Series A: Activity Guidelines



A6

BEST PRACTICE GUIDELINE

Water Management for Underground Mines

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 sixth in a series of the following Activity Best Practice Guideline documents:

BPG A1: Small-scale Mining

BPG A2: Water Management for Mine Residue Deposits

BPG A3: Water Management in Hydrometallurgical Plants

BPG A4: Pollution Control Dams

BPG A5: Water Management for Surface Mines

BPG A6: Water Management for Underground Mines

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APPROVALS

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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.

The 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 & 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 on this page.

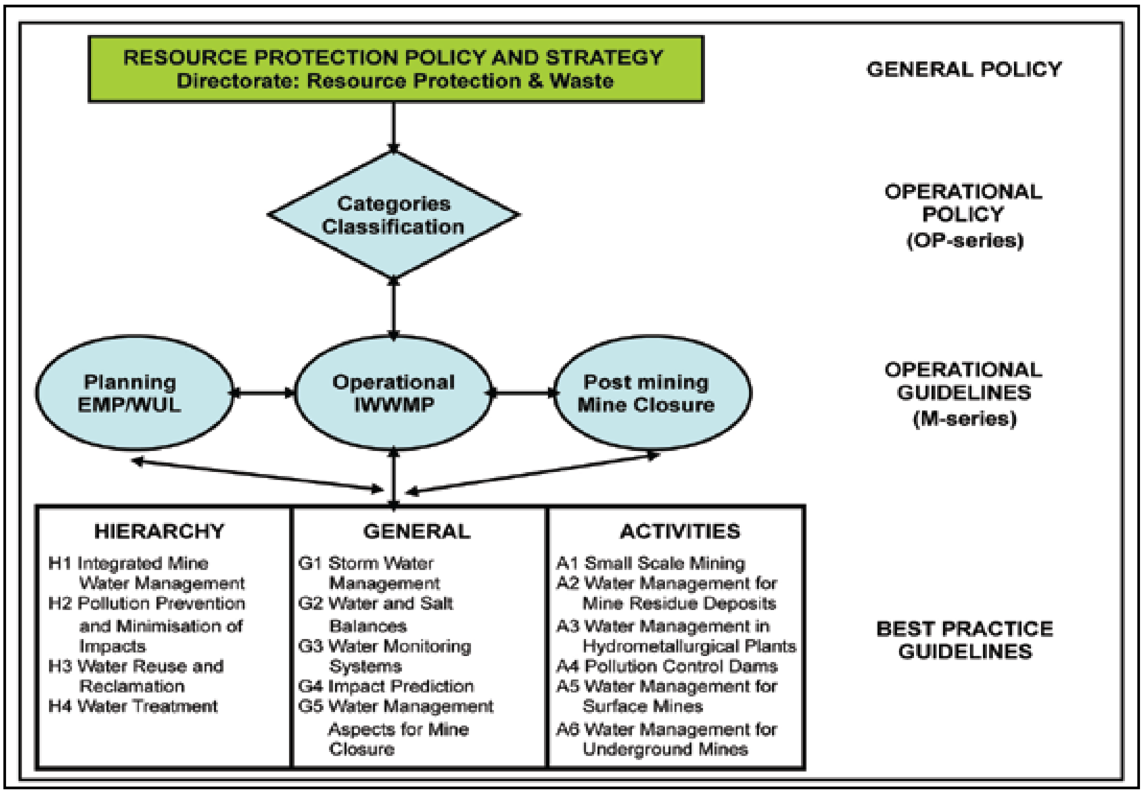
The overall Resource Protection and Waste Management Policy sets out the interpretation of policy and legal principles as well as functional and organisational arrangements for resource protection and waste management in South Africa.

Operational policies describe the rules applicable to different categories and aspects relating to waste discharge and disposal activities. Such activities from the mining sector is 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
- G5. Water Management Aspects for Mine Closure

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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ABBREVIATIONS

ABBREVIATIONS

ABA	Acid Base Accounting
APP	Approved Professional Person
ARD	Acid Rock Drainage
BFS	Bankable Feasibility Study
B&P	Bord and pillar
BPEO	Best Practice Environmental Option
BPG	Best Practice Guideline (documents in this series)
Bq	Becquerel (unit of radioactivity)
CMA	Catchment Management Agency
CMS	Catchment Management Strategy
DEAT	Department: Environmental Affairs and Tourism
DME	Department: Minerals and Energy
DWAF	Department of Water Affairs and Forestry
ECA	Environment Conservation Act, 1989 (Act 73 of 1989)
EIA	Environmental Impact Assessment
EMP	Environmental Management Plan
FRD	Fine Residue Deposit
GCL	Geosynthetic Clay Liner
GN704	Government Notice No. 704, National Water Act, 1998 (Act 36 of 1998)
GRI	Global Reporting Initiative
HDPE	High Density Polyethylene
ICP	Inductively Coupled Plasma
IRP	Integrated Regulatory Process
ISP	Internal Strategic Perspective
IWULA	Integrated Water Use License Application
IWRM	Integrated water resource management
IWWM	Integrated water and waste management
IWMP	Integrated Water Management Plan

LLDPE	Liner Low Density Polyethylene
MEM	Mine Environmental Management
MPRDA	Mineral and Petroleum Resources Development Act, 2002 (Act No. 28 of 2002)
MRD	Mine Residue Deposit
NEMA	National Environmental Management Act, 1998 (Act No.107 of 1998)
NNR	Natural Nuclear Regulator
NWA	National Water Act, 1998 (Act No. 36 of 1998)
NWRS	National Water Resources Strategy
P&IDs	Process and Instrumentation Diagrammes
RMF	Regional Maximum Flood
RO	Regional Office (DWAF)
RQOs	Resource Quality Objectives
SABS	South African Bureau of Standards
SAHRA	South African Heritage Resource Agency
SEA	Strategic Environmental Assessment
TSF	Tailings storage facility
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence Spectrometry
UNEP	United Nations Environment Programme
WC/WDM	Water Conservation and Water Demand Management
WDCS	Waste Discharge Charge System
WRC	Water Research Commission
WUL	Water use licence

GLOSSARY

In assessing the definitions given below, it must be understood that the definitions as provided in the NWA and Government Notice 704 (GN704) are primary.

Active management system: A management system that may require external energy inputs (such as electrical power) or continuous operator attention for its continued successful operation.

Activity: Any mining related process on the mine including the operation of washing plants, mineral processing facilities, mineral refineries and extraction plants, and the operation and the use of mineral loading and off-loading zones, transport facilities and mineral storage yards, whether situated at the mine or not, in which any substance is stockpiled, stored, accumulated or transported for use in such process or out of which process any residue is derived, stored, stockpiled, accumulated, dumped, disposed of or transported.

Approved professional person (APP): A professional engineer approved by the Minister of Water Affairs and Forestry after consultation with the Engineering Council of South Africa (ECSA), for the purposes of executing certain “tasks” relating to dams.

Aquifer: a geological formation which has structures or textures that hold water or permit appreciable water movement through them.

Bord and pillar: A method of working coal seams. First bords are driven, leaving supporting pillars of coal between. Next, cross drives connect the bords, leaving supporting coal as rectangular pillars. Finally, the pillars are mined (extracted, won, robbed) and the roof is allowed to cave in. The bordroom is the space from which bord coal has been removed.

Catchment: In relation to a watercourse or watercourses or part of a watercourse, means the area from which any 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 (Act 36 of 1998)).

Category A Mines: Those mines that exploit orebodies that are associated with sulphide minerals or any other reactive minerals, either in the ore, overburden or waste material.

Clean water: Water that has not been affected by pollution.

Clean water system: Any dam, other form of impoundment, canal, works, pipeline and any other structure or facility constructed for the retention or conveyance of unpolluted water.

Crosscut: A small passageway driven at right angles to the main entry to connect it with a parallel entry or air course. A tunnel driven at an angle to the dip of the strata to connect different seams or workings. A horizontal opening driven across the course of a vein or in general across the direction of the main workings. A connection from a shaft to a vein.

Dam: Any settling dam, slurry dam, evaporation dam, catchment or barrier dam and any other form of impoundment used for the storage of unpolluted water or water containing waste.

Dam with a safety risk: A dam with a storage capacity in excess of 50 000 cubic metres and a vertical height in excess of 5 metres. The design of new dams, alterations to existing dams, quality control during construction, dam safety inspections and dam safety studies are described as “tasks” relating to dams. MRDs are currently exempt but can be classified under certain circumstances.

Dirty area: Any area at a mine or activity which causes, has caused or is likely to cause pollution of a water resource.

Dirty water: Water that contains waste.

Dirty water system: Any dam, other form of impoundment, canal, works, pipeline, residue deposit and any other structure or facility constructed for the retention or conveyance of water containing waste.

Drive: A tunnel or level in or parallel to and near a mineralized lode or vein, as distinct from a crosscut, which only gives access normal to the lode.

Environmental Management Programme: An environmental management programme submitted in terms of section 39 of the Mineral and Petroleum Resources Development Act, 2002 (MPRDA).

Facility: In relation to an activity, includes any installation and appurtenant works for the storage, stockpiling, disposal, handling or processing of any substance.

Fissure water: A common mining term in hard rock mines that refers generically to groundwater that enters the mine.

Floor: The rock underlying a stratified or nearly horizontal ore deposit, corresponding to the footwall of more steeply dipping deposits. The bottom of a coal seam or any other mineral deposit.

Footwall: The wall on the lower side of a reef, lode, or fault.

Goaf: That part of a mine from which the coal has been worked away and the space more or less filled up with caved rock.

Groundwater: Water that occurs in the voids of saturated rock and soil material beneath the ground surface is referred to as groundwater and the body within which the groundwater is found is referred to as an aquifer.

Hanging wall: The overlying side of an orebody, fault, or mine working, especially the wall rock above an inclined vein or fault.

Haulage: A drive used for mechanical transport.

Height of dam: In the case of a dam situated across a water course, the maximum wall height is measured from the natural level of the bed of the water course on the downstream face of the dam to the top of the dam, which is the level of the roadway or walkway. In the case of any other dam the height is measured from the lowest elevation of the outside limit of the dam to the top of the dam which is the level of the roadway or walkway. In the case of a dam consisting of a spillway across the full dam width, the height is measured to the crest level of the spillway.

Inter-alia: Among other things.

Inter-mine flow: The flow of water between adjacent mines, either through direct connections or through boundary pillars due to hydrostatic head (pressure) across the pillar

Life of mine: The life of mine includes all the phases of the mine's existence from the conceptual and planning phases, through design, construction, operation and decommissioning to the post-closure and aftercare phases.

Loca standi: A person who has locus standi, or legal standing, and has the right to appear before a court on a particular matter.

Longwall: method of working coal seams believed to have originated in Shropshire, England, toward the end of the 17th century. The seam is removed in one operation by means of a long working face or wall, thus the name. The workings advance (or retreat) in a continuous line, which may be several hundred metres in length. The space from which the coal has been removed (the goaf or waste) either is allowed to collapse (caving) or is completely or partially filled or stowed with stone and debris. The stowing material is obtained from any dirt in the seam and from the ripping operations on the roadways to gain height. Stowing material is sometimes brought down from the surface and packed by hand or by mechanical means. Also known as longwork; Shropshire method; combination longwall; and Nottingham or Barry system.

Mine Manager: The meanings assigned to them in the Mine Health and Safety Act, 1996 (Act No. 29 of 1996)

Mitigation: Measures taken to reduce adverse impacts on the environment.

Passive management system: A management system that does not require external energy inputs (such as electrical power) or continuous operator attention for its continued successful operation.

Person in control of a mine, activity or holder: In relation to a particular mine or activity, includes the owner of such mine or activity, the lessee and any other lawful occupier of the mine, activity or any part thereof; a attributer for the working of the mine, activity or any part thereof; the holder of a mining authorisation or prospecting permit and if such authorisation or permit does not exist, the last person who worked the mine or his or her successors-in-title or the owner of such mine or activity; and if such person is not resident in or not a citizen of the Republic of South Africa, an agent or representative other than the manager of such a mine or activity must be appointed to be responsible on behalf of the person in control of such a mine or activity.

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 (Act 36 of 1998))

Prevention: Measures taken to minimize the release of wastes to the environment.

Reserve: means the quantity and quality of water required

(a) to satisfy basic human needs by securing a basic water supply, as prescribed under the Water Services Act, 1997 (Act No. 108 of 1997), for people who are now or who will, in the reasonably near future, be

- (i) relying upon;
- (ii) taking water from; or
- (iii) being supplied from,

the relevant water resource; and

(b) to protect aquatic ecosystems in order to secure ecologically sustainable development and use of the relevant water resource;

Residue: Includes any debris, discard, tailings, slimes, screenings, slurry, waste rock, foundry sand, beneficiation plant waste, ash and any other waste product derived from or incidental to the operation of a mine or activity and which is stockpiled, stored or accumulated for potential re-use or recycling or which is disposed of.

Residue deposit: Includes any dump, tailings dam, slimes dam, ash dump, waste rock dump, in-pit deposit and any other heap, pile or accumulation of residue.

Resource quality: means the quality of all the aspects of a water resource including (National Water Act, 1998 (Act 36 of 1998))

(a) the quantity, pattern, timing, water level and assurance of instream flow;

(b) the water quality, including the physical, chemical and biological characteristics of the water;

(c) the character and condition of the instream and riparian habitat; and

(d) the characteristics, condition and distribution of the aquatic biota

Roof: The rock immediately above a coal seam. It is commonly a shale and is often carbonaceous in character and softer than similar rocks higher up in the roof strata. The roof shale may contain streaks and wisps of coaly material, which tends to weaken the deposit. Roof in coal mining corresponds to hanging wall in metal mining.

Seepage: The act or process involving the slow movement of water or another fluid through a porous material like soil, slimes or discard.

Service water: mine service water refers to water sent underground and used for general services such as cooling of machinery, cooling of air, dust suppression, stope cleaning, etc. Mine service water may be chilled or unchilled.

Shortwall: A system of coal working sometimes employed in seams 1.2 m or under in thickness, with the aid of machines. Short faces, each 12 to 30 m wide, are driven at 45- to 60-m centers, with crosscuts to assist coal transport and ventilation. The rippings are used to form roadside packs. The shortwalls are driven to the boundary, and the coal pillars are worked by longwall retreating

Siting: The process of choosing a location for a facility.

Slope: Slope is a dimensionless number and is defined by the vertical distance (drop) divided by the horizontal distance.

Solids content: The volumetric concentration (Cv) is defined as the ratio of the volume of solids to the total volume of the mixture or slurry. The mass concentration (Cw or Cm) is defined as the ratio of the mass of dry solids to the total mass of the mixture or slurry

Stockpile: Includes any heap, pile, slurry pond and accumulation of any substance where such substance is stored as a product or stored for use at any mine or activity.

Stope: To excavate ore in a vein by driving horizontally upon it a series of workings, one immediately over the other, or vice versa. Each horizontal working is called a stope because when a number of them are in progress, each working face under attack assumes the shape of a flight of stairs. When the first stope is begun at a lower corner of the body of ore to be removed, and, after it has advanced a convenient distance, the next is commenced above it. This is called overhand stoping. When the first stope begins at an upper corner, and the succeeding ones are below it, it is called underhand stoping. The term stoping is loosely applied to any subterranean extraction of ore except that which is incidentally performed in sinking shafts, driving levels, etc., for the purpose of opening the mine.

Suitably qualified person: A person with suitable professional expertise for the task who can be accountable for the output of the task.

Surface water: All water naturally open to the atmosphere (rivers, lakes, reservoirs, streams, impoundments, seas, estuaries, etc.); also refers to springs, wells, or other collectors that are directly influenced by surface water.

Watercourse: Watercourse means –

(a) a river or spring;
(b) a natural channel in which water flows regularly or intermittently;
(c) a wetland, lake or dam into which, or from which, water flows; and

any collection of water which the Minister may, by notice in the Gazette, declare to be a watercourse, and a reference to a watercourse includes, where relevant, its beds and banks. (National Water Act, 1998 (Act 36 of 1998)).

