trends or deviations in the dataset. Such a person may also be actively involved in the manipulation of the data through modeling or the development and updating of water and salt balances.

Whatever the requirement, it is important that appropriate reporting formats and procedures are defined that are simple, standardized and user-friendly for the defined user. It is generally advisable to make use of summary data tables, graphical representation of time series data sets, together with reference to defined standards and limits. The use of simple schematics and geographic representations, wherever relevant, is recommended. The reporting format of data and information should be agreed with the recipient to ensure that the correct information is transferred, e.g. the recipient may not only require averages, but also 95th percentiles.

These defined reporting formats and procedures must be incorporated into the development of the databases as described in Step 3.1.

Phase 4: Audit the Monitoring Programme

The auditing of the monitoring programme will evaluate and review the methods used in the monitoring programme and identify additional information required. It is important to recognize that the environmental and water management requirements and driving forces change from time to time and methods of monitoring improve. Monitoring programmes must, therefore, be updated/modified/improved regularly to reflect these changes or modifications in practices and procedures. The rationalization of monitoring programmes is also required to ensure that the programmes remain effective and properly focused and that they do not entail excessive costs. These aspects are addressed in the following two steps:

Step 4.1 Undertake internal/external audits of monitoring systems/programme.

Step 4.2 Review/revise the design of the monitoring system/programme.

Each of these steps is discussed below.

Step 4.1 Undertake Internal/External Audits of Monitoring Systems/Programme

This step should be included within the quality assurance programme defined in Step 2.2. Anomalies in data and the review thereof should be an on-going task. A decision will thus be made as soon as results are back from the laboratory as to whether the sample needs to be re-analyzed to confirm the anomaly or whether the data will be disregarded. It is recommended that there should be internal audits of the relevance and accuracy of all water monitoring programmes once or twice per year. More frequent audits may be required if the monitoring system identifies serious water management problems. These internal audits should include the following:

- Establish whether the detailed procedures developed in Phase 2 are being correctly implemented.
- Evaluate trends in data to establish whether additional data monitoring points, measurement parameters, or increased monitoring frequency are required or, vice versa, whether a scaling down in the monitoring programme is warranted.
- Check the accuracy and reliability of the laboratory as mentioned in Step 2.2, e.g. submit duplicate samples to different laboratories or send spiked samples to the laboratory,
- Define and evaluate anticipated future data requirements and the associated modifications to the monitoring programme.
- Evaluate the continued suitability of databases, reporting systems and other data management tools.

It is recommended that an independent external audit of the monitoring programme be undertaken at the start of the monitoring programme and thereafter on a less frequent basis than the internal audits. The external audit should cover the same aspects as the internal audit. The advantage of the external audit is that it ensures that there is a "fresh look". These external audits may be undertaken by persons from other mines within the same mining Group or by external consultants.

Step 4.2 Review/Revise the Design of the Monitoring Systems/Programme

Based on the outcome of the audits undertaken in Step 4.1, or in direct response to changing regulations or standards, it may be necessary to review or revise the existing monitoring programme, the monitoring procedures (Step 2.1) and the data management systems (Steps 3.1 and 3.2). When doing so, it is important to verify that the proposed changes are acceptable through discussion with the relevant parties.

4

MONITORING TOOLS

As indicated in Chapter 2, effective water monitoring systems on a mine consist of the following components:

- Water quality monitoring system.
- Water flow monitoring system.
- Biomonitoring.
- Data and information management system.

This chapter will discuss the different options related to these components. The discussion of the options will focus primarily on the different measurement and monitoring techniques and different data storage, interpretation and presentation techniques.

4.1 WATER QUALITY MONITORING SYSTEMS

Water quality monitoring systems can be subdivided in different ways, with the primary distinction being as follows:

- Surface water systems
- Groundwater systems
- Process water systems

Whereas groundwater quality monitoring is typically undertaken as discrete grab samples, surface and process water quality monitoring could be either grab samples or continuous monitoring, depending on the monitoring strategy that has been developed.

Wherever water quality samples need to be taken, consideration must be given to the following issues:

Parameters to be analyzed for: The water quality parameters of interest (identified in the monitoring programme, Step 1.5) must be clearly defined and distinguished on the basis of those that should be measured in-situ (for example redox potential) and those that require special sampling or sample preservation techniques (for example metals and coliforms).

Sampling techniques: Samples taken for microbiological analyses generally require special sampling techniques to ensure that sample contamination does not occur. Water quality samples may require on-site filtration (to remove suspended particles) or preservation techniques that will dictate the use of specialized sampling techniques and storage of samples in different containers. Sampling of groundwater/boreholes may require special pumping/purging or stratified sampling techniques (see Weaver 1992a and 1992b). The sampling techniques also depend on the objective/purpose of sampling and end use of results. Sampling from taps and pipelines requires purging of (removing) the “dead volume” of water that is stagnant in the pipe, before sampling, to ensure that the sample is representative of conditions within the flowing water at the time.

For analysis of certain parameters that may change as redox conditions change, i.e. sulphide, it is necessary to ensure that the sampling technique does not aerate the sample. All sample containers should generally be filled to the brim to ensure that aeration cannot take place. Detailed advice and instructions on the precise sampling techniques should be obtained from the analytical laboratory analyzing the samples as the laboratory measurement techniques play an important role in defining appropriate sampling and preservation techniques.

Sample preservation: Application of the correct sample preservation techniques (in combination with correct sampling techniques) is critical in obtaining reliable water quality data. Although sample preservation starts with applying the correct sampling technique, it is also important to ensure use of the correct container (glass versus plastic for example) and chemical preservation technique (acidification for example). Detailed instructions on sample preservation and appropriate sample containers should be obtained from the analytical laboratory. For example, sampling for microbiological contamination requires use of sterile glass containers; sampling for free cyanide requires use of dark, light-proof containers, and sampling for total metals or radionuclides requires sample acidification. Generally, and especially for microbiological analyses, it is recommended that samples be immediately stored at 4°C and be delivered to the analytical laboratory within 24 hours. Many laboratories may prefer this rather than preservation in the field and will then do the necessary preparation and preservation in the laboratory as soon as the samples are received.

Sample identification: The sample location, date and time of sampling, person taking the sample, weather conditions at the time of sampling and any other relevant information should be entered into a sample register. Key identification information should be indicated on the sample container in a manner that it cannot be accidentally removed. A secure chain of custody system should be established (especially for critical samples where the data may be used for modeling techniques or for regulatory enforcement and compliance measurement) to ensure that samples cannot be tampered with between sampling and analysis in the laboratory or do not go missing. Such a system will also require that receipt and delivery systems (with signatures when samples are handed over from one person to another) are developed and documented.

The four aspects of water quality sampling discussed above should be considered during the implementation of the monitoring programme, as discussed under Phase 2 in Chapter 3.

4.1.1 Water Quality Sampling/Monitoring of Surface Water Systems

As discussed earlier, water quality sampling/monitoring can be distinguished as field measurements, grab samples or continuous monitoring. Composite sampling has elements of both grab and continuous sampling.

Field measurements: These comprise measurements that are taken at the site, for example temperature, pH and EC. These measurements give an immediate reading where sampling for laboratory analysis may be impractical, for example with temperature. Field measurements also make laboratory analysis for the measured components unnecessary, and may only be required for verification. Special measuring equipment (weatherproof, robust etc) is required because of rough field conditions, and should be cleaned and calibrated by a suitably qualified person before use. In some instances, for example for geochemical modeling, in-situ measurements are required.

Grab samples: These are the most common form of water quality samples and are samples taken at a specific point at a specific time and may not be representative of average, worst or best case scenarios but they merely represent a once off glimpse of a situation. Advantages of grab samples are:

- Easy to take.
- Generally does not require expensive equipment.
- Versatile and can be taken anywhere at any time.
- Can be analyzed for any parameter of interest, provided correct procedures are used.

Disadvantages of grab samples are:

- Samples are only representative of the instant when they were taken.
- Important fluctuations and variations may be missed.
- A substantial database of repeat samples must be established before statistically relevant interpretation of data can take place.

Care should be taken to prevent incorrect sampling for both grab and continuous sampling, e.g. samples that are taken at the edge of a water body may not be representative of the entire water body, while some cases may require sampling at the edge of the water body depending on the objective. Inconsistency of data can also be aggravated if different personnel collect the different sets of grab samples (see Step 2.1) and if the sampling locations are not properly demarcated (see Step 1.4).

In addition to the more common form of manually taking grab samples, instruments are available for taking grab samples automatically. These devices are fairly expensive and prone to problems. These instruments are, therefore, not commonly used except in instances where there is a need to establish the variation in water quality at a sampling point within relatively short time intervals. Most of the automatic sampling devices use a battery operated pump that is activated by a timer to fill a series of sample bottles. The automatically collected samples may then either be analyzed individually or combined into composite samples.

Composite samples: These are normally only prepared to save money in instances where knowledge of sample variability is not important. Composite samples can either be made on the basis of mixing a number of equal volume samples taken at specified time intervals, or can be made to be more representative of a variable effluent stream. In such cases, the composite samples may be made up of different volumes of individual samples in proportion to the flow rate applicable at the time of each sample.

Another situation where composite samples may be justified, is when a number of samples are taken and analyzed for a key variable (such as conductivity), found to be similar with regards to the key variable and sequential samples that appear to be similar are then mixed together to make a composite, thereby saving on analytical costs.

Care should always be taken to properly document the rationale and procedures employed in making a composite sample.

Continuous monitoring: This is a form of monitoring that is normally only applied at key water quality monitoring points, due to the cost involved. Continuous water quality monitoring systems are normally combined with continuous flow monitoring stations, thereby making the data particularly useful in calibrating water quality models and in calculating waste loads. The parameters that are most often measured in continuous monitoring stations are flow, pH, electrical conductivity and temperature. There are many important issues that need to be considered when designing and specifying a continuous water quality monitoring station, including the following:

- Making the equipment theft and vandal proof.
- Ensuring that the equipment is robust, weatherproof and capable of withstanding flood events.
- Maintenance of monitoring points to ensure that flow systems and sampling devices are not clogged or broken.
- Ensuring that the instruments remain calibrated and that data is reliable.
- Ensuring that data loggers have the capacity to store sufficient data and that this data is downloaded at the required intervals.
- Ensure regular visits to the monitoring site, especially when remote sensing is used.
- Converting the data into a useful format.

These various aspects are the subject of a Water Research Commission project entitled “Field Testing of Continuous Water Monitoring Instrumentation” (completed March 2000). This report should be studied by persons planning to install continuous monitoring stations.