Water resource: Includes a watercourse, surface water, estuary, or aquifer. (National Water Act, 1998 (Act 36 of 1998))

Water system: Water system includes any dam, any other form of impoundment, canal, works, pipeline and any other structure or facility constructed for the retention or conveyance of water. (Government Notice 704 of 4 June 1999.)

Winze: A vertical opening driven downward connecting two levels in a mine. When one is standing at the top of a completed connection the opening is referred to as a winze, while when standing at the bottom, the opening is a raise, or rise.

1

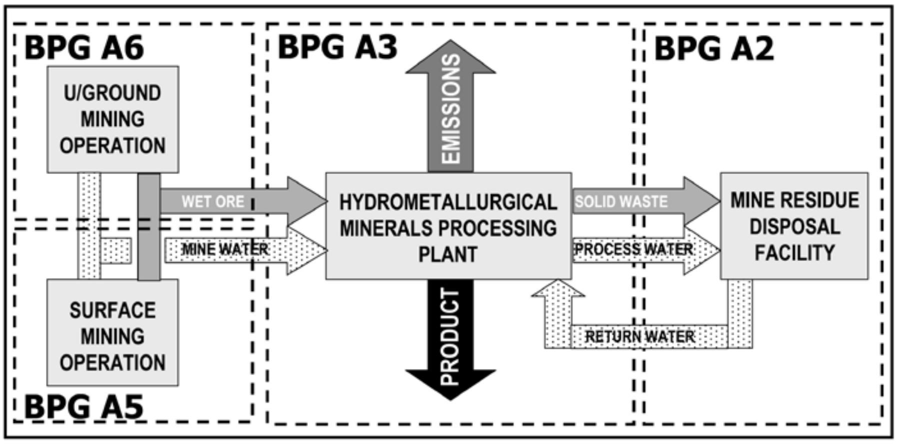
INTRODUCTION AND OBJECTIVES OF THIS BEST PRACTICE GUIDELINE

1.1 INTRODUCTION

The actual underground or surface mining activity where the ore is extracted is the key part of the mining operation on most mines, including gold, coal and platinum. Depending on the nature of the mine, the actual mining operation may be followed by a processing plant (normally hydrometallurgical) with the associated production of mine residues such as waste rock, discard, tailings or slurry that are then subsequently disposed of on a mine residue deposit.

Where a hydrometallurgical processing plant does exist, it typically features as a central component of the mining operation in that it receives the raw ore from the mine and may produce the saleable product, the solid waste streams and a significant portion of the liquid effluent. While the operations and water balance of the average underground mining operation are integrally linked with the hydrometallurgical processing plant and the subsequent residue disposal facility and its associated return water systems, there are particular features that relate to water management within the underground mining operation itself. This Best Practice Guideline (BPG) focuses specifically on those water management issues within the underground mining operation, while water management issues within the surface mining operations are covered in ***BPG A5: Water management for Surface Mines.*** Water management considerations associated with hydrometallurgical processing plants are covered in ***BPG A3: Water Management for Hydrometallurgical Plants*** and water management associated with a residue disposal facility is covered in ***BPG A2: Water Management for Mine Residue Deposits.***

Figure 1.1: Activity best practice guidelines



This BPG (***BPG A6: Water Management for Underground Mines***) therefore only deals with water management issues below surface and within the underground mining operation (see Figure 1.1 above) and excludes water management associated with the subsequent hydrometallurgical processing plant. While the underground water system may partially go to surface before going underground again, this BPG focuses on when water leaves surface and is sent into the mine shaft for use within the various underground mining operations and ends when wet ore (including water/moisture) and water and or slurries from the mining operation arrive at the top of the shaft to be sent to hydrometallurgical processing plants for processing or for storage and/or disposal, or for treatment and subsequent reuse back underground. Underground mines also include many components of their operations on surface, e.g. metallurgical plants, residue disposal facilities, etc. and these features are covered in ***BPG A5: Water management for Surface Mines.***

This BPG applies to all underground mining operations.

While water is used for a variety of applications within an underground mining operation, the typical uses to which water is put within an underground mine are the following:

- Mine service water to operate mining equipment such as rock drills, continuous miners and longwall shearers.
- Dust suppression.
- Mine cooling.
- Underground workshops
- Conveying fine ore from underground to surface as pumped slurries.
- Backfill for ground support
- Potable water and sanitation underground

In addition, underground mining operations are also impacted upon by water ingress into the mining void through sources such as the following:

- Hydraulic connections to surface water resources such as sinkholes in rivers
- Dewatering of the aquifer within which the mine is located through mining operations or specific features such as boreholes (cable holes, rescue holes, prospecting holes)
- Fracturing of overlying strata due to high extraction mining techniques with subsequent leakage of the overlying aquifer into the mine void
- Ingress through geological features or from dewatering of dolomitic compartments
- Mine shafts

This water ingress may result in safety risks and increased cost for dewatering operations.

Finally, underground mining operations may also impact on the water resource in the following manner:

- Water ingress into the mine reduces the ability of the surface and/or ground water resource to provide other water users with water.
- Water quality deteriorates in the mine workings due to contact between the water circuits and sulphide minerals in the ore, explosives used in the mining operation, cyanide from backfill operations, bacterial contamination from poor sanitary practices and other chemicals used in the mining operation.
- Closed mines will fill up and may decant contaminated water into the surrounding aquifers or surface water resources.
- Flooded underground mines may be dewatered in order to initiate re-mining operations
- Intermine flow may occur within a regional setting, where water from an adjacent mine flows into and becomes part of the water balance of the receiving mine.

As with any other industry or component of an integrated mining and processing plant operation, the underground mining operations need to operate within an external environment where water is becoming an increasingly scarce and valuable resource with competing demands, primarily from the need to satisfy the demand for human use and ecological functioning. As a significant user of water and a producer of water containing waste, the minerals industry has an important role to play in ensuring that water is conserved and sustainably used and managed to the benefit of all the water users. The mining and minerals industry is already exposed to the true value of water in having to confront areas where water is in short supply, or where poor quality water needs to be treated before it can be reused or discharged. In addition, legislative developments such as the waste discharge charge system are set to have a major influence in dictating the economics of water supply, water treatment and discharge.

Within this external environment and due to the high costs associated with pumping water up from very deep underground mines, underground mining operations are required to tighten up the degree of water reuse and reduce the amount of wastewater pumped and discharged. This obviously has significant implications for water quality within the underground mining operations' water circuits, primarily in terms of scaling, corrosion, erosion and microbiological quality (human health risks).

To ensure that improved water management within underground mining operations avoids, or at least significantly reduces, the potential negative effects, while still complying with the strategic imperatives imposed by the external environment within which these mines operate, it is necessary that water management operations are firmly based on sound and correct principles. It is the objective of this BPG to provide guidance on these key issues.

1.2 OBJECTIVES OF THIS BPG

The primary objectives of this BPG can be stated as follows:

1) To provide DWAF officials with an understanding of the water management issues involved in underground mining operations in order that they are able to interact with mine water managers on a more proactive basis with regard to water management issues that have their origin in the underground mining operations.
2) To provide information to water managers with the mining industry that will provide clarity on information that DWAF officials will be seeking from them.
3) To promote a strategic water management approach at underground mining operations that views and manages water as a key business asset with social, cultural, environmental and economic value.
4) To provide a practical and logical process whereby water management within underground mining operations can be optimized.
5) To provide guidance on factors that need to be considered when planning for all life cycle phases and particularly closure of underground mining operations.

The first objective is aimed at providing DWAF officials information on water management issues in underground mines in order that they can holistically evaluate water management activities within the underground mining operations against objectives set to manage impact on water resources. This is necessary as many important water management issues that manifest themselves on surface by way of impact on the water resource, have their origin in the underground mining operations. Knowledge of the underground water management issues will enable DWAF officials to better understand water management issues that manifest for the whole integrated mining and minerals processing operation.

The second objective is to provide a detailed discussion of water management issues within underground mines for mine personnel who have responsibility for water management in the underground mining operations insofar as the BPG will describe and present best practice which will result in more optimized underground water management with reduced environmental risk, liability and cost to mining companies.

The third objective is a broad strategic objective, taken from a strategic framework document prepared by the Minerals Council of Australia in 2006. This objective is entirely consistent with sustainable development imperatives and is considered appropriate in a water-scarce country such as South Africa where there is increasing competition and demands on the scarce and limited water resource.

The fourth objective addresses the practical issues and guidance that will be required to give effect to the second objective. The BPG addresses this by presenting a detailed discussion on the manner in which water is used in the underground mining operations and what the typical water-related problems are. The BPG also presents a discussion of the different types of underground mining and what the unique water-related problems and challenges are for these different mining methods.

The fifth objective specifically addresses those features of an underground mining operation that could, if not properly planned and managed, produce high risks and/or impacts on the national water resource. Particular focus is given, in Chapter 5, of the water-related problems associated with different mining techniques that need to be understood and planned for in order to ensure that the impact on the water resource is minimized.

It should also be mentioned that ***BPG A5: Water Management for Surface Mines***, presents a lot of information on aspects of the mining operation that are found on surface. As underground mines also have a footprint on surface, many aspects of ***BPG A5*** will also be relevant to underground mines and the user is referred to ***BPG A5*** to obtain this additional information.

1.3 APPLICABILITY, STRUCTURE AND FOCUS OF THIS BPG

Water management within the underground mining operations has traditionally been the domain of mine water management personnel and there has been little involvement of DWAF officials in these issues. As previous research has shown that a very significant percentage of mine water contaminants originate in the underground mining operations, it is important for DWAF officials to understand what happens in the underground mines with regard to water management , in order that they can ensure that sound integrated water resource management practices are being implemented. The fact that South Africa is faced with a significant legacy of pollution impacts from many historic underground mining operations, makes it even more important for DWAF officials to have this knowledge of underground mining water management in order that they can properly interact with the mining industry in evaluating and agreeing on decommissioning and closure plans for underground mines.

This BPG is structured as follows:

- Chapter 2 covers the general principles for water management in underground mining operations.
- Chapter 3 summarises the current legal framework in South Africa within which underground mining operations must be undertaken.
- Chapter 4 discusses the regulatory water management context within which underground mining operations need to function.
- Chapter 5 presents a discussion of the different types of underground mining typically applied in South Africa, together with the unique water management challenges associated with each of these underground mining approaches.
- Chapter 6 presents and discusses water management considerations in typical generic underground mining operations at different stages in a mine life cycle in order that an understanding of underground water management issues can be developed. This discussion presents the information on typical water uses in the underground mining operation, impacts of water on the mining operation and impacts of the mining operation on the water resource.
- Chapter 7 presents a literature list that was used in compiling this document.

1.4 DWAF ROLE IN UNDERGROUND WATER MANAGEMENT

DWAF is committed to the implementation of integrated water resource management principles and cannot, therefore, ignore water management issues in the underground mining operations. Although DWAF officials will not normally become involved in underground mine water management issues, a knowledge of these issues will assist them in interacting with mine water managers, and will enable them to understand the various mine water management problems and risks when reviewing Integrated Water and Waste Management Plans and Mine Closure Plans.

2 GENERAL PRINCIPLES OF UNDERGROUND MINE WATER MANAGEMENT

The fundamental principle that applies to water management in underground mines is as follows:

Plan, design, operate and close the underground mining operations in a manner that reduces the ingress of clean water into the mine, minimizes the volume of water used in mining operations, maximizes water reuse, minimizes the water quality deterioration within the mine and minimizes the impacts on the water resource.

In order to give effect to this fundamental principle, the following secondary or supporting principles have been defined:

1) Optimise water reuse and reclamation within the underground mining operations and minimize transfer and interchange of water between surface and underground.
2) Plan and undertake prospecting, mine planning and development, active mining operations and mine decommissioning in a manner that minimizes disturbance to existing hydrological and geohydrological systems and minimizes water ingress or water 'make' into the mine.
3) Where practical, intercept clean ingress water as close as possible to its source in order to prevent or minimize water quality deterioration and to allow this water to be pumped up to surface for appropriate use or discharge (this is an underground application of the pollution prevention principle of separating clean and dirty water).
4) Restrict the contact time between water and the mineral being mined (especially the fines with high reactive surface areas) and especially in mining sections where the mineral has a high sulphide content.
5) Ensure that mining sections are left as clean as possible (especially with regard to fines, for example in gold mines) in order to reduce the source term that could cause future water quality deterioration.
6) Design water management and treatment systems underground for extreme variation in flow and quality (especially with regard to suspended solids) due to mining activities in hard rock mines and seasonal effects (high rainfall events) for shallower mines, which due to their shallow nature are affected by surface hydrological conditions.
7) Ensure that mine service water is appropriately treated such that it does not pose a health and safety risk to workers, either through inhalation (atomized water from drilling machines) or consumption.
8) Plan for closure with regard to understanding where water enters the mine and would normally decant, how it flows, how it should preferably flow in order to minimize water quality deterioration and where the preferred discharge point should be.
9) Where appropriate, undertake dewatering operations ahead of the mine to keep the mine dry and prevent water quality deterioration.
10) Consider alternative mining methods to minimize water ingress and associated water quality problems.

While water management and treatment within the underground mining operations has not consistently been considered or evaluated by DWAF in the past, this BPG aims to rectify this. The need for this change is motivated by the recognition and knowledge that the underground mining operations can be the primary and major source of mine water quality deterioration on a mine and that underground mining operations can have a major impact on the sustainability of the water resource through dewatering of aquifers, surface subsidence, sinkholes and diversion of surface water systems into the underground workings through these subsidence features. Additionally, many underground mining operations are included in the mining legacies that will continue to discharge large volumes of contaminated water into the water resource.

3

LEGAL FRAMEWORK FOR UNDERGROUND MINE WATER MANAGEMENT

The current South African legal framework with regards to water management for underground mining is covered in Appendix A. The following details are included in Appendix A:

- The legal requirements for water management for underground mining, within the prevailing mining, water and environmental legislation in South Africa. This review focuses on the requirements of the National Water Act, 1998 (Act 36 of 1998) and the Mineral and Petroleum Resources Development Act, 2002 (Act 28 of 2002). The provisions included in other legislation are also considered
- Summary of the applicable water management policies and strategies developed by the DWAF. These documents are available on the department's website (http:///www.dwaf.gov.za).

The sections below provide a summary of the current principal legal framework for water management for underground mining as well as a list of the applicable water management policies and strategies.

3.1 CONSTITUTION OF THE REPUBLIC OF SOUTH AFRICA ACT, 1996 (ACT 108 OF 1996)

The environmental rights of the people of South Africa are specified in Section 24 of the Constitution. This guarantees everyone the right to an environment that is not harmful to her/ his health or well-being, and for the environment to be protected for the benefit of present and future generations. This is to be achieved through reasonable legislation and other measures.

3.2 NATIONAL ENVIRONMENTAL MANAGEMENT ACT, 1998 (ACT NO.107 OF 1998)

The National Environmental Management Act (NEMA) (Act No. 107 of 1998) provides the guiding legislation and framework for environmental management in South Africa. Chapter 2 of the NEMA describes a set of fundamental guiding principles governing the actions of those organs of state that may significantly affect the environment. These principles need to be considered in all dimensions of water management. The Department of Water Affairs and Forestry is thus guided by these principles in the development and implementation of various policies and strategies.

3.3 THE MINERALS AND PETROLEUM RESOURCES DEVELOPMENT ACT (MPRDA) (ACT NO. 28 OF 2002)

The Minerals and Petroleum Resources Development Act (MPRDA) regulates the prospecting for, and optimal exploration, processing and utilisation of minerals; provides for safety and health in the mining industry; and controls the rehabilitation of land disturbed by exploration and mining. The Act supports the principle of IWRM by promoting the goal of sustainable development in the development of mineral and petroleum resources. The Act specifically states that *"any prospecting or mining operation must be conducted in accordance with generally acceptable principles of sustainable development by integrating social, economic and environmental factors in the planning and implementation of prospecting and mining projects, in order to ensure that exploration of mineral resources serves present and future generations."*

The MPRDA and its regulations require that an environmental impact assessment be undertaken for an underground mine. The EIA will include a scoping report and an environmental impact assessment report.

3.4 NATIONAL WATER ACT, 1998 (ACT NO. 36 OF 1998)

The National Water Act (NWA) emphasises the effective management of South Africa's water resources through the basic principles of Integrated Water Resources Management (IWRM). Both the NWA and IWRM seek to achieve social equity, economic efficiency and ecosystem sustainability, which are undertaken within a framework that includes institutional roles, an enabling environment (legislative, regulation and policy) and management instruments. Efficiency in water distribution and use is a fundamental premise of water conservation and water demand management.

The NWA stipulates that water use authorizations must be obtained for all water uses contemplated as part of underground mining. Section 21 of the NWA stipulates the eleven types of water use. An underground mine will require licenses for each water use. Thus, for example, a mine could feasibly be required to prepare water use applications for the following Section 21 water uses:

(a) taking water from a water resource
(b) storing water
(c) impeding or diverting the flow of water in a watercourse
(d) engaging in a stream flow reduction activity contemplated in section 36
(e) engaging in a controlled activity identified as such in section 37(1) or declared under section 38(1)
(f) discharging waste or water containing waste into a water resource through a pipe, canal, sewer, sea outfall or other conduit
(g) disposing of waste in a manner which may detrimentally impact on a water resource
(h) disposing in any manner of water which contains waste from, or which has been heated in, any industrial or power generation process
(i) altering the bed, banks, course or characteristics of a watercourse
(j) removing, discharging or disposing of water found underground if it is necessary for the efficient continuation of an activity or for the safety of people; and
(k) using water for recreational purposes.

The Department of Water Affairs and Forestry does allow for an Integrated Water Use License Application (IWULA) in instances where more than one water use is being applied for. While an underground mine may require licences in terms of a number of uses, water uses 21 (a), (b), (f) (g) and (j) are most typically encountered.

3.5 WATER USE REGULATIONS

Government Notice No. 704 (GN704) provides regulations on the use of water for mining and related activities aimed at the protection of water resources, was promulgated in terms of section 26 of the NWA on 4 June 1999. The detailed description and implications of these regulations are covered in section 6 of this BPG.

3.6 DAM SAFETY REGULATIONS

The Dam Safety Regulations (published in Government Notice R. 1560 of 25 July 1986) requires that every dam with a safety risk shall be classified in accordance with section 2.4 of the regulation on the basis of its size and hazard potential. An authorization is required from the dam safety office before construction of a dam, classified as having a safety risk, commences.

3.7 DWAF WATER MANAGEMENT POLICIES AND STRATEGIES

The DWAF water management policies and strategies that are summarised in Appendix A include the following:

- National Water Resource Strategy (NWRS)
- Catchment Management Strategies (CMS)
- Internal Strategic Perspectives (ISP)
- Water Resource Availability and Utilisation in South Africa
- The Philosophy and Practice of Integrated Catchment Management: Implications for Water Resource Management in South Africa
- A Strategic Plan for the Department of Water Affairs and Forestry to facilitate the implementation of Catchment Management in South Africa

- Towards a Strategy for Waste Discharge Charge System (WDCS)
- Water Conservation and Water Demand Management (WC/WDM)
- Water Allocation Reform
- Water classification system, and
- The National Groundwater Strategy.

4 WATER MANAGEMENT CONTEXT

Underground mining is not undertaken in isolation of the regional, national and even global water management context. Any water management on an underground mine, and the development of a mine water management plan, must therefore conform and be guided by the overall water management context. Specific aspects of this context include the following:

- The global, national, regional and site-specific water management context
- Integrated mine water management in the regional context
- Specific mine water management requirements for the various life cycle phases of a mine, and
- Integrated regulatory and procedural guidance.

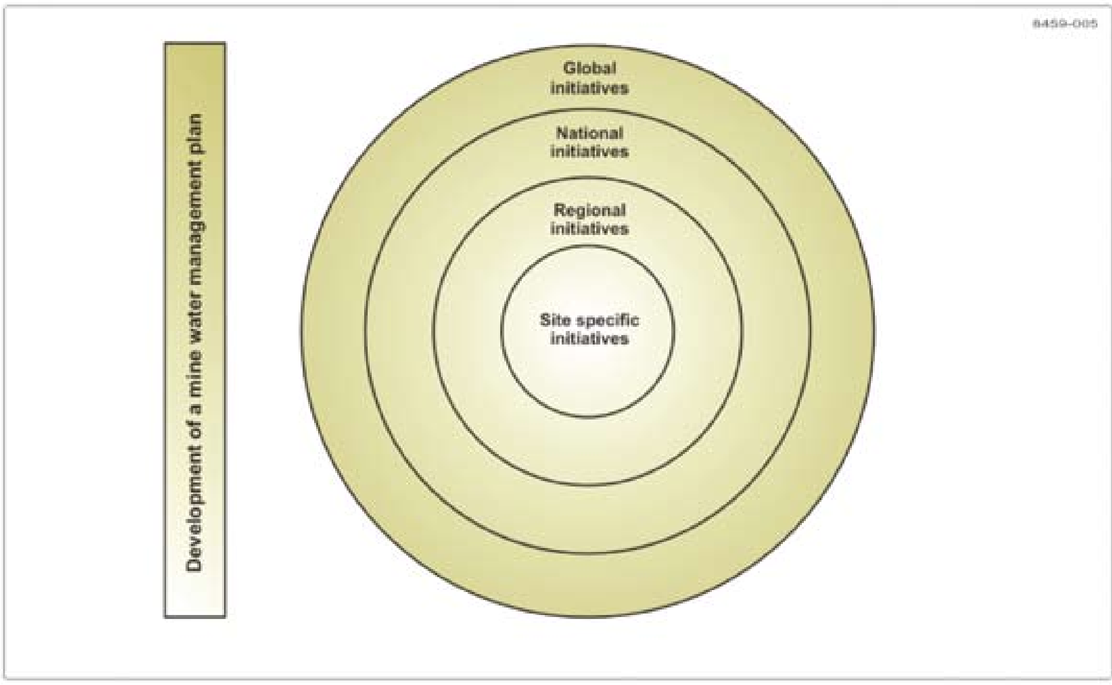
These various aspects are covered in the sections below.

4.1 OVERALL WATER MANAGEMENT CONTEXT

Figure 4.1 illustrates the development of a mine water management plan within the global, national, regional and site-specific context. This context can be summarised as follows:

- Global context: Various organisations have provided guidance on water management, monitoring and reporting on a global basis. One such development is the Global Reporting Initiative (GRI), who have published the following documentation of relevance to underground mines:
  - Sustainability Reporting Guidelines (2002) which provide a global standard and guidance for reporting
  - The Water Protocol (2003) which provides definitions and clarifications of the terms, concepts and expectations embedded in the reporting indicators, and
  - The Mining and Metals Sector Supplement (2005) which capture the relevant issues essential to sustainability reporting in the mining and metals sector
- National context: Section 3 and Appendix A, section A.2 provide details on the national water management legislation that must be complied with in developing the mine water management plan
- Regional context: Section 3 and Appendix A, section A.3 provide details on the water management policies and strategies that have been developed by DWAF, and are to be implemented on the regional/catchment basis. The requirements of these policies and strategies should be taken into account when developing the mine water management plan. Specific considerations include integrated water resource management plans, cumulative water quantity and quality impacts and regional mine closure strategies in terms of the MPRDA, and
- Site-specific context: This includes an understanding of the mine site and the impact that this can have on the mine water management model. Specific site-specific considerations include, amongst others, geology, topography, meteorology, geochemistry, waste management.

Figure 4.1: Overall water management context



4.2 INTEGRATED MINE WATER MANAGEMENT

Best Practice Guideline H1 covers integrated mine water management and provides the following details:

- Discussion on the complete DWAF series of BPGs and how these should be used in the application of integrated mine water management on mine sites
- Discussion of integrated mine water management principles and how these should be applied at a mine site, taking into account both source-directed and resource-directed measures
- Presentation of typical mine site layouts and typical mine water management issues in order to demonstrate practically how integrated mine water management principles and the BPGs should be applied on mine sites
- Guidance on mine water transfer schemes across catchment boundaries
- Specific guidance on the contents and scope of an Integrated Water Management Plan (IWMP) that should be submitted to DWAF by mining proponents, the level of detail required and specific areas where suitably qualified specialists should be used, both in preparation and review of an IWMP
- Links with the Waste Discharge Charge System being developed by DWAF, and
- Guidance on legal aspects.

4.3 MINE LIFE CYCLE PHASE SPECIFIC REQUIREMENTS

Table 4.1 below summarises the information and water modelling and management requirements through the various phases of the mine development, including:

- Prospecting, conceptualisation and planning
- Pre-feasibility study
- Feasibility study, leading to a Bankable Feasibility Study (BFS),
- Mine design,
- Construction and commissioning
- Mine operation, and
- Closure and after-care, with closure certificate.

Table 4.1: Life cycle information and water management requirements

Mine Phase	Baseline Information and evaluation requirements	Links to other information not forming part of the IWMP	Outputs	
			Regulatory	Mine management
Prospecting, conceptualisation and planning	• Background information categorising the receiving water environment (water monitoring data and programmes, meteorological data, etc) • Catchment description, catchment management plan and water availability • Groundwater zone of impact • Information on existing mining in the region	• Geology reports • Preliminary mine plan • Environmental overview (Strategic Environmental Assessment) • Socioeconomic impact assessment • Confirmation of the legal entity for water use authorization	• Mine risk classification • Mapping of the integrated regulatory process • Project specific requirements and constraints for water supply, source management and water quality objectives	• High level mine water management plan that can practically be implemented • Confirmation of adequate water for the mine over the full mine life
Pre-feasibility	• Baseline data (surface water, groundwater and process water) required to assess the impact on the receiving water environment • Monthly time-step water management model • Preliminary sizing of water management infrastructure • Inter-mine flow	• Mine closure objectives • Preliminary groundwater model • Catchment model • Pre-feasibility level mine plan • Initial waste management concepts • Stakeholders/water users database for the catchment • Mine closure plan	• Initial discussions on project specific water requirements and water allocations • Fatal flaw analysis • Request for details on the Reserve from the Regulatory • Discussion on water supply and mine water requirements, including potential supply sources and other water user requirements • Input to EIA • Identified mine water uses • Agreed terms of reference for required information	• Monthly time-step mine water plan • Affordability of water management measures

Table 4.1: Life cycle information and water management requirements - continued

Mine Phase	Information and water management requirements	Links to other information	Outputs	
			Regulatory	Mine management
Feasibility	• Water management model (daily time-step modeling) • Mine water demand and source of reliable water supply • Waste Discharge Charges • Water quantity and quality monitoring • Hierarchy of water management • Discharge quantity and quality • Inter-mine flow	• Groundwater modeling and assessment • Geochemical modeling • Waste management plan • Feasibility level mine plan • Mine closure plan	• Submission of Water Use License Application (WULA) • Input to EIA and EMP/ IWMP documents • Input to socio-economic impact assessment	• Detailed water management plan (infrastructure sizing and operating rules) • BFS cost estimate for water management • Input to mine water management plan covering mitigation of water impacts
Design	• Water Use License • Model updates • Design of water management infrastructure • Closure planning and costing • Inter-mine flow	• Mechanical and electrical design • Instrumentation design • P&IDs • Mine closure plan	• Submit IWMP in support of Water Use License Application (WULA) • Approval for the design of water supply and pollution control dams	• IWMP for the mine • Water management and monitoring plan
Construction and commissioning	• Water infrastructure construction details • Water quantity and quality monitoring • Audits and model revisions, using collected data • Inter-mine flow	• Other construction activities • Mine closure plan	• Reporting to verify that the construction is completed in accordance with the approvals	• Monitoring and audit requirements for construction phase • Water management system enabling requirements • Model updates to confirm that water quantity and quality objectives can be met with required level of reliability • Requirements for reporting against IWMP and WUL
Mine operation	• Regular water management data collection and assessment • Recalibration and revisions to water management model, according to water monitoring results • Ongoing operational management • Inter-mine flow • Update to closure plan and costing	• Operations mine plan • Rehabilitation schedules • Best Practice Guidelines • Mine closure plan	• Reporting and monitoring in terms of compliance against water use authorization conditions • Annual update of IWMP (continual improvement)	• Monitoring and audits • Non conformance follow up and mitigation • Model updates to confirm validity of IWMP • Reporting against IWMP and WUL
Closure, post-closure and after-care	• Design of sustainable water management measures for closure • Maintenance of water quantity and quality monitoring • Inter-mine flow • Implement closure	• Catchment level water management plan • Mine closure plan	• Approved Closure and Rehabilitation Plan • Monitoring and reporting against Closure Plan	• Reporting against IWMP and WUL • Closure plan for water aspects • Closure certificate

The information and water management requirements for each of the mine phases are discussed in more detail in the sections below. Note that the information provided in this section should be used as a guideline only and is not prescriptive. Items and/or actions mentioned in a particular phase or stage of mine development may overlap into a preceding or subsequent phase. For example, a WULA does not always need to be submitted at the feasibility stage, but may be submitted at any appropriate phase in the mine development.

4.3.1 Prospecting, conceptualisation and planning

The prospecting, exploration, conceptualisation and planning stage will constitute the first high-level assessment of the water management requirements for the mine. It will be necessary at this stage to collect any background information that is available, such as meteorological data, water quantity and quality monitoring data for both the catchment and the site-specific area of the mine, topographical mapping, geological data, environmental information (such as a Strategic Environmental Assessment for the area) and any reports on water monitoring and modeling (both quantity and quality) and receiving water quality objectives that may exist.

Furthermore, as set out in ***BPG H2: Pollution Prevention and Minimisation of Impacts,*** there are a number of important issues relating to groundwater systems that need to be considered and addressed at the prospecting stage. While the action of prospecting may have negative impacts on the groundwater during the actual prospecting phase, the drilling of exploration boreholes, if not planned and rehabilitated correctly, could have major long-term impacts for water balances and movement of contaminants.

Potential sources of information include the conceptual mine plan, the database of the Department of Water Affairs and Forestry (Regional and National office), the South African Weather Bureau and other information in the public domain.

The legal entity that will be submitting the Integrated Water Use Licence Application (for water management) should also be identified during this phase.

Initial discussions with the regulatory authorities should be held at this stage to map the integrated regulatory process, discuss time-frame and the financial provisions related to water management.

A first-order or low detail level water management plan will be prepared as the output of this phase. This plan should include details on sealing of boreholes and closing of trenches, bulk sample pits and adits, to minimise the impact of these on the surface and groundwater regime. Particular attention should also be paid to identification and incorporation of pollution prevention measures – see ***BPG H2: Pollution Prevention and Minimisation of Impacts.***

4.3.2 Pre-feasibility study

Baseline meteorological and water quantity/quality data, including a regional borehole census for the mine site should be collected during this phase, with a view to preparing a first-order water management model (monthly time steps). The model should be integrated into the pre-feasibility mine plan and should be aligned with the mine closure objectives, the preliminary groundwater plan and the waste management plan.

The first-order water management model will have the following uses during the pre-feasibility study:

- To provide the preliminary sizing and costing of the water management infrastructure
- To provide a first order assessment of water supply and water demand for the mine
- Input to baseline studies on water management for the mine,
- Input to the high-level risk assessments that will be undertaken for the mine at this stage, and
- Input to the high-level impact assessments.

Further discussions with the regulatory authorities during this phase will focus on the mine water requirements and identifying potential water supply sources and other water user demands. The first order mine water plan should be updated as part of this phase.

This phase should include initial mine closure planning and closure costing

4.3.3 Feasibility study

A detailed water management model (continuous daily time step modeling) should be developed at the mine feasibility stage. This will be integrated with the feasibility level mine plan, the detailed groundwater model, geochemical modeling and the detailed waste management plan.

This model will provide details on the water supply to the mine, the water management of the mine and the discharge quantity and quality (if applicable). The model should also be used to identify a water monitoring plan for the mine and to size the water infrastructure to meet the regulatory requirements.

The Integrated Water Use Licence Application (IWULA) should be prepared and may be submitted during this phase. This will also provide a check on the sizing of the water management infrastructure. The details from the water management model should also be used as input for the Environmental Impact Assessment (EIA) process, the Environmental Management Plan (EMP) and the Socio Economic Impact Assessment (SIA).

All water management infrastructure should be sized during this phase, and a cost estimate identified. The mine closure planning and closure costing details should be updated.