The advantages of continuous monitoring systems are:

- Supply good data sets that indicate water quality and flow variations over time.
- Data sets that can be used to calibrate hydrological and water quality models are obtained.
- The ability to measure storm events.

Problems identified by the mines and industry with continuous monitoring systems are:

- Expensive to construct and maintain.
- Prone to vandalism, theft and flood damage.
- Must be maintained on an ongoing basis.
- Cannot directly measure specific contaminants such as sulphate, metals, etc.
- Additional cost is involved to develop and maintain the database.

4.1.2 Water Quality Sampling/Monitoring of Groundwater Systems

A basic understanding of the nature and occurrence of groundwater in South African aquifers is important for the design of a groundwater monitoring system. Aquifer types, aquifer yield, aquifer vulnerability and groundwater utilization are factors to be considered. Geophysical investigations to locate groundwater barriers and aquifers as well as other specialist studies might be required before the implementation of a groundwater monitoring system.

Groundwater monitoring systems may include warning monitoring systems, plume monitoring systems and regional monitoring systems. Warning monitoring systems will indicate early signs of possible pollution and areas requiring management measures to be implemented. Plume monitoring systems will indicate the rate and direction of pollution movement and possible future liabilities and will assist with risk assessment. Regional monitoring systems will indicate the regional water quality or baseline water quality to assess whether pollution has occurred and to what extent.

Groundwater quality is generally fairly stable and changes occur slowly (dictated by groundwater flow paths and velocities). For this reason, samples are normally taken as grab samples and typically at a reduced frequency compared to surface water samples. Groundwater sampling should at least be undertaken bi-annually to account for seasonality. Depending on the purpose of the water quality sampling, it may be desirable to sample the borehole in a stratified manner with depth, or it may be desirable to purge the borehole and sample the fresh, mixed inflow into the borehole (composite sampling). Techniques for borehole sampling are well defined in a study undertaken for the Water Research Commission (Weaver 1992a and 1992b).

Stratified sampling: This is done by sampling a small volume of water from specific depths within a borehole. A prerequisite is that the water column should not be disturbed unduly while sampling. The intention of stratified sampling is to determine the vertical distribution of water quality within a borehole, thus identifying horizons where pollution enters into the borehole. To determine the need and detail of stratified sampling, it is advisable to first conduct an electrical conductivity profile in the borehole to give an indication of inorganic pollution. In more than 90% of instances, pollution in South African aquifers enters boreholes through fractures in the rock. Stratified sampling therefore constitutes an important component in the understanding of the distribution of contributing fractures in aquifers.

Composite sampling: It is usually done by slowly pumping water from a borehole. For purging, three times the volume of water contained in the borehole should be removed in high yielding boreholes to remove the dead volume. Bladder or submersible pumps can be used. The newly accumulated groundwater should be sampled after recovery or partial recovery of the water level in the borehole.

4.2 Water Flow/Quantity Monitoring Systems

Water flow monitoring systems are the most neglected components of water monitoring systems at most mines, making it very difficult to sensibly use the associated water quality database for management purposes. From a technical viewpoint, flow measurement systems and techniques can be divided as follows:

- Flow measurement in open channels
- Flow measurement in closed pipes
- Groundwater flow measurement

Furthermore, measurement techniques can also be distinguished on the basis of whether they are permanent, in-line systems or whether they are portable, hand-held systems. A detailed literature review of flow monitoring techniques is given in *A Manual on Mine Water Treatment and Management Practices in South Africa* (Pulles, 1996).

The ideal properties of any flow meter are the ability to accurately measure a wide range of flow rates and the versatility of measuring any type of fluid or mixture. Other desirable properties include ease of installation and instrument robustness, particularly for the mining environment. The range of flow meter types available is extensive and the principles employed in their operation differ markedly. Each flow meter type is particularly suited to a specific application and a basic understanding of the principles involved is essential in understanding the range of possible applications. In the case of a permanent installation, the decision is made easier because the possible range of flow and stream conditions may be known or at least estimated fairly accurately. When a flow meter is required for temporary installation or test work, the conditions at different test sites may differ widely and the versatility of the instrument is the predominant factor.

4.2.1 Flow Measurement in Open Channels

By employing level measurement over specially designed and constructed open flow channels, it is possible to calculate flow rate as a function of fluid depth. In many cases, fluid flow around a mine is by means of open channels and the flow measuring techniques developed for piped flow are thus unsuitable. The actual means of measuring the level or depth of flows are discussed in section 4.2.1.3. The requirements in terms of channel shape and applicable equations are also discussed as these are necessary in the conversion of a level measurement to a calculated flow rate.

There are many different weir shapes and each is designed to cater for the measurement of low, high or variable flow rates. Ease of construction and installation are often required but usually at the expense of accuracy.

Design and calculation details of the range of possible open channel flow measurements are given by Henderson (1966), but two of the simpler and popular designs are discussed briefly below. Additional guidance for flow measurement in rivers is given in Van Heerden (1986).

4.2.1.1 Rectangular weir

This shape and approach can be used at most sites, including rivers, as the river bed and banks can very easily be adapted to a rectangular cross section. If L is the width of the profile, h_0 is the depth of the water and g is gravitational acceleration, then the flow rate is given by:

$q = 0{,}415(L-0{,}2h_0)h_0^{1{,}5}(2g)^{0{,}5}$

There are various limitations to this modified Francis formula but a high degree of accuracy is possible when flow is correctly conditioned.

4.2.1.2 Triangular (V-notch) weir

The advantage of this cross section design is the ability to accommodate a wide range of flow rates. If A is the angle formed by the V notch slope and ground then the flow rate is given by:

$q=(0{,}31h_0^{2{,}5}(2g)^{0{,}5})/\tan A$

where h_0 is again the depth of water flowing over the weir and g is gravitational acceleration.

4.2.1.3 Level Measurement

Most open channel flow meters require the measurement of water flow depth as the variable, which is then converted to indicate a calculated flow rate. Different devices are available for measuring depth and these can be equally used for measuring depth in water storage systems such as tanks and dams.

Visual Devices: Generally, the range of visual devices which include dipsticks, sight glasses and gauge plates are manual methods of level measurement. These methods cannot be integrated into control circuits but are useful as constant and visible indicators in non-critical installations. Visual devices are usually essential for calibration of continuous monitoring devices.

Float Actuated Devices: The variations in this category can be differentiated by the method of coupling to the level indication system and include chain or tape, lever and magnetic coupling. A variation on the float is the displacer, which uses the resultant buoyant force on a partially submerged object to indicate level.

Head Devices: The use of hydrostatic head as a level measurement is one of the more common principles involved but the configurations are varied and site specific. The measurement of differential pressure, as with the range of flow meters utilizing this principle, is very dependent on fluid characteristics and this is often too variable for sensible level measurement.

Other Methods: Among the wide range of alternative methods are capacitance and conductive-type meters that utilize the electrical characteristics of a fluid to measure depth. In applications where fluid contact is not recommended, an ultrasonic method, which relies on reflection of a sound wave from the fluid interface, may be used. It is usually this type of level detection that is used in conjunction with a weir construction for the determination of flow rates.

4.2.2 Flow Measurement in Closed Pipes

Flow meters for pipelines may be broadly classified into two design types: insertion and full-bore. In general, full-bore meters are more expensive but offer greater measurement accuracy.

4.2.2.1 Insertion Type Flow Meters

As the name implies, these flow meters use a sensing element that is inserted through the pipe wall and into the fluid flow. The element is small in comparison to the pipe diameter and relatively small head losses are caused. An additional advantage with insertion type meters is the possibility of installing the instrument without the need for process downtime, as the element may be hot tapped into the flow line. The accuracy of any insertion type meter is dependent on the ultimate position of the element with respect to the velocity profile of the fluid. Ideally, the element should record the velocity at a point that represents average fluid velocity. Generally, insertion meters are less accurate than full-bore instruments but are usually cheaper and have a high degree of measurement repeatability. Many applications, such as dosing control arrangements rely on a comparative measurement using predetermined set points as the control limits. In these cases, it is not essential to obtain a highly accurate flow value.

Many of the insertion type flow meters use principles similar to their full-bore counterparts and these are discussed in section 4.2.2.2.

4.2.2.2 Full-Bore Flow Meters

Full-bore meters usually require substantial alteration to existing pipelines (reticulation system), and where this involves expensive downtime of critical operations, this factor needs to be considered. This type of meter is usually threaded into or flanged to an existing pipeline and has an inside diameter equal to that of the pipe. Many of the full-bore flow meters utilize a flow restricting element and the measurement is by means of the differential pressure principle.

Flow meters using the differential pressure (DP) principle, employ a restriction to flow, referred to as the primary element, which converts available potential energy to kinetic energy, thereby causing a differential pressure, which is measured on either side of the restriction. This measurement is a function of the square of the upstream velocity as well as the fluid density. Since the density is not usually monitored, a normal fluid density is used but this introduces an error if flow conditions deviate from the assumption. The DP created by the primary element, is measured by an electronic DP transmitter that is called the secondary element. These transmitters are considered to be usefully accurate over a DP range of 10:1 that, due to the square relationship between flow rate and differential pressure, translates to a useful accuracy of the flow meter of a 3:1 range between minimum and maximum flow rate. There have been advances in DP transmitter technology that allow a flow range limit of 10:1, but the installed cost may be prohibitive. The various types of full-bore differential pressure flow meters are listed below.

- Concentric orifice plate
- V-element
- Venturi tube
- Target meter
- Rotameter

Other full-bore flow meters that are commonly used and that do not operate on the DP principle are as follows:

- Magnetic Flow Meters
- Vortex-shedding Flow Meters
- Turbine Flow Meters
- Positive Displacement Flow Meters
- Ultrasonic meters – Transit time and Doppler meters
- Mass flow meters

More detail on these different types of flow meters is given in *A Manual on Mine Water Treatment and Management Practices in South Africa* (Pulles, 1996).

4.2.3 Groundwater Flow Measurement

Measuring groundwater flow is a technical procedure that should be undertaken by a suitably qualified person. Groundwater flows are usually determined by means of tracer studies and modeling. A good understanding of the geohydrology is required to develop a groundwater flow monitoring programme and to interpret the data from the programme. Groundwater flow monitoring is very site specific, as it is dependent on the local geohydrology, which may vary significantly from one area to another. Measuring water levels in boreholes and knowing borehole depths should be a standard part of a groundwater monitoring programme. Groundwater levels can be measured using an electrical contact tape, float mechanism or pressure transducer. Consider the following in groundwater flow: topography (Bayesian relationship), streams, stream flow, fountains, dams, geology, excavations.