4.3.4 Mine design

The detailed design of the water management infrastructure (dams, pumps, pipelines, etc) should be undertaken during this phase. This should be integrated with the detailed mine plan, including details on underground mine service water systems, mine cooling systems, plans for handling water inflows, etc. This civil design should also be integrated with the mechanical, electrical and instrumentation design work. The water management model will be updated during this phase, as required.

The IWULA document, together with any mine licence requirements if the water use licence has been issued, should be converted to an Integrated Water Management Plan (IWMP) for the mine during this stage. This will provide details on the water management and monitoring plan for the mine.

This phase should also include obtaining approval for the construction of the water management infrastructure (in particular any dams with a safety risk). The mine closure planning and closure costing details should be updated, based on the mine design. The mine water management plans should take account of the water make and water use for the underground mines over the life of mine.

4.3.5 Construction and commissioning

The phase will include the construction of the water management infrastructure. Data will be collected on water quantity and quality. This data will be used to report to the regulatory authorities against the requirements of the IWMP.

Regular monitoring and audit reports will be provided to the mine management and construction team during this phase. The water management model should also be updated, as required.

4.3.6 Mine operation

Water quantity and quality data should be collected on a regular, ongoing basis during mine operations in accordance with a defined monitoring programme. These data will be used to recalibrate and update the mine water management model, to prepare monitoring and audit reports, to report to the regulatory authorities against the requirements of the IWMP and as feedback to stakeholders in the catchment, perhaps via the CMA.

The water management model should be used to consider and design the water management measures required for mine closure including making financial provision for closure costs. The mine closure planning and closure costing details should be regularly updated during mine operations, taking into account the mine operations planning at that time.

4.3.7 Closure, post-closure and after-care

The water management measures will form an integral part of the mine's Closure Plan. The design of these water management measures for mine closure will be confirmed and costed during this phase. These measures will then be implemented. Details of the water management measures for mine closure are covered in more detail in ***BPG G5: Water Management Aspects for Mine Closure.***

Regular monitoring and reporting against the IWMP and closure plan will be required during this phase.

4.4 INTEGRATED REGULATORY AND PROCEDURAL GUIDANCE

Figure 4.2 provides a proposed guide on Integrated Regulatory Process (IRP) for use by water managers on an underground mine. Note that this diagram is included as a guide only to illustrate a process that may be followed. It is not prescriptive and is subject to change in line with any changes in the legal environment in South Africa. There is a need to liaise with the relevant Provincial departments to confirm the regulatory requirement.

Figure 4.2: Guide for Integrated Regulatory Process (IRP)

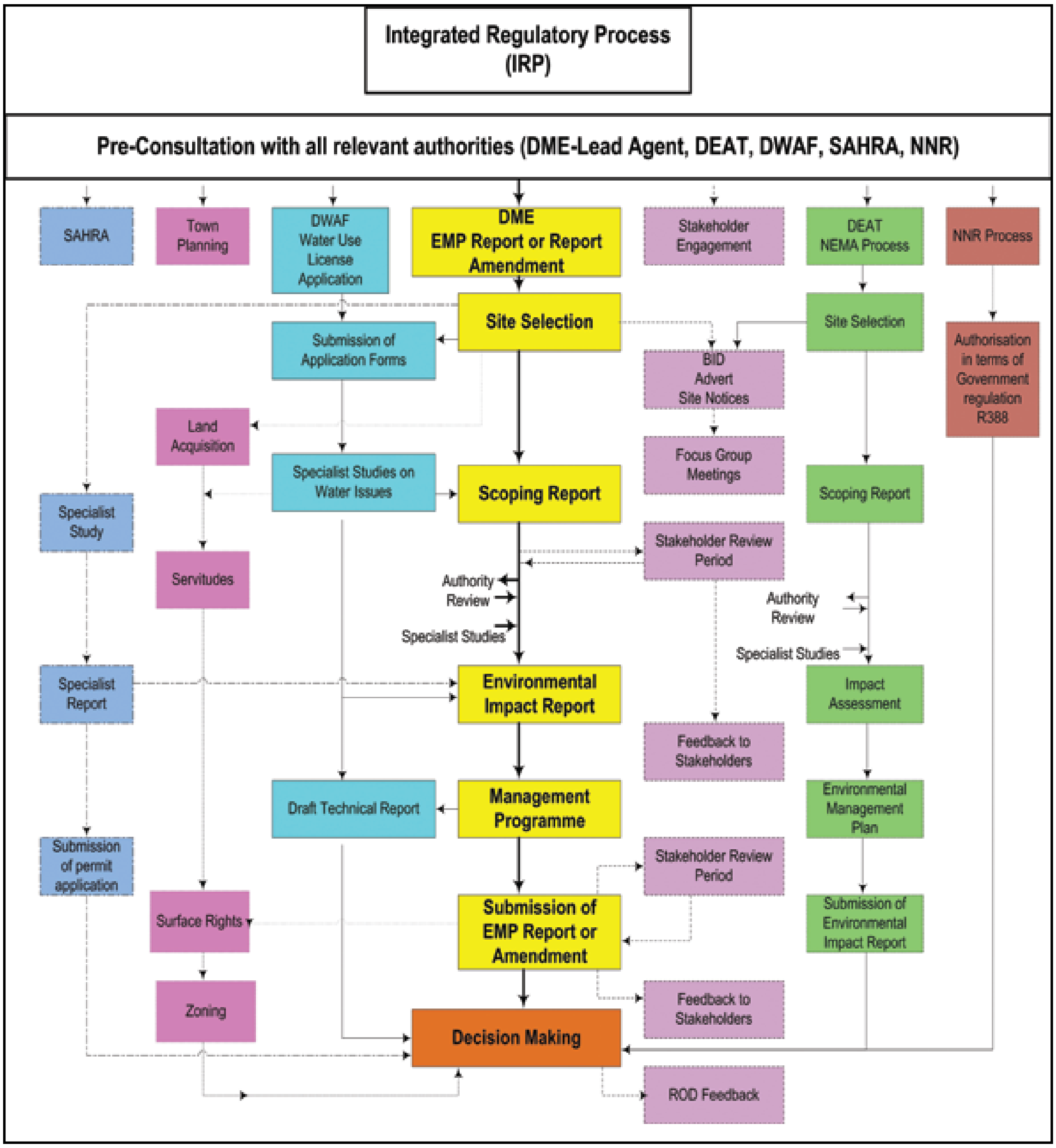


Figure 4.2 indicates the following:

- The procedural requirements and process for each regulatory authority (DME, DWAF, DEAT, SAHRA, Town Planning, NNR, etc.). This is generally at a provincial/catchment level, but may also be at national or local level
- The procedural requirement for stakeholder engagements, and
- The inter-linkages between the various regulatory processes,

Under the current legislation, it is a requirement that the mine management follow all of the regulatory processes identified in Figure 4.2 in the development, expansion or amendment of a mining operation. Co-operative governance may however, in some instances, streamline the process.

5

DESCRIPTION OF UNDERGROUND MINING METHODS AND ASSOCIATED WATER MANAGEMENT CONSIDERATIONS

5.1 INTRODUCTION

This section describes typical mining methods used in the South African mining industry and describes water ingress paths into the workings and best practices to reduce such ingress. Mining methods are described for reef orebodies, tabular orebodies and massive orebodies.

5.2 MINING METHODS AND WATER INGRESS PATHS

Each of the diagrams of the mining methods described in the sections below has been replicated to depict and describe water ingress pathways. The mining method description text has been removed to allow space for describing the ingress water pathways and impact on surface topography.

Water ingress paths vary greatly between mining methods, however, there are generic pathways which are listed below.

- Ingress into mine workings that are on surface or close to surface through outcrop openings and shafts (adits, vertical and incline shafts), either through stormwater runoff or through river bedloss where these features intersect watercourses.
- Ingress through boreholes that have not been properly sealed.
- After removal of the orebody, the weight of the overlying strata starts to weaken the support provided during the mining operation, resulting in strata movement which causes cracks to form in the overlying strata. Water bodies overlying the mined area then start to drain into the mine workings.
- Groundwater aquifers above the mining horizon tend to drain into mine workings through cracks that are formed due to subsidence caused as a result of mining.
- Adjoining mines do not necessarily mine the orebody at the same rate and as a result some mines are deeper than their adjacent neighbors. When this occurs, water from the adjacent shallower mines migrates through boundary pillars into the lower lying mines resulting in the lower lying mines having to handle more water than they would normally have to.
- Direct rainfall

Water ingress pathways specific to a mining method are described for each method in the sections below.

5.2.1 Reef orebodies

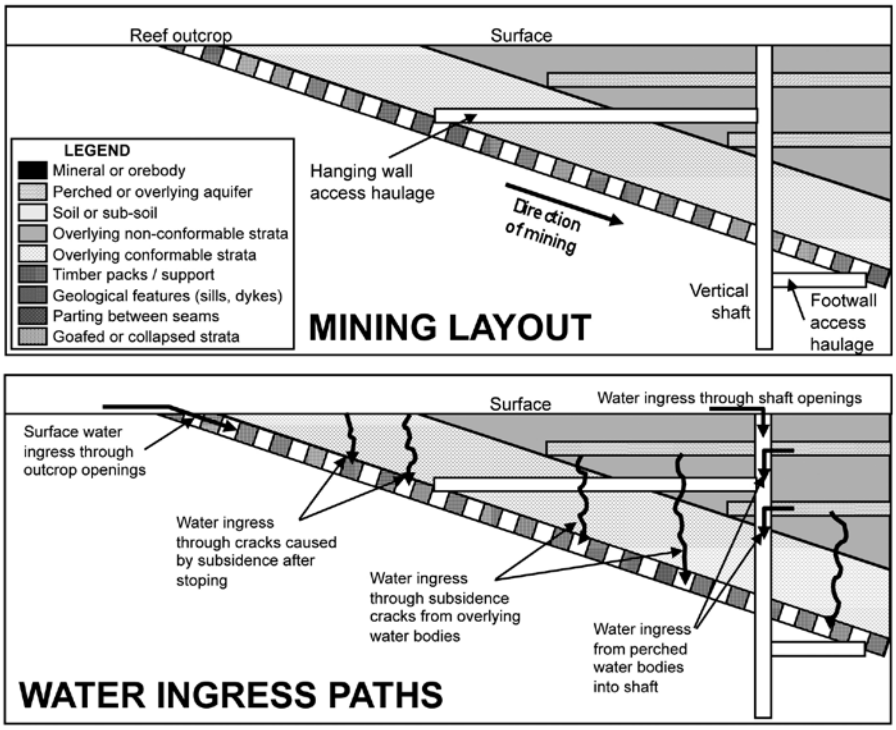
These orebodies generally tend to be sheet-like with narrow mining heights of less than 2m and employ *stoping* methods to extract the ore. The orebodies vary in inclination from flat to vertical and in rare cases are overturned. Mining methods described are deployed primarily for gold, platinum and chrome ore extraction. Orebodies vary in depth from surface outcrop to several thousand meters and deploy primary, secondary and tertiary shafts to access the reefs. Two mining methods are shown.

Reef mining generally employs support systems to keep the stopes open during mining. After a stope has been mined out, the weight of the overlying strata crushes the support, resulting in the overlying strata cracking and subsiding. This cracking provides pathways for overlying water bodies to drain into the workings. During mining operations, large volumes of water may also be liberated into the mine workings, particularly where the mine is located within dolomitic compartments (eg. Gold mines on the Far West Rand) or within deep archaic aquifers (e.g. Free State mines).

5.2.1.1 Shallow reef mining

Figure 5.1 is a typical cross section through a shallow reef mine and also shows the typical water ingress paths associated with this type of mining.

Figure 5.1: Cross-section through a typical shallow reef mine



The ore-bearing formations outcrop, allowing the reef to be exploited from surface. As the mining progresses, the ore-bearing formations are overlaid by younger formations lying un-conformably on the older ore-bearing formations. Access to the orebody starts from surface on the reef horizon with winzes and inclined shafts. As the ore-bearing horizon gets deeper, vertical shafts are sunk with hangingwall and footwall crosscuts accessing the ore horizon. After blasting, ore is extracted with the assistance of gravity to the haulage below the stope and is hauled by rail or conveyor to the vertical shaft and hoisted to surface for processing.

Large volumes of water are used in the mining operation to cool air, cool machines, for dust suppression and washing the stopes clean of fine ore.

The un-conformable overlying strata generally dip and strike at different angles to the ore-bearing strata and in many cases include water-bearing strata which could be intersected during the mining operations or intersected by cracks formed when the stopes close and the overlying strata collapses. Such intersections may lead to significant water ingress into the underground workings.

Recommended best practice guidelines to reduce water ingress into shallow reef mine workings:

- All openings to the mine need to be sealed or have adequate berms surrounding the openings to prevent surface water entering.
- All boreholes should be sealed from the bottom to the top to prevent groundwater entering the hole and feeding into the mine workings.
- All depressions created by mining need to be profiled for self drainage of surface water away from the workings.
- Should depressions created by mining not be able to be filled, then the areas need to be surrounded by berms to prevent surface water ingressing the mine workings.

5.2.1.2 Deep reef mining

Figure 5.2 is a typical cross section through a deep reef mine. The ore-bearing strata are totally covered by younger formations masking the sub-outcrop of the ore-bearing formations. Extensive exploration is required to determine the sub-outcrop boundaries ahead of sinking access shafts and driving haulages.

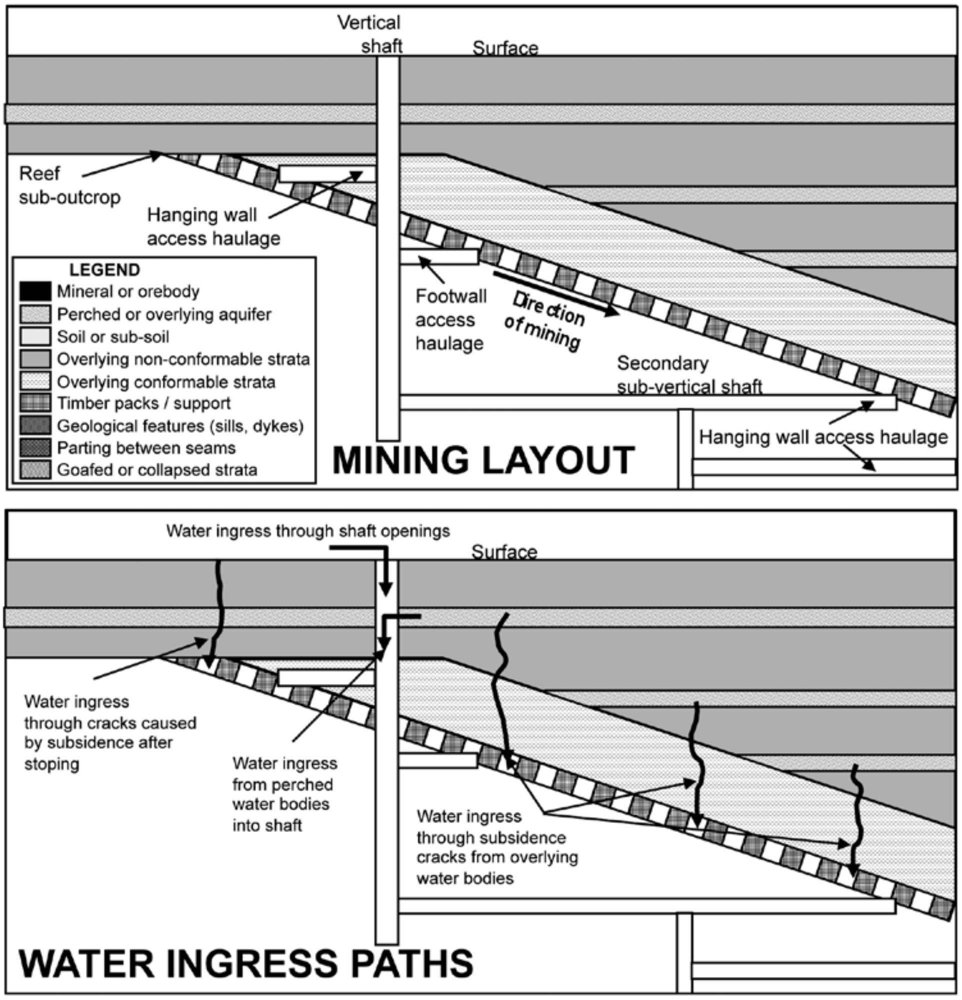
Due to the depth of the reef, the orebody is accessed by primary shafts from surface followed by secondary and tertiary vertical shafts extending many thousands of meters below surface. Hangingwall and footwall access haulages are developed to intersect the reef.

After blasting, ore is extracted with the assistance of gravity to the cross-cut or haulage below the stope and is hauled by rail or conveyor to the vertical shaft and hoisted to surface.

Large volumes of water are used in the mining operation to cool air, cool machines, for dust suppression and washing the stopes clean of fine ore.

The un-conformable overlying strata generally dip and strike at different angles to the ore-bearing strata and in many cases includes water-bearing strata which could be intersected during the mining operations or intersected by cracks formed when the stopes close and the overlying strata collapse. Such intersections may lead to significant water ingress into the underground workings.

Figure 5.2: Cross-section through a typical deep reef mine



<u>Recommended best practice guidelines to reduce water ingress into deep reef mine workings:</u>

- All openings to the mine need to be sealed or have adequate berms surrounding the openings to prevent surface water entering.
- All boreholes must be sealed from the bottom to the top to prevent groundwater entering the hole and feeding into the mine workings.
- Intersections with perched aquifers should be sealed as effectively as possible.
- Mine planning and operation should be undertaken on the basis of a detailed understanding of groundwater compartments, especially where large-scale dewatering will occur, to ensure that the minimum number of compartments are affected.
- Where significant water ingress cannot be prevented, measures should be put in place to intercept ingress water as close as possible to the source in order that it can be pumped out of the mine before its quality can deteriorate through contact with sulphide minerals.

5.2.2 Tabular orebodies

Tabular orebodies are generally horizontal or dip gently and are characterised by being from 1.5m to 10m thick. Typical mining methods employed to extract the ore are bord and pillar (B&P) and <u>maximum extraction</u> methods such as <u>stooping and longwall</u> mining. Minerals typically extracted by these methods are coal, gold, iron ore and manganese.

Coal mining methods employed in South Africa are described in the following sections but can also be used for extracting other minerals. Coal seams in South Africa vary in depth below surface from some 3m to over 1 000m.

Mining methods are described for the Witbank Coalfield and the Natal Coalfield. Although similar mining methods are deployed in both fields, the surface topography differs markedly resulting in different impacts on the surface overlying mined out areas. The surface topography in the Witbank Coalfield is gently undulating whereas the topography in the Natal Coalfield is very hilly with deep valleys resulting in the seams outcropping from the sides of hills.

These orebodies tend to be shallow, <150m below surface, and any collapses have a major impact on the surface and groundwater aquifers.

5.2.2.1 Bord and pillar method

Bord & pillar (B&P) mining commenced during the late 1890's where mining was very shallow, <50m below surface. These shallow reserves were mined by B&P methods as large scale surface mining machinery had not yet been developed. Figure 5.3 shows a typical B&P mining method used in the Witbank Coalfield for a multi-seam mine. This mining method is generally used where the seams occur between 20m and 80m below surface. Where seams occur less than 30m below surface, surface mining methods are generally employed.

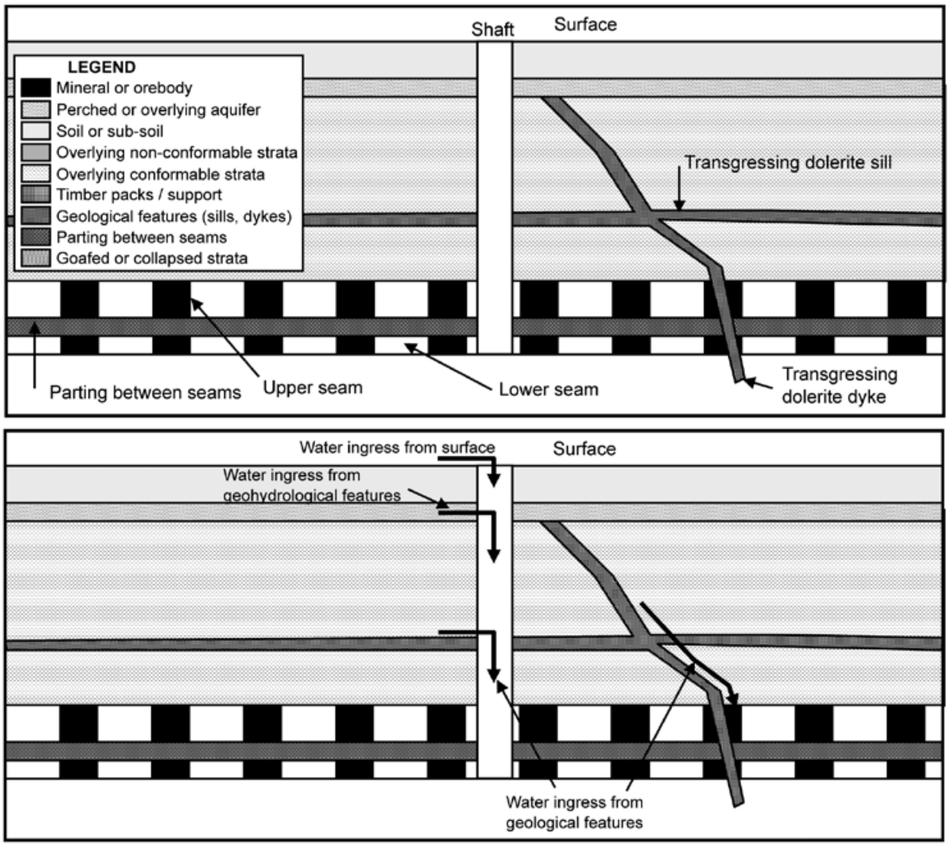
B&P mining methods should be employed where the overlying strata are competent and at least 20m thick. Pillars should be designed with at least a factor of safety (FOS) greater than 2.5 with sufficient strength to support the overlying strata. The FOS is the ratio of the strength of the pillar to the load imposed on it. The FOS is arrived at by carrying out compressive strength tests on core and taking into account the specific gravity of the overlying strata. Good pillar design will support the overlying strata and not result in collapses which impact on the surface land use and water aquifers.

Where two seams are mined, pillars should be superimposed and designed to support the overlying strata. When designing a B&P mine, cognisance needs to be taken of the surface infrastructure and larger pillars need to be left to provide long-term support for the infrastructure.

Mining methods employ either; drilling, blasting, loading and conveying the coal to a shaft for transporting to surface or continuous miners which cut and load the coal from the face for transporting to surface. Water is primarily used in the operations for cooling machines and dust suppression.

Due to the shallowness of the historical workings, insufficient un-weathered overlying strata was kept above the mining horizon which resulted in bord collapses which disturbed the surface and groundwater aquifers. Typical water ingress paths are shown in Figure 5.3. Furthermore, pillars left were too small to support the overlying strata resulting in pillars failing and causing disturbance to the surface and groundwater aquifers.

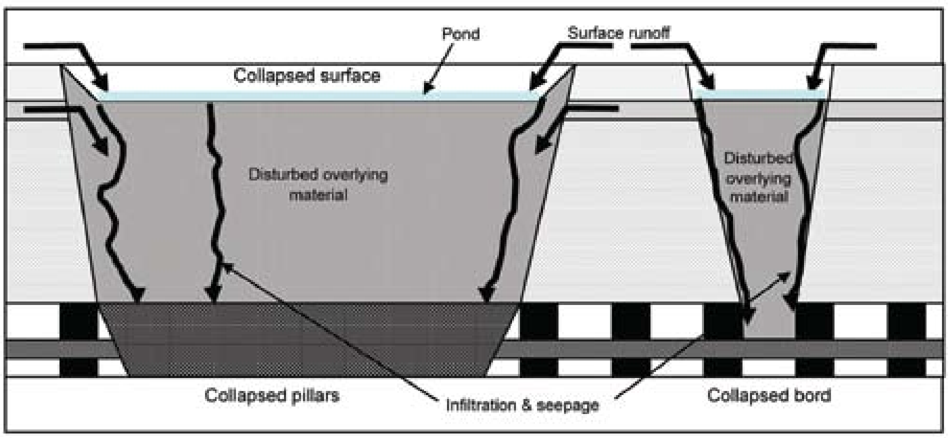
Figure 5.3: Cross-section through a typical bord & pillar mine



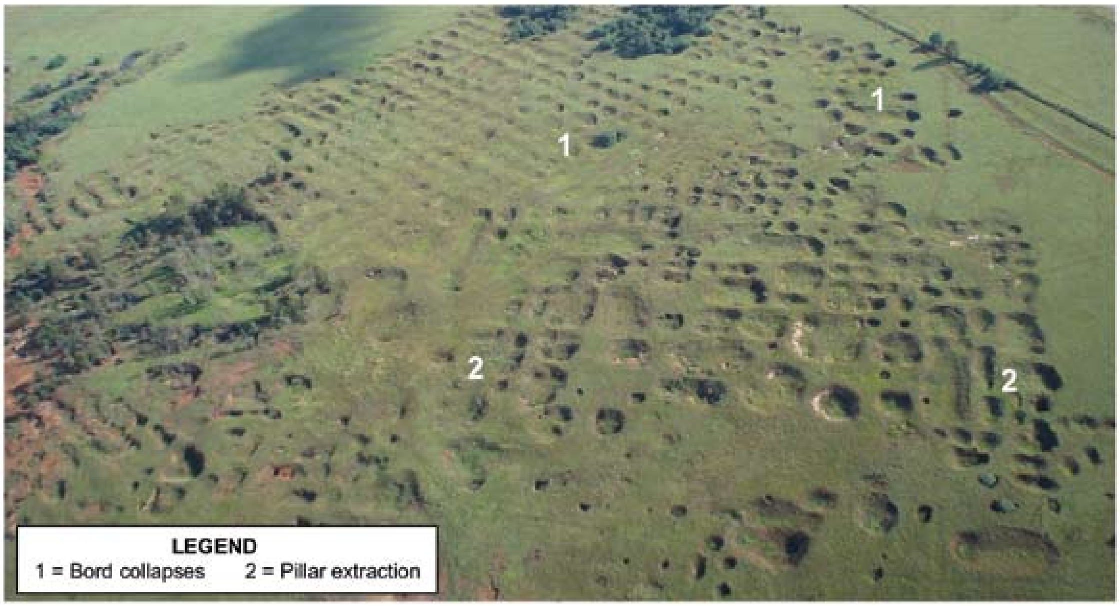
When a pillar or bord collapse occurs, the impact on surface and groundwater aquifers is catastrophic. Figure 5.4 shows the impact diagrammatically which is supported by Photograph 5.1 showing actual collapses. The irregular arrows show the water paths for surface and groundwater into the mine workings.

After closure, water is allowed to collect in the voids left by mining. In the shallow mines, account needs to be taken of the seam and surface topography elevations to ensure that mine water does not decant into the natural environment.

Figure 5.4: Typical impact of pillar and bord collapses from B&P mining



Photograph 5.1: Typical collapses in bord & pillar mines



5.2.2.2 High extraction

Figure 5.5 shows a cross section through a typical high extraction mine – in particular, a longwall operation. High extraction methods are employed in deeper-lying seams where the pillar size required to support the overlying strata becomes too great, resulting in a greatly reduced extraction of the ore which could result in the mine becoming un-economical. High extraction methods employed are longwall, shortwall and stooping methods.

Longwall and shortwall mining are essentially the same but differ in the length of the panels. These methods deploy shearers to cut the coal which is mechanically loaded onto conveyors and transported to a shaft system for conveying to surface. As all of the coal seam is removed, the overlying strata collapse. This is known as goafing. The face operation is protected from the collapsing overlying strata by a hydraulically operated advancing support system.

The stooping method starts with primary mining advancing away from the main haulages as a B&P operation, see Figure 5.3, and retreats back to the main haulage with the pillars being extracted. This results in the overlying strata collapsing. All the maximum extraction methods disturb the overlying strata resulting in surface disturbances and fracturing the groundwater aquifers.

Figure 5.5: Cross-section through a typical longwall operation

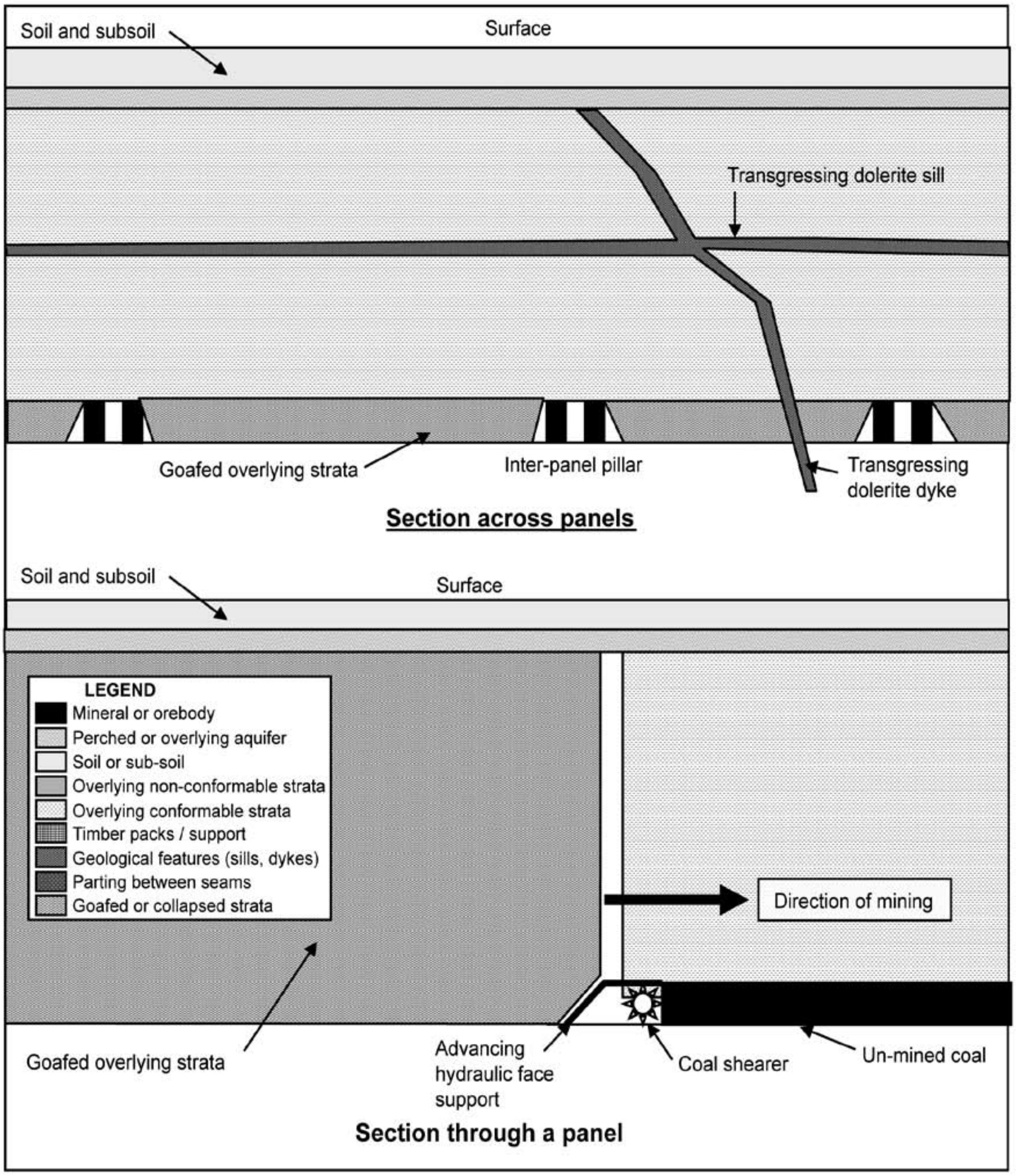
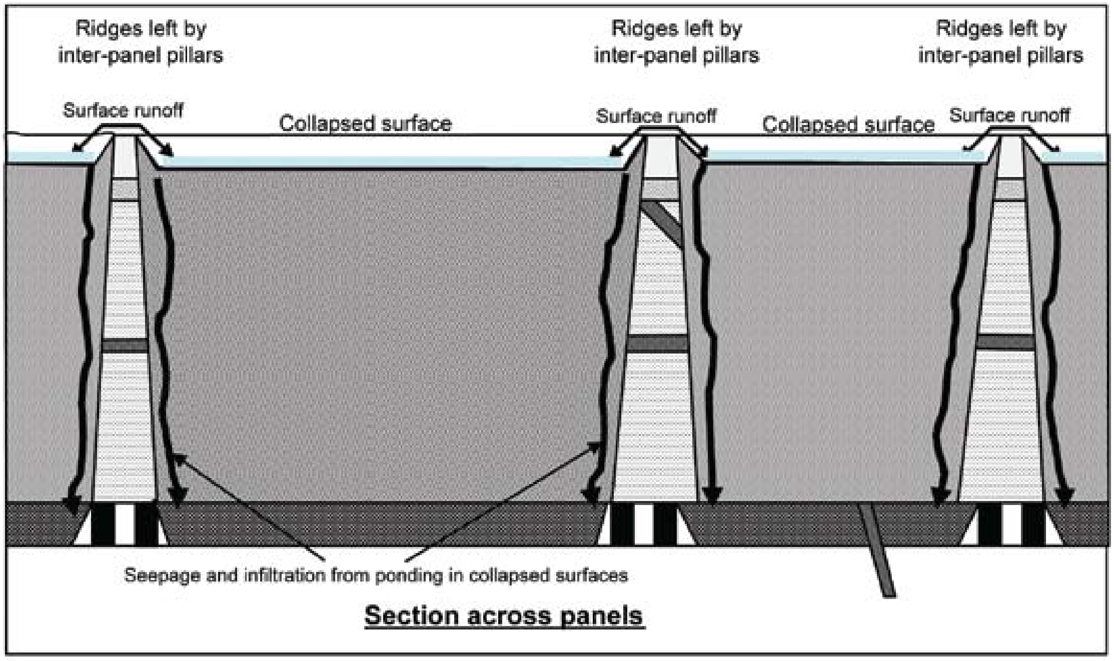