4.3 Biomonitoring

The Department of Water Affairs and Forestry (DWAF) is the public trustee of South Africa's water resources. As such it must ensure that waters remain fit for use on a sustainable basis. The National Water Act, 1998 (Act 36 of 1998) specifically requires that national monitoring systems be established (Chapter 14, Part 1). Furthermore, the Minister is also required to establish national information systems regarding water resources (Chapter 14, Part 2). A national water quality monitoring system is one source of information feeding into such an information system.

The focus of DWAF has changed from controlling pollution at source by means of regulatory standards, to a philosophy based on maintaining the fitness for agreed or specified uses, to the current emphasis on the protection of aquatic ecosystems. Ecosystems form the resource base on which sustainable utilization of water resources depend.

Internationally, biological monitoring is seen as a more cost effective manner to determine the sustainability or health of an aquatic ecosystem. Biological monitoring is more cost effective than the classical chemical monitoring. If the biological monitoring aspects of a catchment programme indicate that the organisms have been impacted then the more typical chemical water quality monitoring can be used to determine what the impacts were and who was responsible.

A successful biomonitoring index must meet a number of criteria:

- it must provide a meaningful and accurate representation of the river condition,
- it must be based on field data that is simple to collect, and
- it must be simple to interpret by the non-specialist manager.

It is not always easy to marry the first criterion with the second and third and most indices will be a compromise. Indices can also be developed at a number of levels. The manager would like a single value, which can be used to flag problems, but this single index may be disaggregated into its component parts so that the cause of the problem can be pinpointed.

A multitude of factors determine the health of a river ecosystem: geomorphological characteristics, hydrological and hydraulic regimes, chemical and physical water quality and the nature of in-stream and riparian habitats. The River Health Programme (RHP) focuses on selected ecological indicator groups.

The RHP can detect (amongst other things) the effects of deteriorating water quality (due, for example, to the presence of toxicants). However, the nature of the biomonitoring indicators is such that:

- the observed effects cannot easily be linked directly to the presence of toxicants; and
- the time from the sudden appearance of toxicants (from whatever source) to measured impact can be too long (possibly weeks or months).

Biomonitoring is relatively complex and requires a suitably qualified person to develop, implement and operate the biomonitoring programme. Due to the complexity of biomonitoring, it will not be discussed in detail in this guideline, but the reader is referred to the documents indicated under references.

Many of the tools for biomonitoring are still under refinement and the following websites have the latest versions of these tools http://www.dwaf.gov.za/iwqs/ http://www.csir.co.za.

The frequency of biomonitoring will depend on the type of water resource being monitored as well as the biological monitoring tool being used. For example, macroinvertebrates should be monitored on a seasonal basis (four times a year) whilst a geomorphological assessment would only take place after major hydrological events (floods) or land use changes.

4.3.1 Macroinvertebrates

South African Scoring System 5 (SASS5) for aquatic invertebrates (e.g. insects, mussels, snails, crabs, worms) is used. All these organisms require specific aquatic habitats and water quality conditions for at least part of their life cycles. Changes in the composition and structure of aquatic invertebrate communities are signs of change in overall river conditions. As most invertebrates are relatively short-lived and remain in one area during their aquatic life phase, they are good indicators of localized conditions in a river over the short term. The SASS is a relatively simple index which is based on the families of aquatic invertebrates present at a site. This information is translated into a reflection of the quality of the water in the river. See references for further reading.

4.3.2 Index of Habitat Integrity (IHI)

Habitat availability and diversity are major determinants for the suite of biota found in a specific ecosystem. Therefore, knowledge of the quality of habitats is important in an overall assessment of ecosystem health. The IHI is designed to assess the impact of major disturbances on river ecosystems. Such disturbances include water abstraction, flow regulation and river channel modification. The index accounts for both the condition of the riparian zone and the in-stream habitats.

4.3.3 Riparian Vegetation Index (RVI).

Healthy riparian zones provide habitat for aquatic and terrestrial species, contributing towards maintaining the form of the river channel and serve as filters for sediment, nutrients and light. The structure and function of riparian vegetation are altered with vegetation removal, cultivation, construction, inundation, erosion, sedimentation and alien vegetation invasion within or close to the riparian zone. The RVI is used to determine the degree of modification of riparian conditions.

4.3.4 Geomorphology Index

River channels are geomorphological features which are formed by the water and sediment that they transport. It is not surprising, therefore, that fluvial geomorphology has become an important component of many river management initiatives. The geomorphological processes determine the morphology of the channel, which in turn provides the physical framework within which the stream biota live. Geomorphology is therefore an important consideration in the assessment of RHP.

Invertebrates, fish and vegetation together give a good picture of the ecological integrity of a site and reflect the condition of the bio-physical habitat which is described by the remaining components, habitat integrity, water quality, hydrology and geomorphology. Changes to the stream biota must therefore be assessed against a background of possible changes to channel morphology and channel condition. Two components of the geomorphological index have been recommended as part of a site rating and monitoring programme: firstly, a channel classification and index of channel stability and secondly, an index of channel condition.

A geomorphological classification of a site serves three purposes:

- to classify the channel with respect to channel type so as to allow similar sites to be grouped together;
- to provide archival reference data to which later surveys can be related;
- to provide data from which a geomorphological index of channel stability can be derived.

Channel change can occur for two reasons. It can occur both naturally (over short and long time periods) and as a result of anthropogenic modification to rivers or their catchments (e.g. impoundments, water transfers, agriculture). A geomorphological index of channel stability is used to classify sites according to their potential for morphological change as a result of both natural and anthropogenic change. Such an index is important in interpreting biotic changes observed during the monitoring programme. It is unlikely that the site classification would change over the time span of the envisaged monitoring programme and would therefore only need to be carried out during the site rating.

4.3.5 Biological Toxicity

The design of a monitoring programme for the occurrence of toxic (or potentially toxic) compounds is particularly complex. It is important to be fully aware of the extent of the problems facing such a design before proceeding, including the following:

- There is an extremely diverse range of classes of toxicants.
- There is an extremely diverse range of individual toxicants in each class.
- There is an even wider range of potential negative impacts since each individual toxicant can exhibit a range of effects on a range of target organisms (including plants and animals). These effects also depend on many environmental variables.
- Many toxic or potentially toxic chemicals released into the environment degrade or are metabolized into a range of other chemicals, each of which may be toxic in its own right.
- Partly because of the former issue, many toxicants will exhibit non-conservative behaviour in the environment. However, many are particularly persistent.
- Direct chemical analysis for many toxicants can be difficult and expensive.
- Although a range of toxicity tests are available, many are relatively difficult to apply and interpret, particularly compared to typical standard analyses for the more common chemicals such as calcium, sulphate, etc. used in such programmes as the National Chemical Monitoring Programme.

A National Toxicant Monitoring Programme (NTMP) is being developed by DWAF. This programme will initially concentrate on internationally acceptable acute and chronic methodologies for aquatic toxicity and the principles of whole effluent toxicity.

4.3.6 Fish Assessment Integrity Index (FAII).

Fish being relatively long-lived and mobile, are good indicators of longer-term influences on a river reach and the general habitat conditions within the reach. The number of species of fish that occur in a specific reach, their sensitivity to various forms of disturbance, as well as factors such as different size classes and the health of fish, can be used as indicators of river health. The FAII integrates such characteristics of a fish assemblage. The output of the FAII is an expression of the degree to which fish assemblage deviates from what would have been expected in the absence of human impacts.

4.4 Data and Information Management Systems

Various information management tools are available, as mentioned in Step 3.1. The various tools and methods that can assist with the management of information will be discussed according to the following classifications:

- Manual systems
- Computer database systems
- Geographic information systems (GIS)
- Reporting systems

To assist with the decision of which tool to use, the advantages and disadvantages of the various tools will be discussed.

4.4.1 Manual Systems

A manual system refers to a system where all the data and information are used, integrated and stored in hard copy format, e.g. paper documents, drawings and maps. Advantages and disadvantages of manual systems are shown in Table 4.1 below:

Table 4.1: Advantages and disadvantages of manual data systems

Advantages	Disadvantages
Minimum capital cost is involved to implement the system.	Manual manipulation of data may require specialized skills.
No specialized computer training is required to implement and manage the system.	The update of the information is usually labour intensive and time consuming.
No specialized equipment is required.	The long-term management of the information can become expensive due to the labour and time involved with updating the system.
	Physical storage space is required for the information.
	Reporting information and data in graphs, drawings and maps is usually labour intensive and can become expensive

To assist the manual system, it may be possible to have a computer system that is only used for the storage of data and/or tracking the data and information that are in hard copy format. This system is an overlap between the manual system and the computer database system, discussed in 4.4.2. and will thus not be addressed separately.

4.4.2 Computer Database and Spreadsheet Systems

Various computer aided database systems are available to assist with the management of information relevant for a monitoring programme. A database programme on its own is usually used as a data storage facility and requires an interface with another programme for interpretation and reporting, like a spreadsheet programme. Advantages and disadvantages of computer database and spreadsheet system are shown in Table 4.2.

Table 4.2: Advantages and disadvantages of computerized data systems

Advantages	Disadvantages
Information can be updated with relative ease and relatively quickly.	Software programmes and computer equipment are required.
The information can easily be presented in a user-friendly format.	Some training is required to use the software.
Vast amounts of data can be processed quickly (statistical calculations and manipulation of data).	Changes and updates of the software can result in non-compatibility between systems of different users.
Data can be retrieved selectively for specific reports.	Spreadsheets can become personalized and difficult to be managed by another person.
Storage of data requires minimal physical space.	Back-up of the information is required to prevent loss of data if files become corrupt.

4.4.3 Geographic Information Systems (GIS)

Geographic Information Systems (GIS) can relate many layers of information to each other. They can perform a number of complex data manipulations and analyses for any combination of information and then display the information graphically. Advantages and disadvantages of GIS are shown in Table 4.3.

Table 4.3 Advantages and disadvantages of GIS data systems

Advantages	Disadvantages
Information can be updated with relative ease and relatively quickly.	Relatively expensive software is required.
The information can easily be presented in a user-friendly format.	Special training and experience are required to use the software programmes.
Vast amounts of data can be processed quickly.	
Data can be retrieved selectively for specific reports.	
Storage of data requires minimal physical space.	
A number of different types of data, e.g. maps, monitoring data in databases and sampling locations, can be integrated.	
Various options for presentation of the information are available.	
The GIS can be used with some modeling programmes, e.g. to model surface water runoff.	