Figure 5.6 shows the typical water ingress pathways after panels have *goafed*. The degree of disturbance of the surface is dependant on the depth of mining below surface and the bulking factor of the overlying strata. Generally, shallow mining has a more marked affect on the surface topography than deep mining. Another factor affecting the surface disturbance is the thickness of coal mined; the thicker the coal extracted the greater the impact on the surface. The irregular arrows In Figure 5.6 show the water paths for surface and groundwater into the mine workings.

Figure 5.6: Typical water ingress paths for longwall mining



It is good practice to profile the disturbed surface to enhance surface water flow off the mined area. All visible cracks seen on surface should be deeply tined to seal them to reduce water ingress into the mine.

5.2.2.3 Natal Coalfield mining

Figure 5.7 shows a cross section through a typical Natal Coalfield mine. Although multi-seam mining is largely practiced, this section only shows a single seam mine to demonstrate the principles of mining and the generation of water pathways.

Due to the highly undulating surface topography the depth of coal below surface varies from <1m to many hundreds of meters. Due to this great variation, the pillar dimensions vary according to the depth of overlying strata requiring support. This results in three types of mining methods being employed:

- Surface contour mining around the fringes of the coal outcrop.
- B&P mining for the shallower areas too deep for surface mining.
- High extraction for the deeper areas where very large pillars are required to support the overlying strata.

All three methods are shown in Figure 5.7.

Figure 5.7: Cross-section through a typical Natal Coalfield mine employing surface, B&P and high extraction mining methods

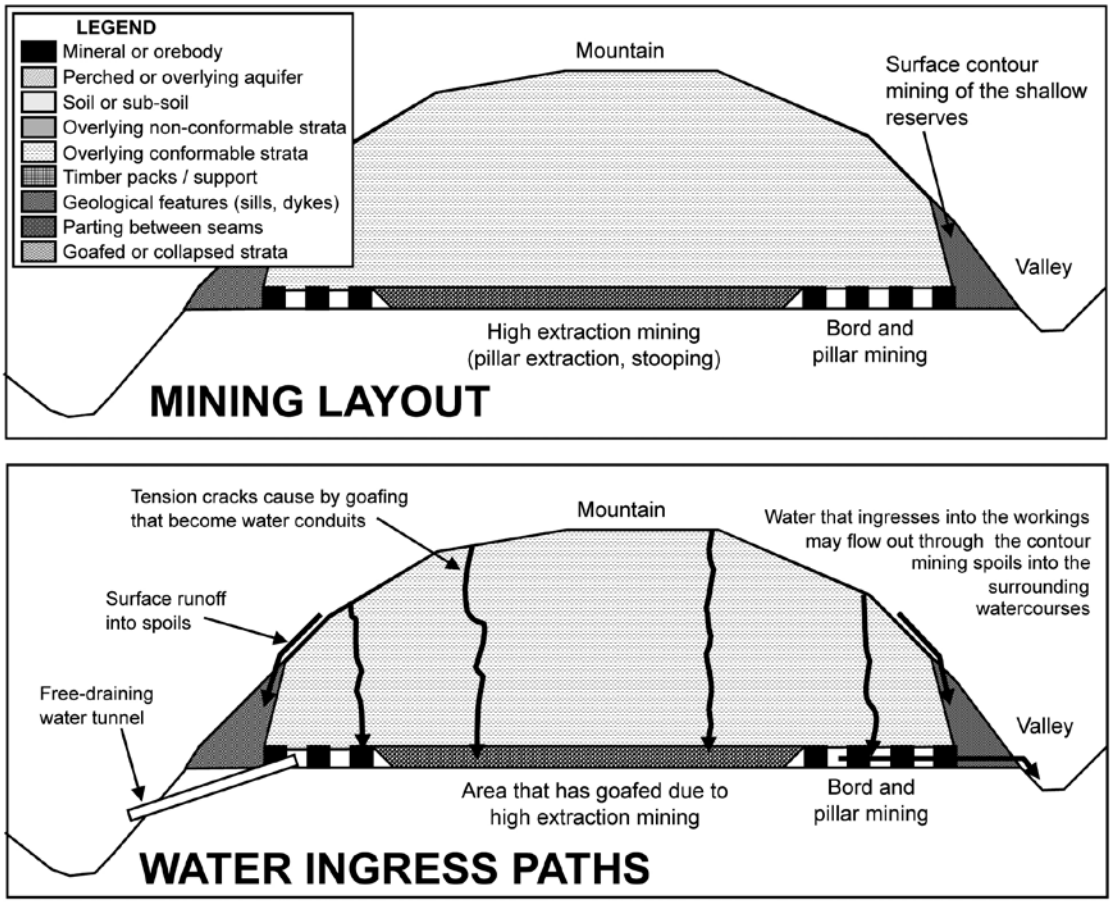


Figure 5.7 shows the main water pathways for coal mining in the Natal Coalfield. An important feature of the area is that the mines are essentially free-draining – i.e. all ingress water finds its way out of the mine.

Photograph 5.2: Crack caused by high extraction in mountain

As high extraction mining is carried out, the area goafs and the overlying stratum subsides and cracks are formed (see Photograph 5.2). These cracks then become conduits for groundwater and surface water to gravitate downwards into the mined area. Due to surface contour mining that has taken place on the outcrop of the seam, ingress water flows from the underground workings through the spoils and out into the surrounding water courses. Due to the nature of the terrain and mining methods employed there is very limited water storage capacity in the old workings.

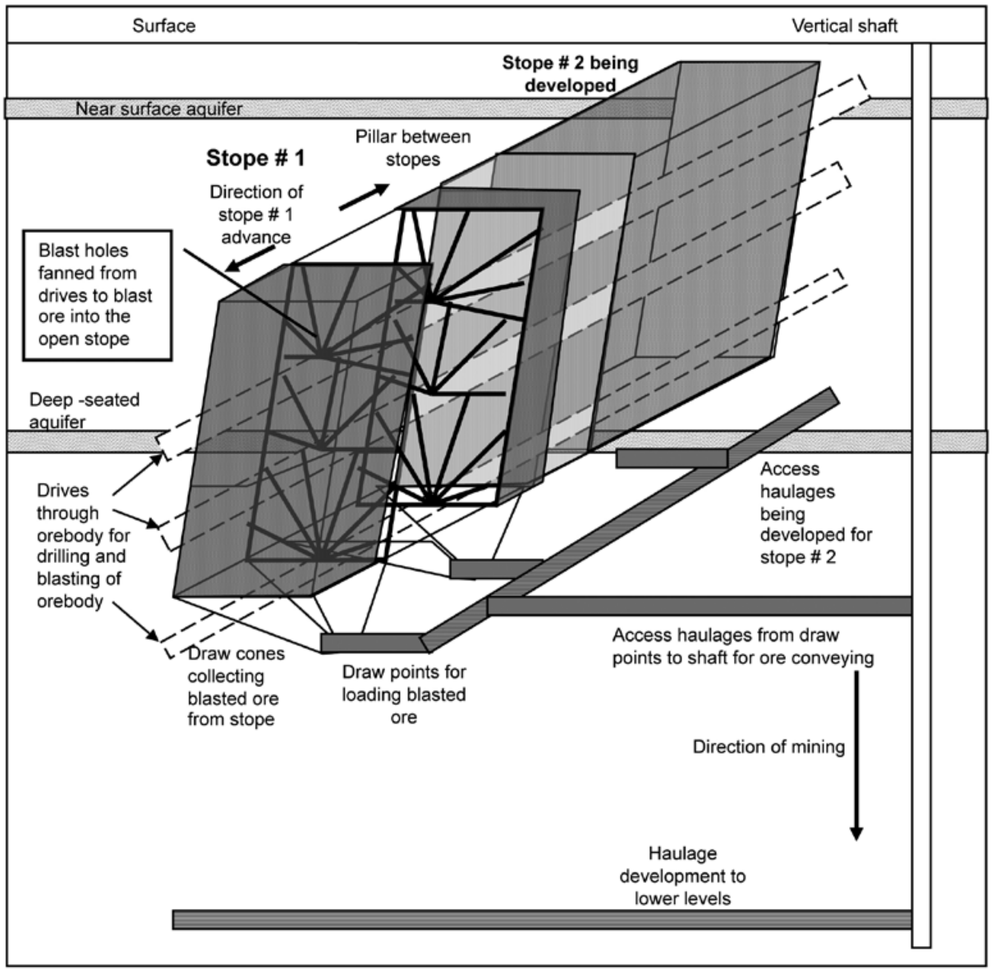
5.2.3 Massive orebodies

Massive orebodies generally contain diamonds and base metals (copper, lead, zinc, tin, etc.). Two mining methods are described; firstly, sub-level open stoping for a typical base metal operation exploiting a massive tabular sulphide orebody and secondly, block caving typically employed in a diamond mining operation.

5.2.3.1 Massive tabular orebodies

Figure 5.8 shows a typical open stoping mining method employed to mine a massive tabular sulphide orebody. The diagram shows a steeply plunging body with access shaft and haulages situated in the footwall of the body. The diagram also shows development taking place for stope # 2 as well as development for stopes at lower levels.

Figure 5.8: Isometric view through a massive orebody employing sub-level opening stoping mining method



To extract the ore, drives are driven on strike through the centre of the orebody from which a slot is cut, and into which successive slices of ore are blasted. Blasting takes place from the strike drives where blast holes fan out to the extremities of the orebody. The broken ore falls into draw cones from which the ore is extracted and conveyed to the shaft for hoisting to surface.

The orebody is divided into stopes separated by pillars which serve to support the rock strata after mining is completed. Many mines fill the stopes with material to stabilise the rock strata prior to removing the ore in the pillars. After mining, the surrounding rock is no longer fully supported, resulting in the hangingwall subsiding, causing disturbance to the overlying rock formations, surface and water aquifers.

The mining footprints of these orebodies are generally much smaller than those of tabular and reef mining due to the very steep dipping nature of the orebody. Surface water ingress (rainfall) is therefore limited to the surface area of the orebody. Groundwater infiltration is generally limited to water bearing geological features that intersect the orebody.

Once the stopes have had all of the ore extracted, a large cavity is left which eventually collapses into the void causing depressions on surface through which rain water and surface water can ingress the workings. The inter-stope pillars generally do not provide sufficient long-term support for the surface. Figure 5.9 shows the open stopes filled with collapsed material and the water pathways along which water will move into the workings.

Major surface disturbance can also occur as shown in Photograph 5.3.

After considering the surface and groundwater regimes for the area in which the mine is established, a pumping system needs to be installed to control the mine water level so as not to impact on the groundwater system. Good practice is to construct adequate berms around the area of caving to direct all surface water away from the area.

Photograph 5.3: Subsidence from sub-level caving

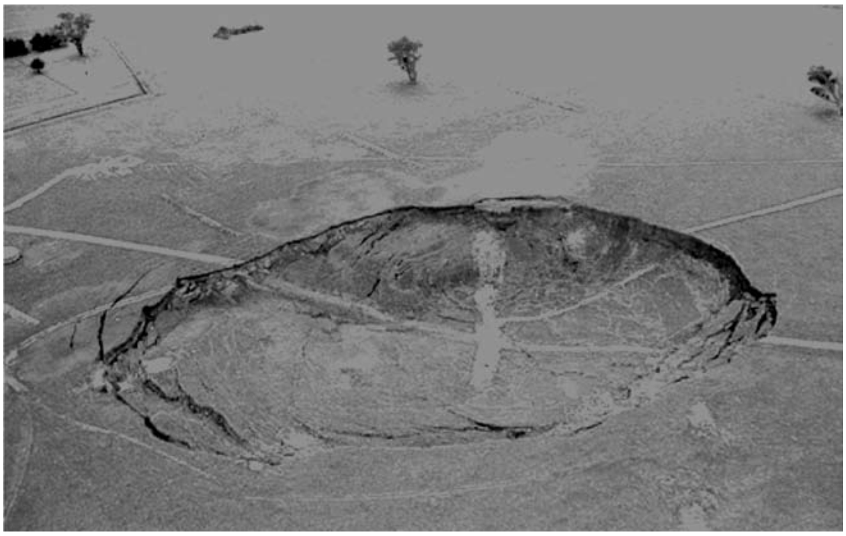
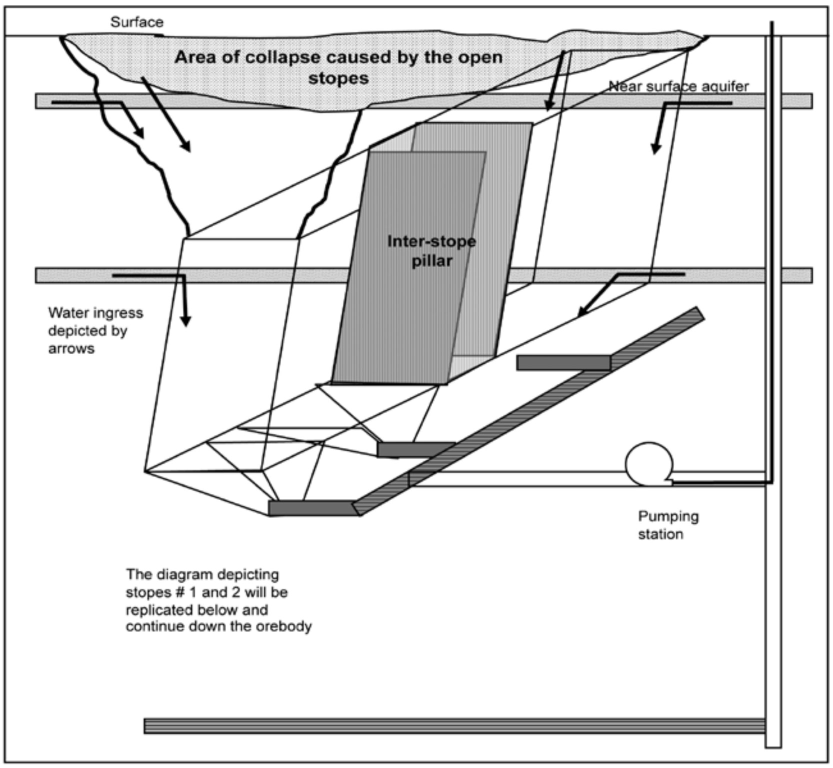


Figure 5.9: Typical water ingress paths for massive orebodies



5.2.3.2 Massive pipe orebodies

Figure 5.10 shows a typical layout for a sub-level caving operation employed on a diamondiferous pipe. The figure shows a pipe that has been mined by surface mining methods to its economic depth followed by underground sub-level caving. After attaining the maximum depth by surface mining, a *crown pillar* is left to separate the surface mining from the underground mining. Generally the underground mine is developed whilst surface mining takes place and there is a gradual buildup of the underground mine whilst the surface mine's production gradually declines.