4.4.4 Reporting Systems

Data and results from a monitoring programme can be presented in various ways, as mentioned in Step 3.2. These presentations can either be tabular, graphical or a combination of the two. Tabular presentations are generally more difficult to interpret and should only be used where detailed knowledge of the actual data values is required. Graphical presentations can take many forms and Figures 4.1 – 4.3 give examples of diagrams that can be used to report the data. More complex diagrams that can be used for the interpretation of chemistry are the Piper and Durov diagrams. These diagrams are discussed in detail in the *Minimum Requirements for Monitoring at Waste Management Facilities* (DWAF, 2005).

The specific method of presentation and reporting is dependent on the objectives of the monitoring programme and the needs of the users. There are instances where data is submitted to and used by other agencies or government, especially DWAF. In these cases it is necessary to determine whether the data is required in a specific format. Data may also be available from external agencies or government and it is advisable to determine the format of the data, so that it is possible to optimize the system that incorporates this data.

Figure 4.1: Example of a schematic diagram

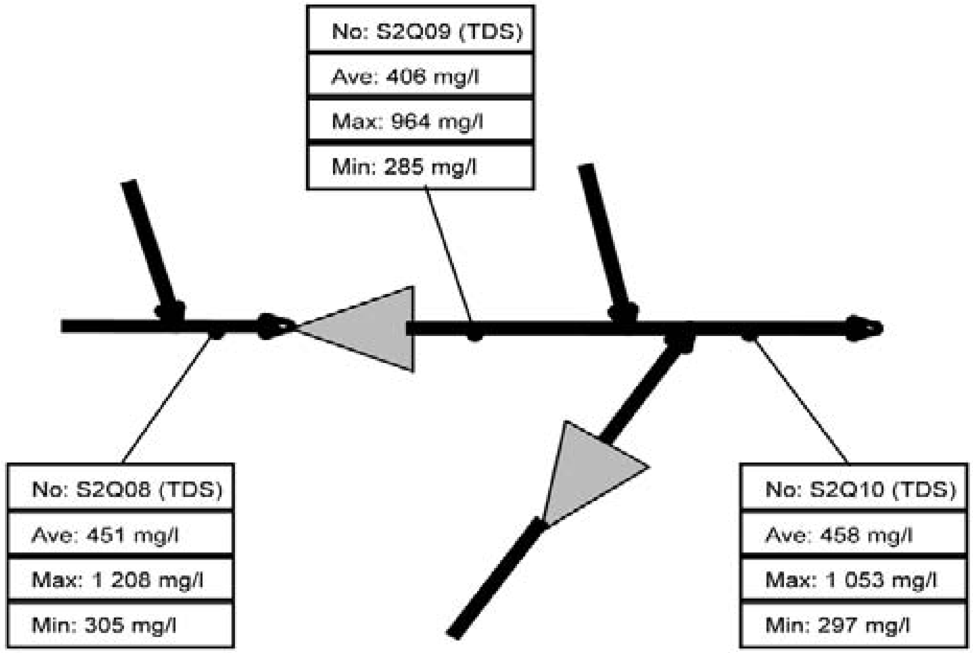
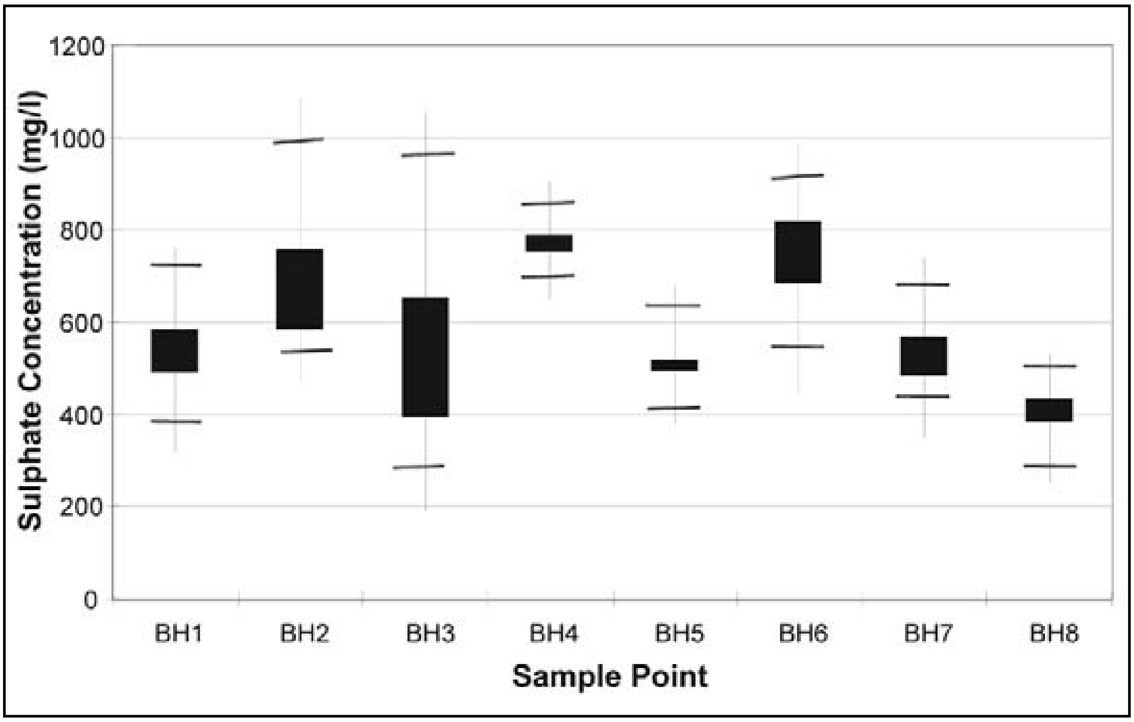


Figure 4.2: Example of a line diagram

Figure 4.3: Example of a box-and-whisker diagram



5

WORKED PRACTICAL EXAMPLE

A hypothetical mine will be used to illustrate the practical development of a monitoring programme. The development of a monitoring programme on a mine will be very site specific and will most likely have different objectives. It should be noted that this is only an example to illustrate the practical use of the concepts from Chapters 1 – 4. Although a coal mine is used in this example the same principles and procedures are applicable to all mines. The different components that are relevant for the monitoring programme of the specific mine in this example are indicated in Figure 5.1.

The development of the monitoring programme for the mine will follow the stepwise procedure as discussed in Chapter 3. This example will only focus on Phase 1, namely the design of the monitoring programme. Phases 2 – 4 are dependent on the specific situation and requirements of the users, and an example to accommodate all the different scenarios will be impractical.

Phase 1 Design the Monitoring Programme

Step 1.1 Define the Management Action of Interest

As part of the water management at this hypothetical mine, it is necessary to understand the pollution on the mine and to monitor how the pollution changes with time. The overarching water management action that is of interest for this specific mine can, therefore, be defined as:

- Prevent pollution and thereby protect the receiving water environment.
- Develop an understanding of the current pollution on the mine and monitor how it changes over time.
- Assess performance of pollution prevention measures, i.e. compliance with license conditions and catchment objectives.

STEP 1.2 Define objectives of the intended management action

The objective of the management action defined above in Step 1.1 can be defined as:

- Identify, quantify and monitor all point and diffuse pollution sources on the mine.

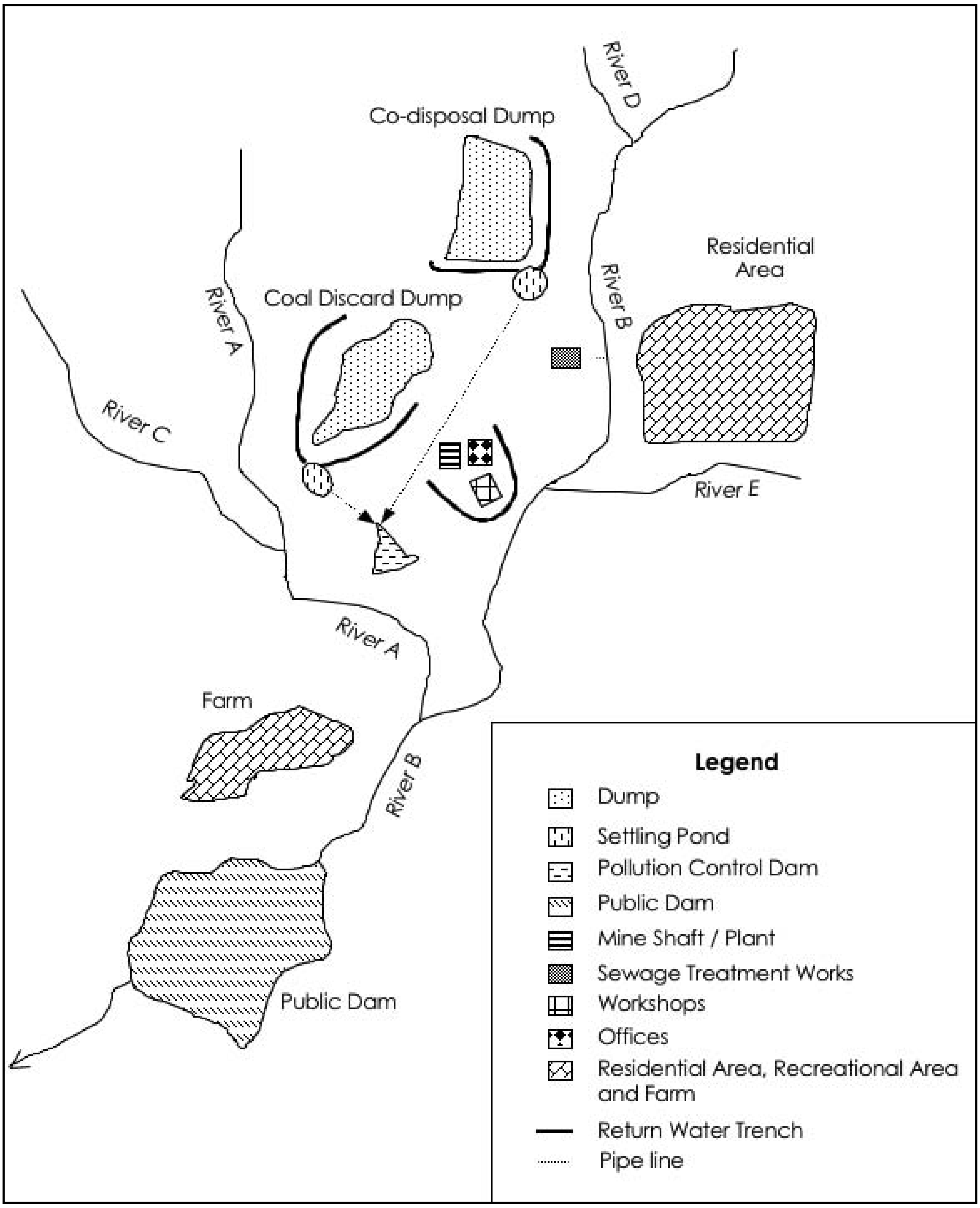
This objective adheres to the requirements of being specific, measurable and feasible, as stipulated in Chapter 3 under Step 1.2.

STEP 1.3 Define data requirements that support objectives

To achieve the objective defined in Step 1.2 the following action plan of eight practical steps have been defined:

- Identify and quantify all known potential point and diffuse sources of pollution, and their associated pollution pathways.
- Define key indicators of pollution for each source.
- Evaluate groundwater qualities in the vicinity of the potential pollution sources.
- Divide mine into sub-catchments on the basis of stream confluences, known pollution points, abstraction points and mine boundaries.
- Collect flow data, together with key surface water quality indicator data at the upstream and downstream point of each sub-catchment and at all discharge and abstraction points.
- Establish whether the calculated added or subtracted pollution load can be accounted for by known quantified sources or abstraction points.

Figure 5.1: Layout of hypothetical mine



- Develop water and salt balances for the different sub-catchments, sources or whole mine area.
- Establish whether there will be any long-term changes to the point and diffuse sources.

These eight steps, as well as data that have been collected, are discussed in more detail below.

1.1. Identify and quantify all known potential point and diffuse sources of pollution, and their associated pollution pathways.

The following potential point and diffuse sources of pollution, with an indication of the potential pollution pathways, have been identified within the mine's boundaries:

- Coal discard dump seepage to River A
- Coal discard dump seepage to groundwater
- Pollution control dam seepage to River A
- Pollution control dam seepage to groundwater
- Pollution control dam spillage to River A
- Co-disposal dump seepage to River B
- Co-disposal dump seepage to groundwater
- Shaft/workshop area runoff to River B
- Sewage treatment works discharge to River B

1.2 Define key indicators of pollution for each source.

The key indicators of pollution that have been identified for each of the identified sources of pollution are indicated in Table 5.1.

Table 5.1: Key indicators of pollution at each source of pollution

Source of Pollution	Key Indicators of Pollution
Coal discard dump seepage to River A	pH, EC, TDS, SO_4, Fe, Al, Mn
Coal discard dump seepage to groundwater	pH, EC, TDS, SO_4, Fe, Al, Mn
Pollution control dam seepage to River A	pH, EC, TDS, SO_4, Fe, Al, Mn
Pollution control dam seepage to groundwater	pH, EC, TDS, SO_4, Fe, Al, Mn
Pollution control dam spillage to River A	pH, EC, TDS, SO_4, Fe, Al, Mn
Co-disposal dump seepage to River B	pH, EC, TDS, SO_4, Fe, Al, Mn
Co-disposal dump seepage to groundwater	pH, EC, TDS, SO_4, Fe, Al, Mn
Shaft/workshop area runoff to River B	pH, EC, TDS, SO_4, Fe, Al, Mn, oil and grease
Sewage treatment works discharge to River B	pH, TDS, COD, NH_4, NO_3, PO_4, E. coli

It should be noted that the identified key indicators of pollution are specific to this example and may, therefore, differ for another mine.

To develop an understanding of the pollution load contribution from the various pollution sources on this specific mine, it was decided to use sulphate (SO_4) as the main key indicator of pollution. The sulphate (SO_4) concentrations that were measured at the various sources of pollution are presented in Table 5.2.

In order to determine the pollution load contributions from the sewage treatment plant, additional key indicators ammonia (NH_4) and phosphate (PO_4) can also be measured, together with SO_4. As this example aims to illustrate the principles of the procedure, an overload of data is not desirable and the data will, therefore, be limited to sulphate (SO_4) and phosphate (PO_4).

1.3 Evaluate groundwater qualities in the vicinity of the potential pollution sources.

The location of existing monitoring boreholes on the mine is indicated in Figure 5.2.

It is important that a suitably qualified person should interpret the borehole data, as this data can be misleading. The existing boreholes may, for example, be too shallow or be placed at incorrect locations, which can lead to data that indicates no pollution from the source, when pollution may in fact be occurring. It is therefore also important that a suitably qualified person provide input to the location of monitoring boreholes based on knowledge of groundwater flow and aquifer characteristics as well as depending on the objective (identification of pollution sources; extent of pollution plume etc). A suitably qualified person should thus interpret data from existing boreholes with the necessary caution. In cases where a groundwater study has not been undertaken and/or there is not a clear understanding of the geohydrology of the area it may be best practice to disregard this data.

In this example, a suitably qualified person has completed a groundwater study and sited the locality of the boreholes originally when they were drilled. This person has identified four boreholes that are relevant for the indication and quantification of pollution, as indicated in Table 5.2, and has also determined that boreholes A and B can be used for background data.

The SO_4 concentrations measured at boreholes A and B are 952 mg/l and 441 mg/l respectively, while the PO_4 concentration at both these boreholes is 22 µg/l. The SO_4 and PO_4 concentrations measured at the various other boreholes are indicated in Table 5.2.

Table 5.2: SO_4 and PO_4 concentrations at the identified sources of pollution

Source of Pollution	Borehole	SO_4 Conc. (mg/l)	PO_4 Conc. (µg/l)
Coal discard dump seepage to River A	E	3 125	38
Pollution control dam seepage to River A	I	1 435	33
Pollution control dam spillage to River A	Surface	1 498	35
Co-disposal dump seepage to River B	O	2 901	28
Shaft/workshop area runoff/seepage	L	897	121
Sewage treatment works discharge	Surface	680	593

1.4 Divide mine into sub-catchments on the basis of stream confluences, known pollution points, abstraction points and mine boundaries.

The division of the mine into sub-catchments based on stream confluences, known pollution points, abstraction points and mine boundaries is indicated in Figure 5.3.

1.5 Collect flow data, together with key surface water quality indicator data at the upstream and downstream point of each sub-catchment and at all discharge and abstraction points.

The monitoring points relevant for each of the sub-catchments are indicated in Figure 5.4. SO_4 and PO_4 were used as the key indicators for a preliminary assessment of the pollution from the different pollution sources. The flow data and key water quality indicators (i.e. SO_4 and PO_4) that were collected are presented in Table 5.3. The collection of data at this stage of the process is a once-off occurrence within this step and is required to develop a preliminary understanding of the water circuits.