Sub-level caving is similar to open stoping in layout, with the major difference being that the orebody is not blasted. The orebody is undercut and allowed to cave (collapse) into the draw cones where it is extracted at the draw points and hauled to the shaft for hoisting to surface. As the ore is withdrawn, space is created between the solid ore and broken ore. The solid ore then collapses into the void. This process continues until the crown pillar is reached, when extraction ceases. The crown pillar then acts as a barrier between the surface mine and underground mine. At this point a lot of broken ore is left which can be won together with the *crown pillar* at a later stage by continuing to draw the broken ore and finally the *crown pillar*.

Whilst ore is being extracted from the upper level, development takes place below to prepare the next lift in the process. This continues until the economic limit is reached or the orebody truncates. Where an orebody is not mined by surface mining methods, the caving generally induces large scale surface collapse.

Figure 5.10: Isometric view through a pipe orebody employing sub-level caving

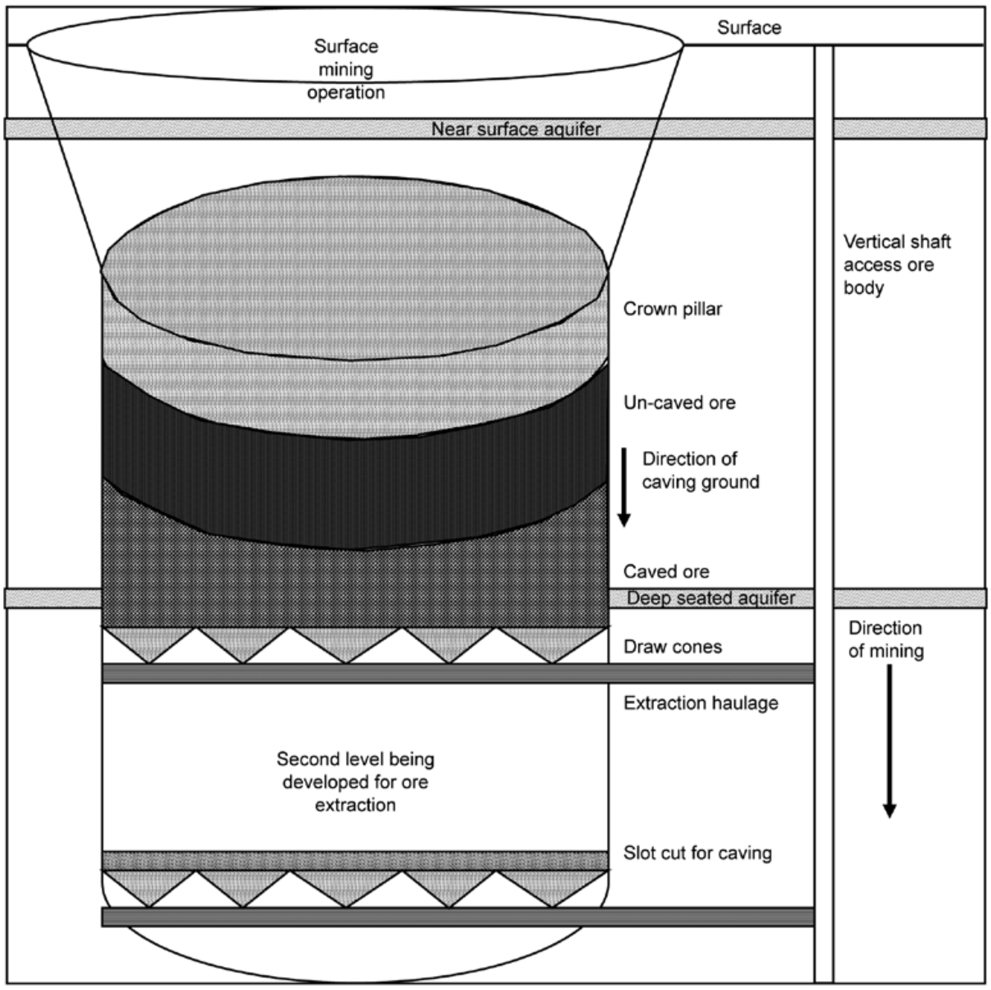
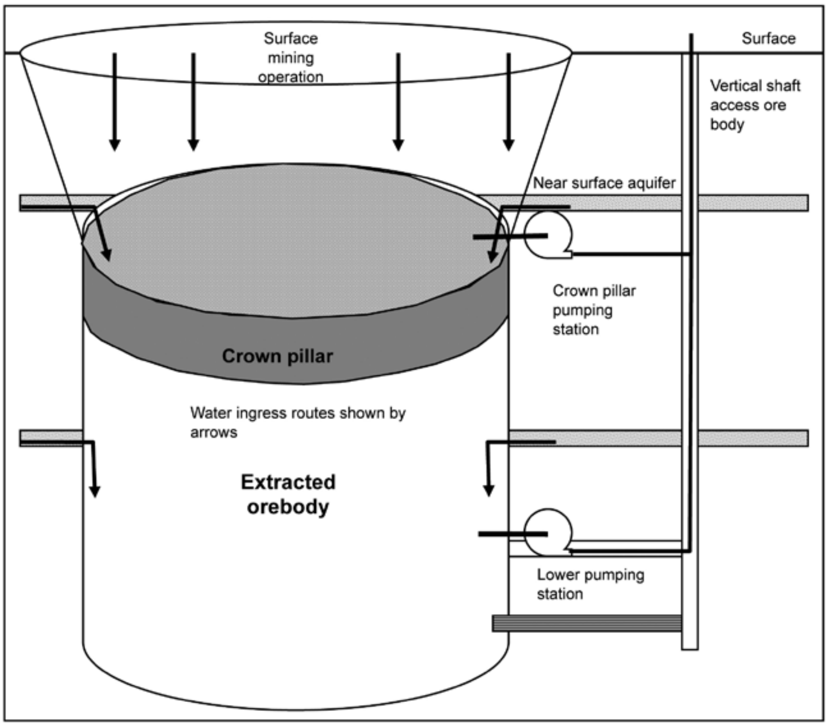


Figure 5.11 shows the situation of the mine after extraction of the orebody. After the orebody has been extracted a decision needs to be taken on whether or not to remove the *crown pillar*. The *crown pillar* can reduce inflow of water into the lower levels of the mine. After considering the surface and groundwater regimes for the area in which the mine is established, a pumping system needs to be installed to control the mine water level so as not to impact on the groundwater system.

Figure 5.11: Typical water ingress paths for massive pipe orebodies



5.3 BACK-FILLING METHODS

Various back-filling methods are used in mines to provide support to the overlying strata or to fill the cavity created after extraction of the orebody to facilitate removal of the inter-stope pillars. Two typical examples of back-fill methods are described below.

5.3.1 Back-filling to provide additional support

Stopes surrounding a shaft, together with the shaft station infrastructure, are back-filled to prevent the strata overlying the stope subsiding – see Figure 5.12. Subsidence of the strata results in cracks developing and together with strata movement can result in structural damage to the shaft and its associated infrastructure. Material used to back-fill must be inert and have minimum impact on the water regime. Special issues apply to backfilling in kimberlite mines.

5.3.2 Back-filling to extract pillars

Very often the quality of the mineral in an orebody is very high and warrants the additional costs incurred to back-fill mined out stopes and extract the inter-stope pillars. Figure 5.13 shows a typical system where the stopes have been back-filled and the inter-stope pillar is being extracted. Material used to back-fill must be inert and have minimum impact on the water regime.

Figure 5.12: Typical back-filling to provide support and protection to overlying infrastructure

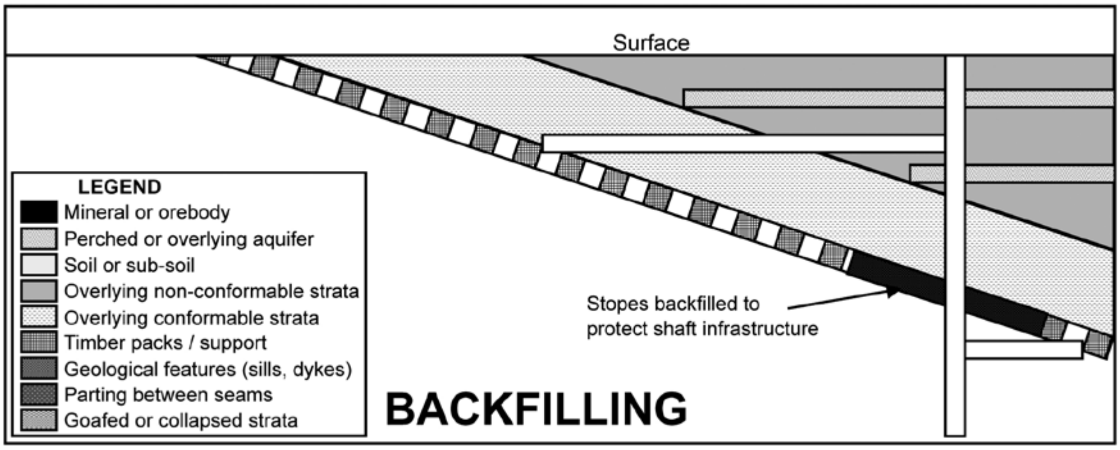
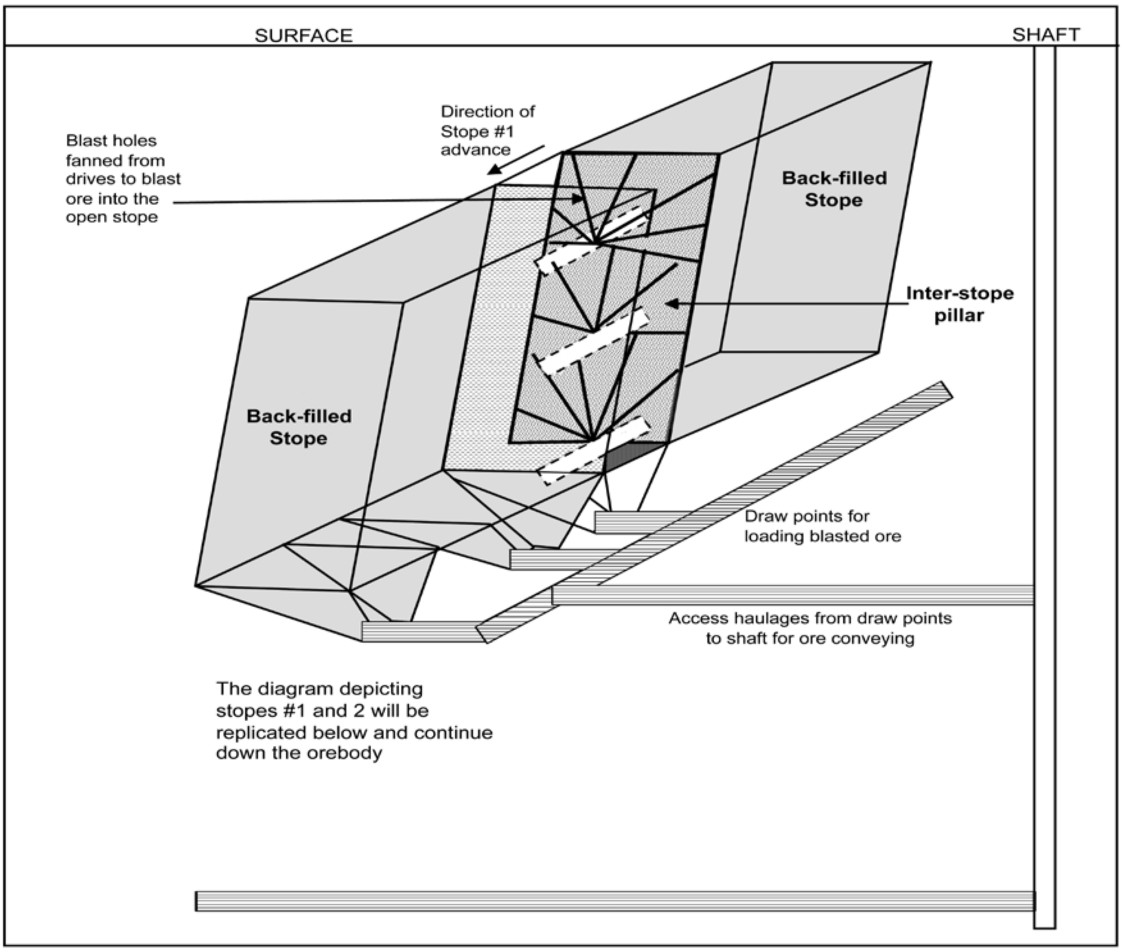


Figure 5.13: Schematic through a massive orebody showing stope back-filling and inter-stope pillar removal



6

DESCRIPTION OF TYPICAL UNDER-GROUND WATER MANAGEMENT SYSTEMS AND CONSIDERATIONS

Although there are a number of similarities between the underground water management issues in deep underground hard rock mines and the shallower underground mines (e.g. coal mines), there are also a number of important differences that warrant the separate discussion of each type of mining, and this is the approach that has been adopted in this BPG.

Underground mines also include a wide range of activities that are undertaken on surface, such as beneficiation plants, construction and operation of residue deposits, pipelines and conveyors for ore and/or mine residues, pollution control dams, etc. ***BPG A5: Water Management for Surface Mines*** is therefore also relevant to underground mines, specifically with regard to the infrastructure that is found on surface. This BPG deals specifically with those water management aspects that are specific and unique to underground mining operations.

6.1 WATER MANAGEMENT IN UNDERGROUND HARD ROCK MINES

Underground hard rock mines (e.g. gold mines, platinum mines) in South Africa are typically deep mines with water used underground primarily as mine service water (including dust suppression) and for mine cooling. In some cases these mines may be very deep (> 3 500 m) which results in particular mine water management challenges as the mines tend to get hotter as they get deeper. They will then require a number of separate shaft systems as the deepest sections may require a further two or three sub-vertical shafts in addition to the main shaft from surface. In these mines, there will often be large underground refrigeration plants and water treatment plants at each of these sub-vertical shafts to feed the levels serviced by that shaft. Additionally, the deeper the mines become, the more costly it becomes to pump large volumes of water back up to surface and the greater is the financial motivation to implement effective underground water reclamation strategies.

The water management issues at underground hard rock mines are differentiated and discussed in the following manner:

- Mine life-cycle considerations
- Mine water balance considerations
- Mine water quality considerations
- Mine service water systems
- Mine cooling systems
- Other mine water uses

6.1.1 Mine life cycle considerations

While the broad life-cycle phase requirements that apply to all mines are given in Section 4.3 above and also need to be applied at underground mines, the following specific issues pertinent to underground mining in the individual life cycle phases are highlighted (additional detail is also given in Appendix B):

Prospecting, conceptualisation and planning phase

Consider the following specific issues:

- Underground hard rock mines are generally quite deep below surface and are often located beneath overlying aquifers. There is normally a direct linkage between the surface and groundwater in developed mines and this aspect needs to be clearly defined and understood and then fed into the mine planning phase. As there is a need to minimise the inflow of groundwater into the underground mines, it is important to properly seal exploration boreholes that may otherwise serve as conduits for dewatering of overlying or underlying aquifers into the mine void (see section 6.2.2.1 for more detail and information on sealing of boreholes).

- Where underground mines are located in areas where high potential risks to the groundwater exist, such as in dolomitic areas, particular attention must be paid to understanding the groundwater system and the impact that the intended mining will have on the system.
- If the new underground mine is in an area where there are a number of existing mines, particular attention must be paid to the potential for inter-mine flow from existing mines into the new mine or vice versa.
- Consideration must be given to other groundwater users and the potential impacts that these will have on the mine and vice versa.