Figure 5.2: Location of boreholes

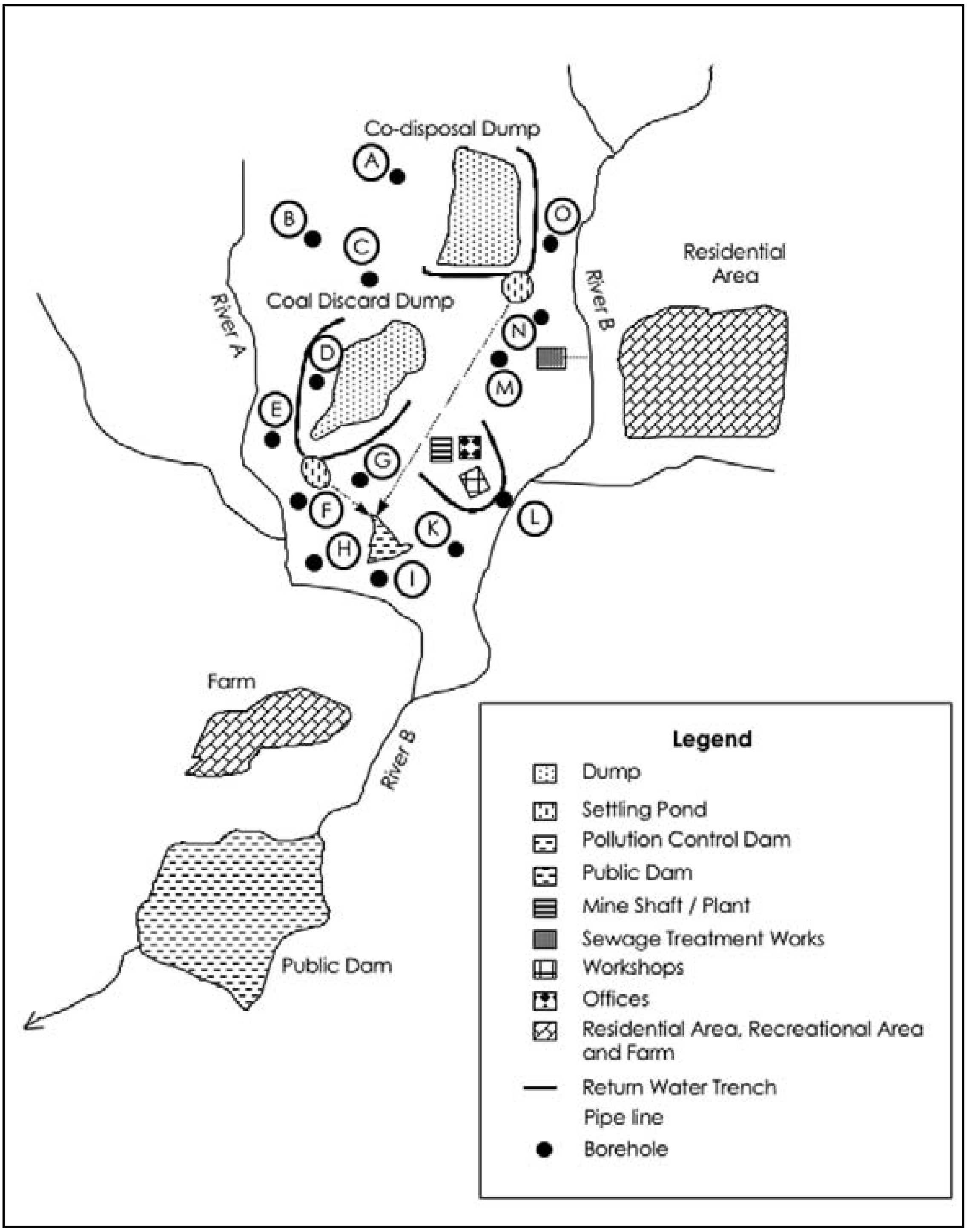


Figure 5.3: Sub-catchments

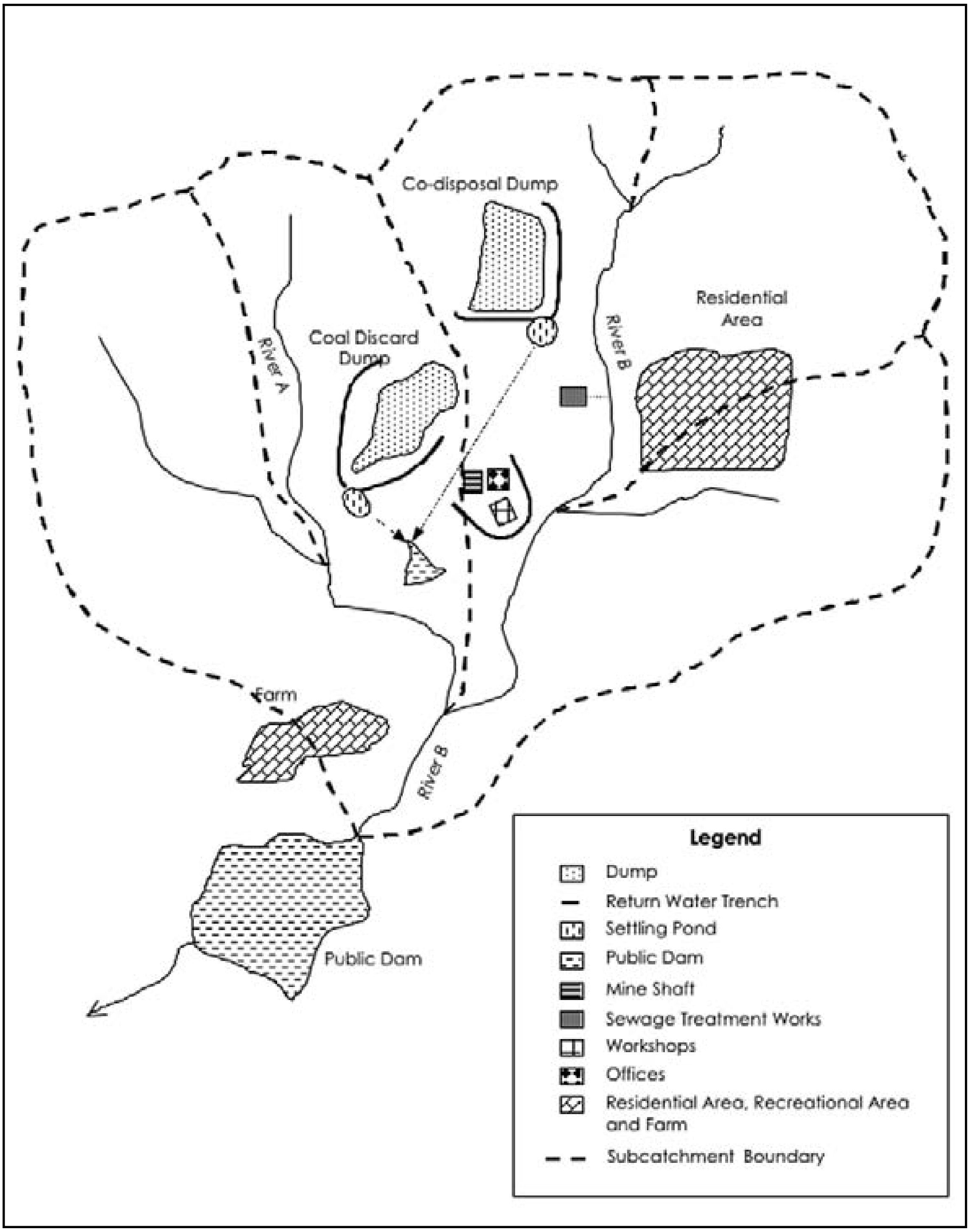


Table 5.3: Collected flow and key water quality data

Monitoring Point No.	Flow (m^3/d)	SO_4 (mg/l)	SO_4 Load (kg/d)	PO_4 (µg/l)	PO_4 Load (g/d)
1	5 450	301	1 640	23	125
2	7 050	811	5 718	25	176
3	4 618	263	1 215	19	87
4	12 476	658	8 209	23	287
5	24 168	863	20 856	141	3 408
6	10 652	1 123	11 962	298	3 173
7	6 500	1 127	7 326	321	2 087
8	3 422	755	2 582	297	1 015
9	3 812	965	3 679	289	1 102
10	908	2 215	2 011	28	25
11	453	1 643	744	35	15
12	978	680	665	593	580
13	4 653	1 202	5 593	242	1 126

1.6 Establish whether the calculated added or subtracted pollution load can be accounted for by known quantified sources or abstraction points.

The SO_4 and PO_4 loads at the various monitoring points have been calculated and are presented in Table 5.3. To assess the pollution loads, it is necessary to calculate load balances for the river reaches in the different sub-catchments. An example of such a calculation is presented for the section between surface monitoring points (MP) 1 and 2:

Load in = MP 1 + MP 10

= 1 640 + 2 011

= 3 651 kg/day

Load out = MP 2

= 5 718 kg/ day

Load out – Load in = 2 067 kg/day

This indicates that 36.2% of the load at monitoring point 2 cannot be accounted for by the point source discharges or abstractions. It is, however, deduced that there is seepage from the coal discard dump and the return water trench. It may be possible to calculate the volume of seepage using a water balance for the specific river reach:

Flow out – Flow in = MP 2 – (MP 1 + MP 10)

= 7 050 – (5 450 + 908)

= 692 m^3/day

It is assumed that this flow is an indication of the volume of seepage and the SO_4 concentration of the seepage will then be:

SO_4 concentration = SO_4 load/flow x 1 000

= (2 067/692) x 1 000

= 2 987 mg/l

This value is comparable to the measured SO_4 concentrations of the coal discard dump, see borehole E in Table 5.2, i.e. 3 125 mg/l. The volume and quality of the seepage may be confirmed and quantified more accurately by means of a river profile or a groundwater study.

Similar calculations can be done for the other river reaches to determine whether the calculated added or subtracted pollution load can be accounted for by known quantified sources or abstraction points. The results of these calculations are indicated in Table 5.4.

Table 5.4: Calculated added or subtracted pollution load for river reaches in sub-catchments

River Reach	Unaccounted Flow (m^3/d)	Unaccounted SO_4 Load (kg/d)	Calculated SO_4 conc. (mg/l)	Unaccounted PO_4 Load (kg/d)	Calculated PO_4 conc. (mg/l)
A: MP 1 to MP 2	692	2 067	2 987	26	38
B: MP 2 to MP 4	355	532	1 499	9	25
C: MP 8 to MP 13	1 231	3 011	2 446	111	90
D: MP 13 to MP 7	869	1 068	1 229	381	438
E: MP 7 to MP 6	340	957	2 815	-16	N/A

MP = surface monitoring point

Each river reach will be discussed according to the letter, i.e. A to E, as indicated in the first column of Table 5.4.

River reach A (MP 1 to MP 2) has been discussed above.

For river reach B (MP 2 to MP 4) both the flow and the load balances are within the 90 – 95% accuracy recommended in *BPG G2: Water and Salt Balances.* The calculated SO_4 value is, however, comparable to the measured SO_4 of the pollution control dam (see MP 11 in Table 5.3). Seepage from the dam has been identified as a potential source of pollution. It appears from the preliminary balance that the seepage from the dam is minimal. This observation may need to be quantified and supported by a river profile.

At river reach C (MP 8 to MP 13), the calculated SO_4 is close to the measured SO_4 for the co-disposal dump (see Borehole O in Table 5.2). One can, therefore, assume that the main cause of the additional pollution is seepage from the co-disposal dump. The lower calculated SO_4 value (2 446mg/l), compared to the measured seepage concentration (2 901 mg/l), may be ascribed to dilution. The increased PO_4 concentration (28 - 90 mg/l) may be caused by a pollution source on the opposite side of the river, i.e. next to the residential area. These assumptions may be confirmed and quantified more accurately with a river profile and/or groundwater study and an investigation of the area next to the residential area.

The unaccounted additional SO_4 and PO_4 loads in river reach D (MP 13 to MP 7) may be caused by the runoff and/or seepage from the residential area or nearby industrial areas. This assumption may be confirmed and quantified in more detail with a river profile, groundwater study and surface water runoff study.

The load and flow balances for river reach E (MP 7 to MP 6) indicate that both balances are within the recommended accuracy of 90 - 95% (*BPG G2: Water and Salt Balances*); 3.2% for the water balance and 8.0% for the SO_4 balance. In this area no seepage or any other non-point source of pollution has been identified. The calculated SO_4 concentration (2 815mg/l) is also higher than any of the measured SO_4 concentrations. The differences in the balances may, therefore, be a result of inaccuracies. This assumption seems to be justified by the PO_4 balance, where a negative load is calculated and the balance is within the recommended 90 - 95% accuracy. This assumption may be confirmed by an audit on the monitoring programme for this river reach.

1.7 Develop water and salt balances for the different sub-catchments, sources or whole mine area.

Water and salt balances are discussed in detail in *BPG G2: Water and Salt Balances.*

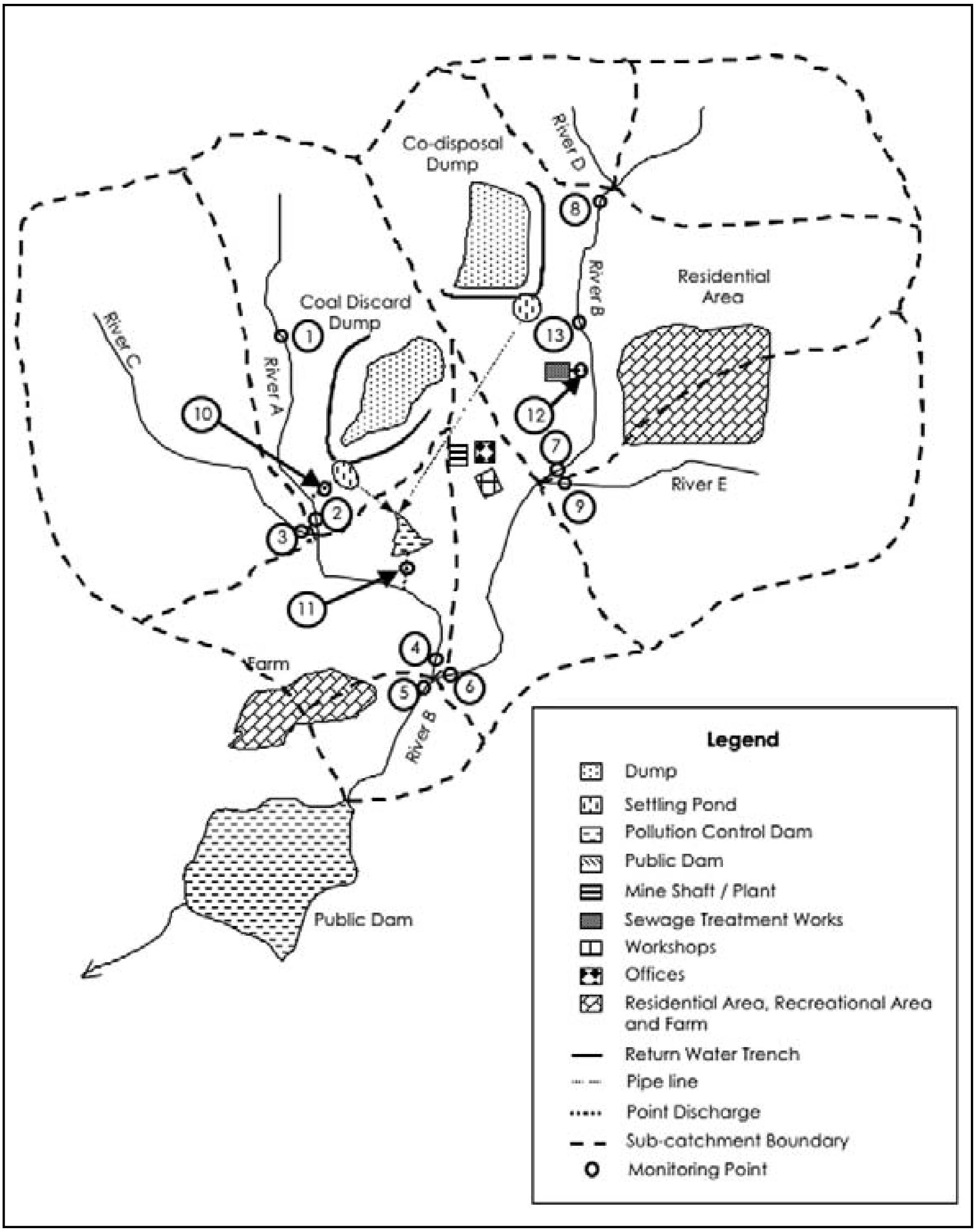
1.8 Establish whether there will be any long-term changes to the point and diffuse sources.

Long-term changes in water quality are expected at both the coal discard dump and the co-disposal dump. This will have an effect on the seepage from the two dumps as well as from the return water dam. These long-term changes need to be evaluated using appropriate geochemical prediction techniques (see *BPG G4*).

Step 1.4 Define location of monitoring points

The location of the monitoring points, both for surface water and groundwater, should take the data requirements

Figure 5.4: Location and numbering of surface monitoring points



that were identified under step 1.3 into consideration. The location of the surface water monitoring points for the mine is indicated in Figure 5.4. The borehole sampling points are indicated in Figure 5.2.

Step 1.5 Define parameters to be measured

Table 5.5 indicates the parameters that are identified and rationalized into lists. The steps that were followed are similar to the discussion in Example 1 under Step 1.5 in Chapter 3. The requirements from DWAF at compliance points should also be taken into consideration. At this hypothetical mine all the required parameters to be monitored for compliance form part of list B in Table 5.5.

Table 5.6 summarizes the monitoring points with the identified parameters to be measured.

Step 1.6 Define frequency of measurement

The type of sampling method and the frequency of sampling are indicated in Table 5.6. These specifications are relevant for the initial monitoring programme and might be changed during the operation of the monitoring programme, if necessary. An accredited laboratory will be used to analyze the samples and the required detection limits and accuracy will be obtained from them.

Step 1.7 Define Data/Information Reporting Requirements

This step is very site specific as it depends on the facilities available at the mine and will therefore not be addressed in this example.

Table 5.5: Rationalized lists of parameters

A	B
pH	pH
EC	EC
TDS	TDS
SO_4	SO_4
Al	K
Fe	Al
Mn	Fe
PO_4	Mn
	NH_4
	NO_3
	PO_4
	E.coli

Table 5.6: Monitoring points with monitoring detail

No	Description	Parameter list[2]	Type of sampling	Flow measurement [3]
MP 1	Upstream of mine in River A	A	GS 3	No
MP 2	River A before confluence with River C	A	GS 3	Yes
MP 3	River C before confluence with River A	A	GS 3	No
MP 4	River A before confluence with River B	B	GS 3	Yes
MP 5	DWAF compliance point in River B[1]	B	GS 1	Yes
MP 6	River B before confluence with River A	B	GS 3	No
MP 7	River B before confluence with River E	B	GS 3	Yes
MP 8	River B after confluence with River D	B	GS 3	No
MP 9	River E before confluence with River B	B	GS 1	Yes
MP 10	Settling pond overflow	A	GS 2	Yes
MP 11	Pollution control dam overflow	A	GS 2	Yes
MP 12	Sewage treatment works discharge	B	GS 2	Yes
MP 13	River B after seepage from co-disposal dump	B	GS 3	Yes
BH A	Background for Eastern catchment	B	GS 3	N/A
BH B	Background for Western catchment	A	GS 3	N/A
BH E	Coal discard dump seepage	A	GS 3	N/A
BH I	Pollution control dam seepage	A	GS 3	N/A
BH L	Shaft/workshop area runoff/seepage	B	GS 3	N/A
BH O	Co-disposal dump seepage	B	GS 3	N/A

(1) Includes continuous monitoring station for flow, EC, pH
(2) A and B indicate the label of rationalized parameter lists as per Table 5.5.
(3) The specific type of flow measurement will also depend on the available capital.

Abbreviations:

BH *Borehole.*
MP *Surface monitoring point.*
GS 1 *Grab sample; frequency as indicated by license.*
GS 2 *Grab sample; fortnightly.*
GS 3 *Grab sample; monthly.*
N/A *Not applicable.*

6 REFERENCES

Anon. 1989. Selecting modern flow and level measurement systems, in *Process Engineering*, July 1989.

Chutter, F.M. 1998. *Research on the rapid biological assessment of water quality impacts in streams and rivers* (Water Research Commission Report No 422/1/98). Pretoria: Water Research Commission.

Clark, L. 1988. *The field guide to water wells and boreholes*. England: Open University Press.

Dickens, C.W.S and P.M Graham. 2002. The South African Scoring System (SASS) Version 5 Rapid Bioassessment Method for Rivers. *African Journal of Aquatic Science 2002, 27: 1.10.*

DWAF, 1998. *Minimum requirements for water monitoring at waste management facilities*. Pretoria: DWAF. Second edition

DWAF, 1997. *Tender specifications for laboratory analyses*. Pretoria: DWAF.

DWAF & WRC, 1995. *Procedures to assess effluent discharge impacts*. Appendix D

Dandy, D.R. and Moore, S.F. 1979. Water quality sampling programs in rivers, *Journal of Environmental Engineering Division, ASCE*, 105 EE4, pp. 695 – 712.

Daniel, D.E. (Ed.) 1993. *Geotechnical practice for waste disposal*. London: Chapman & Hall.

Environmental Protection Agency (EPA), 1995. Best practice Environmental Management in Mining: Environmental Monitoring and Performance. Australian Federal Environmental Department, June 1995.

Ginesi, D and Grebe, G. 1987. Flowmeters – A performance review, *Chemical Engineering*, June 1987.

Grabow, G.L., Mote, C.R., Sanders, W.L., Smoot, J.L. and Yoder, D.C. 1993. Groundwater monitoring network design using minimum well density, *Water science and technology: Diffuse pollution*, Vol. 28 No. 3 – 5, pp. 327 - 335. Oxford: Pergamon Press Ltd.

Harmancioglu, N.B. and Alpaslan, N. 1994. Basic approaches in design of water quality monitoring networks, *Water Science and Technology: Water Quality International '94 – Part 10: Water quality monitoring; Lake management*, D. Ballay and IAWQ Programme Committee (Ed.). Oxford: Pergamon, pp. 49 – 56.

Henderson. (1966). *Open Channel Flow.* New York: McMillan.

Kleynhans, C.J. 1996. A qualitative procedure for the assessment of the habitat integrity status of the Levuvhu River (Limpopo System, South Africa), *Journal of Aquatic Ecosystem Health* (5: 1 – 24).

MacKenzie, M., Palmer, R.N. and Millard, S.T. 1987. Analysis of statistical monitoring network design, *Journal of Water Resources Planning and Management*, 113(5), pp. 599 – 615.

Mangold, S. 2001. *An Implementation Manual for the River Health Programme - a hitch hiker's guide to putting the RHP into action* Institute for Water Quality Studies, Department of Water Affairs and Forestry, Pretoria, South Africa. NAEBP Report Series No 15

Mar, B.W., R.R. Horner, J.S. Richley , R.N. Palmer and D.P. Lettenmaier. 1986. Data acquisition: cost-effective methods for obtaining data on water quality. *Environmental Science and Technology* 20(6): 545 – 551.

Minerals Council of Australia, 1997. *Minesite water management handbook*. Dickson: Minerals Council of Australia.

Moore, A. 1986. Selecting a flowmeter, *The Chemical Engineer*, April 1986.

National Water Act, 1998 (Act no. 36 of 1998). Republic of South Africa.

Palmer, R.N. and MacKenzie, M. 1985. Optimization of water quality monitoring networks, *Journal of Water Resources Planning & Management*, 111(5), pp 478–493.

Pulles, W., Heath, R. and Howard, M.R. 1995. *A manual to assess and manage the impacts of gold mining operations on the surface water environment* (WRC Report No. K5/647/0/1). Pretoria: Water Research Commission.

Pulles, W., Howie, D., Otto, D. and Easton, J. 1996. *A manual on mine water treatment and management practices in South Africa: Appendix Volume 1 Literature Review*. Water Research Commission Report No 527/1/96.

Reeve, A. 1989. Can you select the right flowmeter?, in *C&I*, February 1989.

Reinelt, L.E., Horner, R.R. and Mar, B.W. 1988. Nonpoint source pollution monitoring program design, in *Journal of Water Resources Planning and Management*, 114(3), pp. 335 – 352.

Rossouw, J., Loubser, C., Rooseboom, A. and Bester, A. 1998. *Sluicing flumes: A new structure for discharge measurement in sediment-laden rivers* (WRC Report No. TT 103–98). Water Research Commission.

Rowntree, K.M. and G. Ziervogel. 1999. *Development of an index of stream geomorphology for the assessment of river health* (NAEBP report series no. 7). Pretoria: Department of Water Affairs and Forestry.

Rowntree K.M. and Wadeson R.A., 1999. A hierarchical framework for categorizing the geomorphology of selected river systems. Water Research Commission Report.

Rowntree K.M. and Wadeson R.A.,. 2000. *Field manual for channel classification and condition assessment* Institute for Water Quality Studies, Department of Water Affairs and Forestry, Pretoria, South Africa. *NAEBP Report Series No 13*

Sanders, T.G., R.C. Ward, J.C. Loftis, T.D. Steele, D.D. Adrian and V. Yevjevich. 1983. *Design of Networks for Monitoring Water Quality*. Littleton CO: Water Resources Publication.

Slabbert JL, Oosthuizen J, Venter EA, Hill E, du Preez M and Pretorius PJ, 1998a. *Development of Guidelines for Toxicity Bioassaying of Drinking and Environmental Waters In South Africa.* Water Research Commission Report No. 453/1/98.

Slabbert JL, Oosthuizen J, Venter EA, Hill E, du Preez M and Pretorius PJ, 1998b. *Development of Procedures to Assess Whole Effluent Toxicity*. Water Research Commission Report No. 453/1/98.

Soliman, W.R. and Ward, R.C. 1994. The evolving interface between water quality management and monitoring, *Water International*, 19 (1994) pp. 138 – 144.

Thirion, C., A. Mocke and R Woest. 1995. *Biological monitoring of streams and rivers using SASS4* (Report No N 0000/00/REQ/1195). Pretoria: Department of Water Affairs and Forestry – Institute for Water Quality Studies.

Thoma, M and Grant, D. 1992. Sampling program provides accurate pollution data, *WWI*, June, 1992.

Tily, P. 1986. Practical options for on-line flow measurements, *Process Engineering*, May 1986

Van Heerden, J.J.; Van der Spuy, D., Le Roux, P.J. 1986. *Manual for the planning, design and operation of river gauging stations.* (Technical report TR 126). Pretoria: Department of Water Affairs – Directorate of Hydrology.

Ward, R.C., Loftis, C.J., McBride, G.B. 1990. *Design of water quality monitoring systems.* New York: Van Nostrand Reinhold.

Water Research Commission (WRC), The Department of Water Affairs and Forestry (DWAF), The Department of Health, 1998. *Quality of domestic water supplies. Volume 1: Assessment Guide.* WRC No TT 101/98.

Water Research Commission (WRC), The Department of Water Affairs and Forestry (DWAF), The Department of Health, 2000. *Quality of domestic water supplies. Volume 2: Sampling Guide.* WRC No TT 117/99.

Water Research Commission (WRC), The Department of Water Affairs and Forestry (DWAF), The Department of Health, 2001. *Quality of domestic water supplies. Volume 3: Analysis Guide*. WRC No TT 129/00.

Weaver, J.M.C. 1992a. *Groundwater sampling: A comprehensive guide for sampling methods* (WRC Report No. TT 54/92). Pretoria: Water Research Commission.

Weaver, J.M.C. 1992b. *Groundwater sampling: An abbreviated field guide for sampling methods* (WRC Report No. TT 56/92). Pretoria: Water Research Commission.

Whitfield, P.H. 1988. Goals and data collection designs for water quality monitoring, *Water Resources Bulletin*. 24(4): 775 - 780

7 GLOSSARY

aquifer:	Geological formation which has structures or textures that hold water or permit water movement through them (National Water Act, 1998).
audit:	A systematic, documented, periodic and objective evaluation of how well management systems and equipment are performing, with the aim of facilitating management control of practices and to assess compliance with relevant policies and objectives, which include meeting regulatory requirements.
background data:	Data that is collected at an area before any impact has been made on the water body.
baseline data:	Data from a proposed site before a proposed development is started or management actions have been implemented, i.e. the status quo.
catchment:	In relation to a watercourse or watercourses or part of a watercourse, means the area from which rainfall will drain into the watercourse or watercourses or part of a watercourse, through surface flow to a common point or common points. (National Water Act, 1998)
consistency checks:	Checking data and calculations to assess the trends or patterns for any significant deviations. An explanation for the significant deviations should be determined and identified causes of the deviations should be rectified if applicable.
data logger:	Equipment that collects and stores data automatically in electronic format.
electrical conductivity:	Ions in water solution conduct electrical currents. The more ions that are present in the water the higher the conductance and vice versa. The electrical conductivity of a solution is thus an indication of the amount of ions present in the solution.
groundwater:	The water contained in interconnected pores located below the water table in an unconfined aquifer or located in a confined aquifer (Minerals Council of Australia, 1997).
key monitoring points:	Key monitoring points are of primary importance for a monitoring programme. The motivation for the importance of the points varies and may include legislative requirements and/or the significance of the stream within the water circuit. (See also primary, secondary and tertiary monitoring points)
management tools:	Management tools can be regarded as the building blocks of a water quality management system, like models, water and salt balances and databases.
monitoring, compliance:	Monitoring with the specific aim to collect data required by regulations or law.
trend:	Monitoring with the specific aim to determine whether any changes occur over time.
pollution:	Pollution means the direct or indirect alteration of physical, chemical or biological properties of a water resource so as to make it – (a) less fit for any beneficial purpose for which it may

	reasonably be expected to be used; or (b) harmful or potentially harmful – (aa) to the welfare, health or safety of human beings; (bb) to any aquatic or non-aquatic organisms; (cc) to the resource quality; or (dd) to property. (National Water Act, 1998)
prediction and assessment models:	Models that assist with the assessment and prediction of future trends by simulating dynamic reactions, for example models that simulate dynamic pyrite oxidation reactions to predict future changes in sulphate concentrations.
preservation of samples:	It is generally not possible to analyze samples immediately after collection. Preventative measures need to be taken to prevent significant changes in the sample's characteristics, e.g. precipitation of metals or a reaction between the chemicals and sample container. These measures can include cooling the sample, adding acid and using the correct sample containers.
primary monitoring point:	Monitoring points that have been identified as the main points for compliance and/or are required to determine the overall pollution contribution from the mine, are classified as primary monitoring points. These points will have continuous flow and water quality monitoring devices and will usually be upstream and downstream of the mine.
process water:	Water that is used within the operational process is referred to as process water.
purge:	Prior to sampling of a monitoring well, the water standing in the well must be removed, permitting 'fresh' water from the aquifer to enter the well. This procedure, called 'purging', is intended to remove water which may have been subjected to chemical change due to extended contact with unnatural conditions and materials within the well (Daniel, 1993).
river profiling:	To establish a quality profile of a river, a number of samples are required at regular intervals along its length. If an EC profile is developed, it will be necessary to take EC readings at regular intervals, for example every 50 m. The EC readings can be plotted on a graph and the profile will enable one to determine any significant changes within the river system related to EC.
river reach:	Defined section or portion of a river.
secondary monitoring point:	Secondary monitoring points refer to those points that are required to understand the water systems on the mine. These monitoring points will usually not have continuous flow monitoring devices or water quality monitoring devices. These points are generally required to develop a water and salt balance and to determine pollution sources and loads, and some form of instantaneous flow monitoring (e.g. V-notch) is normally included.
suitably qualified person:	Suitably qualified means a person having a level of training and experience with the type of work to be done and recognized skills in the type of work to be done.
surface water:	Water that is flowing or collected on surface and does not form part of the process water system is referred to as surface water.
tertiary monitoring point:	Tertiary monitoring points are usually required on an ad hoc basis when data is required for a specific purpose or to understand a water system in more detail. The monitoring is usually done by means of grab samples and field measurements.
total dissolved solids:	A concentration term used to express the total amount of dissolved solids in a solution (normally expressed in ppm or mg/l).

8

SYMBOLS AND ABBREVIATIONS

A	angle
BH	borehole
BOD	biological oxygen demand
Ca	calcium
$CaCO_3$	calcium carbonate
COD	chemical oxygen demand
DO	dissolved oxygen
DP	differential pressure
DWAF	Department of Water Affairs and Forestry
EC	electrical conductivity
EMPR	environmental management programme report
GIS	geographic information system
GS 1	grab sample; frequency as indicated by license
GS 2	grab sample; fortnightly
GS 3	grab sample; monthly
h_0	depth of water
IWQS	Institute for Water Quality Studies
L	width of weir profile
MP	surface monitoring point
N/A	not applicable
pH	measurement of hydrogen ion concentration
q	flow
QA	quality assurance
QC	quality control
TDS	total dissolved solids
WRC	Water Research Commission

APPENDIX A: IONIC BALANCES

Laboratory analytical reports usually express most ions in concentration by volume as milligrams per litre (mg/l) or parts per million (ppm). The various types of hardness and alkalinity are often expressed in terms of calcium carbonate, which is required for the calculation of ionic balances. An ionic balance requires that the concentration of cations (positively charge ions) and anions (negatively charge ions), where all ions are converted to $CaCO_3$ concentration, are added separately. The two summations should balance within 5% and a significant difference might indicate a possible error. Table A.1 gives the conversion factors from mg/l to mg/l as $CaCO_3$ for various ions.

Table A.1: Conversion factors for converting mg/l to mg/l as $CaCO_3$ for different cations and anions.

Cations	Conversion Factor	Anions	Conversion Factors
Hydrogen	50.00	Hydroxide	2.94
Ammonium	2.78	Chloride	1.41
Sodium	2.18	Bicarbonate	0.82
Potassium	1.28	Nitrate	0.81
Magnesium	4.10	Bisulphate	0.52
Calcium	2.50	Carbonate	1.67
Ferrous	1.79	Sulphate	1.04
Ferric	2.69	Other	
Cupric	1.57		
Zinc	1.53		
Aluminium	5.55	Carbon dioxide	2.27
Chromic	2.89	Silica	1.67

Example: 60 mg/l as Ca = 60 x 2.50 (conversion factor)
= 150 mg/l as $CaCO_3$

A more detailed discussion of calculating an ionic balance together with an example are presented in *A manual on mine water treatment and management practices in South Africa: Appendix - Volume 1* (Pulles, 1996 pp. 1.10 – 1.13).