Pre-feasibility study phase

Consider the following specific issues:

- Based on a preliminary groundwater model, make predictions on inflow volumes into the mine over its projected life and incorporate the data into the mine water balance to determine impact on the need to purchase and/or discharge water.
- Determine the potential for the mine to fill and decant/discharge to groundwater or surface water on closure. If a potential does exist, determine the location of the discharge point.
- Using preliminary geochemical data, make initial predictions on the quality of water that may be discharged during operations and after closure – ***see BPG G4: Impact Prediction***. Compare these with receiving water resource quality objectives and determine water treatment requirements and costs to be incorporated into pre-feasibility report.

Feasibility study, leading to a Bankable Feasibility Study (BFS) phase

The same issues as listed for the pre-feasibility study phase will need to be addressed here, just at a higher level of detail and confidence.

Mine design phase

Consider the following specific issues:

- Finalise all groundwater and geochemical modelling on water volumes and qualities for operational and post-closure phases and ensure that adequate financial provision is made for water treatment plants.
- Design systems to intercept major groundwater inflows in a manner that prevents their mixing with mine service water and pump this water to an appropriate water user, underground or on surface, as quickly as possible
- Plan and design for maximum underground recycling of water in order to reduce pumping costs.
- For deep mines, ensure adequate supply of chilled drinking water (possibly use heat exchangers to cool potable water using chilled mine service water systems) close to the working face in order to reduce the health risk associated with drinking chilled mine service water.
- Ensure that underground water management systems (neutralization, coagulation/flocculation, settling, disinfection) are all sized to take account of extreme flow and solids loading variations typical of underground mine water systems.

Construction and commissioning phase

Consider the following specific issues:

- Properly mark all significant water ingress points encountered during mine construction and development and ensure that their physical location, flowrate and water quality are recorded and incorporated into the existing groundwater model and the mine water and salt balance.
- Properly seal all major water ingress points and ensure that the details of the sealing operation are recorded.
- Ensure that all approved design measures are properly implemented and modify mine plans and drawings to indicate 'as-built' systems wherever they deviate from the original designs, together with motivations on the design variation.

Mine operation phase

Consider the following specific issues:

- Geochemically characterise the different stopes and mining sections to determine which are the most geochemically reactive and then implement priority water management actions to minimise water retention time within these areas and also ensure that these sections are cleaned thoroughly in order to reduce the post-closure source term.
- Develop a detailed 3-dimensional model of the mine showing all potential water pathways (e.g. stopes,

haulages, shafts, etc) after mine closure, together with all known groundwater ingress points and projected final post-closure discharge point or points. Based on the geochemical characterisation referred to in the previous point, develop a post closure water flow and quality model that evaluates a number of alternatives with regard to how the underground water flow can be controlled after closure to ensure best quality discharge water. This would entail identifying haulages and shafts that should be sealed on closure to prevent/retard water flow and haulages and shafts that should be reinforced on closure to ensure long-term sustainability as major water conduits. **It is imperative that this detailed plan be developed and submitted to DWAF for approval at least 5 years before mine closure and definitely before any underground water pump systems are removed and before sections of the mine are allowed to start flooding.** This also applies to where sections of the mine are closed before complete mine closure is considered. Reference should be made to ***BPG G5: Water Management Aspects for Mine Closure.***

Closure and after-care phase

Consider the following specific issues:

- Confirm the existence and/or potential for inter-mine flows into or from adjacent mines after mine closure and flooding of the mines.
- Institute appropriate water level and water quality monitoring programmes to confirm rate of water rise and water quality as the mine floods. Maintain an ability to access the underground workings until long term discharge and quality predictions have been confirmed.

Reference should be made to ***BPG G5: Water Management Aspects for Mine Closure***.

6.1.2 Mine water balance considerations

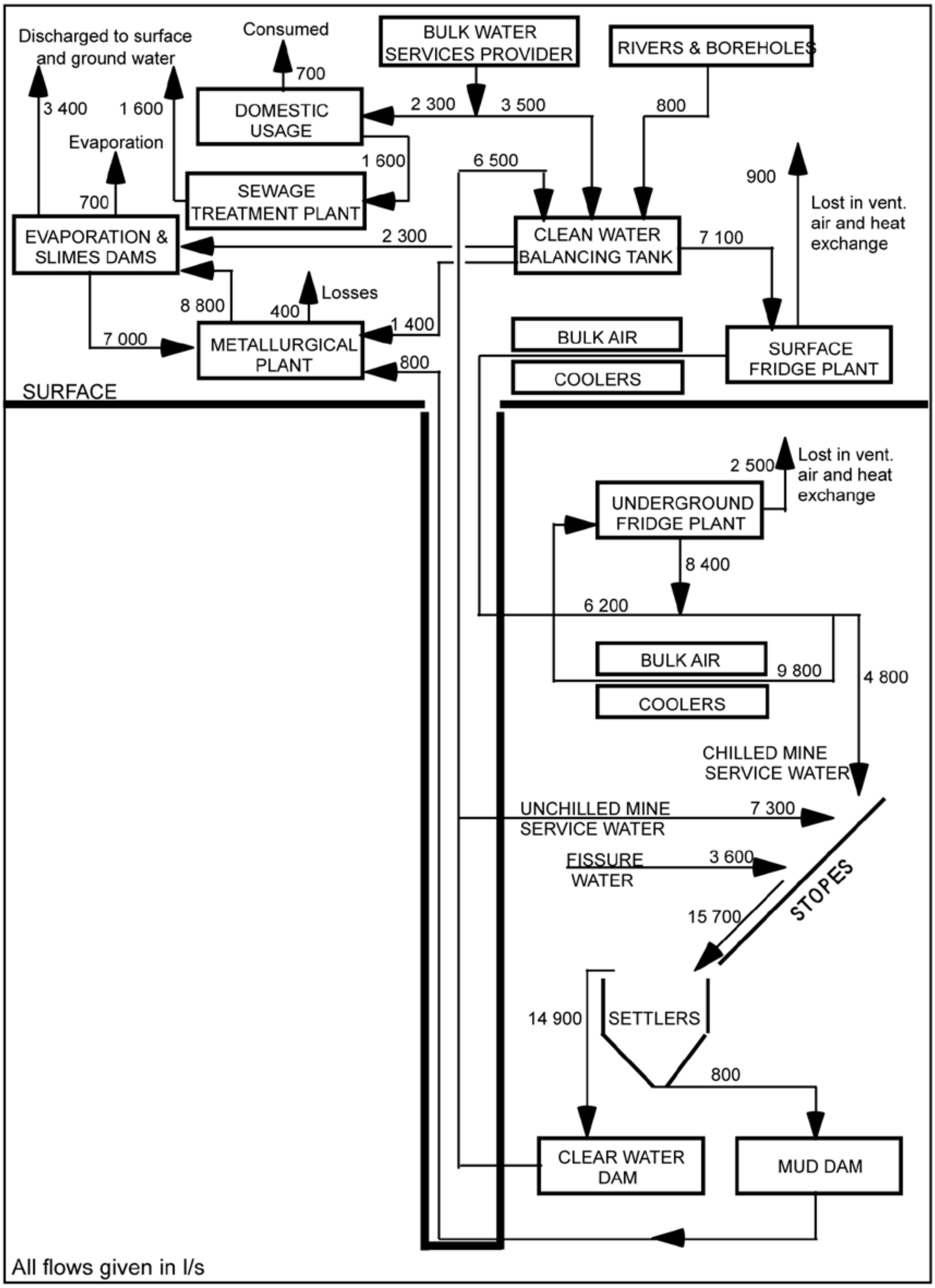
Water in hard rock mining is used underground for a variety of uses and an underground water balance would typically need to consider the following water flows:

- Acid seepage
- Backfill water
- Chilled mine service water
- Chilled water for cooling circuits
- Condensor circuit make-up
- Drinking water
- Fissure water
- Mud from settlers
- Ore/reef surface water
- Settled clear water
- Unchilled mine service water
- Ventilation and evaporation losses

The actual volumes of water used varies from mine to mine. Some mines have large amounts of fissure water which need to be disposed of, others have to purchase large volumes of clean water, and others still recirculate much of the water and so only need to purchase make-up water.

Pulles (1992) developed a mass water balance for the complete gold mining industry which is shown schematically in Figure 6.1. Although this water balance was developed in 1990 and is no longer accurate in 2007, no industry-wide water balance has previously or subsequently been attempted and the water balance is presented here as it is indicative of water use patterns within the underground gold mines and may also provide insights into water use patterns in other underground hard rock mines that have major mine cooling requirements.

Figure 6.1: Mass water balance for the whole gold mining industry (1990)



In 1990, it was estimated that the gold mining industry consumes and circulates 73 000 l/s (6 400 Ml/day) of water. Approximately 63 600 l/s (5 500 Ml/day) of this water is circulated in closed loops. The bulk of this water (34 700 l/s) is circulated as condenser water for the refrigeration plants, while 9 800 l/s of water is circulated to bulk air coolers to cool the air underground. A further 12 100 l/s of water is circulated for mining purposes, of which 4 800 l/s is chilled water, which performs a supplementary cooling function in the stopes. Taken together, a full 78 per cent of the water in circulation is associated with mine cooling in one way or another. Finally, approximately 7 000 l/s of water is circulated between the metallurgical plant and the slimes dam.

In terms of water sources, approximately 70 Ml/day of water is abstracted from rivers and boreholes, bulk water service suppliers provide 510 Ml/day and fissure water accounts for 320 Ml/d. Volumes of water discharged account for 440 Ml/day and some 460 Ml/day is lost through evaporation.

Particular attention will need to be placed on obtaining an accurate measurement of the groundwater inflow into the underground water balance, keeping this water from becoming contaminated, and routing it through a separate clean water system to an approved water user without allowing the water quality to deteriorate.

6.1.3 Mine water quality considerations

As detailed earlier, some 5 500 Ml/day are in circulation within the gold mining industry. This circulation of water can result in water quality changes, as a result of the actual mining operations as well as the mixing with fissure water which enters the mine. During the mining operation, explosives are used to break the rock. This requires drilling into the rock, to lay the charges of explosives. These drills require cooling. Additionally, a large amount of dust is generated, and this has to be suppressed with large amounts of water (Bosman, 1985). The chemicals contained within the explosives also find their way into the spent water circuits (Schmitz, 1984). The fissure water typically contains relatively high concentrations of salts, which have been leached from the rock. When this mixes with the spent service water, the net result is a deterioration in water quality underground.

The underground water quality problems can be divided into the following:

Dissolved Salts

Acid mine drainage (see ***BPG G4: Impact Prediction*** for a discussion on mechanisms and processes) increases the salinity of most mine waters. It has been shown that on average, mine service water will experience an increase of 20 per cent in the dissolved salts due to leaching in the stopes. Ammonia and nitrates enter the water circuits from explosives, and calcium or sodium levels are increased by addition of neutralising agents.

Cooling water circuits (bulk air coolers, spray chambers) experience an increase in dissolved salts due to evaporative losses and adsorption of airborne salts.

Water quality problems resulting from increased dissolved salts depend on the nature of the salts and the subsequent usage of the water. Salt increases may lead to corrosion problems, depending on the materials used in the particular water reticulation system. Corrosion is a complex process and may be a function of many water quality parameters, such as dissolved oxygen content, pH, concentration of sulphate and chloride ions, TDS content and the degree of biological activity.

Corrosion could lead to some practical problems like increased friction loss in pipes, increases in suspended solids may occur - increasing erosion (abrasion) and blockage of equipment, uniform thinning or localised penetration caused by pitting or crevice corrosion can lead to pipe and fitting failure, high calcium contents lead to scaling of pipes and heat exchanger tubes.

Nitrogen Compounds

Nitrate is a common constituent in mine water, particularly in mines using nitrate-based explosives. Ammonia in mine water originates from the use of ammonium based explosives. Ammonia reacts with chlorine and can markedly impair its disinfection properties.

Acidity

Acidic water leads to corrosion, while high alkalinity could lead to scaling. High acidity will also reduce settling and flocculation ability. Increased acidity is a direct consequence of acid mine drainage. See Appendix C for further detail.

Suspended Solids

Spent mine water reaching settlers may contain between 100 and 40 000 mg/l of suspended solids. Problems that this may create include; silting up of clear water dams, erosive wear on high pressure multistage centrifugal pumps, fouling and loss of efficiency in heat exchanger tubes in refrigeration plants and ineffective water disinfection - leading to health risks.

Microbiological Quality

Underground spent water is often contaminated with human faeces and urine. This water is often put through refrigeration plants and reused as mine service water. Workers do, however, sometimes prefer to drink this water instead of the potable water provided. If the chilled water is not adequately disinfected, the drinking thereof may lead to health risks through the spread of diseases such as cholera, typhoid or dysentery (Pulles, 1992).

Radioactivity

Concentration levels of uranium in the Witwatersrand and Far West reefs range from below 50 g/t to about 200 g/t of U_30_8. At Beisa at the southern end of the Free State goldfields, uranium grades reach 600 g/t of ore, and at Afrikander Leases near Klerksdorp, uranium grades reach 640 g/t of ore. This contrasts with the situation in areas mined primarily for uranium such as Canada, USA and Australia, where ore grades of between 20 000 and 40 000 g/t uranium are extracted. There is therefore a difference of about two orders of magnitude in the radionuclide concentrations in Canadian, USA and Australian tailings compared with those in South Africa.

The radioactive material contaminates spent mine water, and although settlers remove most of the radionuclides, some is retained and could be ingested by workers if the water is consumed. Underground mine waters which are in contact with uranium-bearing reefs can be contaminated to a high degree.

Cyanide

Water draining from underground backfill paddocks, may be extremely polluted and may contain high concentrations of suspended solids and cyanide. The cyanide becomes a problem when the backfill water enters the mine service water circuit. If the cyanide concentration is high enough it can also leach gold from fines in the drains, which will then be lost with the discharged waste. Ferrous sulphate is often used to immobilise cyanide in the backfill.

Oils and grease

Use of diesel machinery in trackless (mechanized) mining results in fuel and oil spills, which create a problem in the underground settlers and may also give rise to health problems if these contaminants are consumed from recycled mine service water.

This deterioration in quality affects different processes, depending on the specific elements within the water. Table 6.1 presents information on water use, the main water quality parameters which affect the use and the associated problems.

Table 6.1: Water use, water quality parameters affecting use, and associated problems

WATER USE	MAIN WATER QUALITY PARAMETERS	ASSOCIATED WATER USE PROBLEMS
General mine service water	Suspended solids	Increased consumption of chlorine for disinfection; increased erosion & clogging of orifices and fouling
	Ammonia (from explosives)	Inhibits adequate disinfection
	Acidity	Corrosion; affects disinfection of water
	Microbiology	If disinfection is impaired - potential for cholera, typhoid and dysentery increased.
	Radioactivity	Risk at present is estimated to be low - further research required.
	Diesel, fuels, oils from mechanised mining	Accidental spillage and dumping affects settlers; blinds carbon in CIP process; affects chlorine disinfection
Cooling/ Refrigeration	Total dissolved salts	Scale formation on heat exchange surfaces; corrosion of pipes;
	Suspended solids	Fouling of heat exchanger tubes
Pumps	Total dissolved salts	Scale formation, corrosion, pitting;
	Suspended solids	Blockage of screens; excessive wear; reduced efficiency;
	Acidity	High acidity leads to increased corrosion; high alkalinity leads to increased scaling

WATER USE	MAIN WATER QUALITY PARAMETERS	ASSOCIATED WATER USE PROBLEMS
Dust suppression	Suspended solids	Health problems if vapour is inhaled;
	Microbiology	Vapour may contain Legionella spp.
Settlers	Suspended solids	Highly variable loading can lead to silting up of clear water dams as a result of impaired settling
	Acidity	High acidity (low pH) interferes with flocculation
Backfill	Suspended solids	Places additional load on settlers
	Cyanide	Potential health risk; may further leach gold which is “lost”;

Water quality management problems in underground water circuits are primarily manifested through high reticulation system costs. The prime motivation in addressing these problems is therefore to reduce the costs associated with the damaging effects of erosion, corrosion, fouling and scaling. Health and safety of workers also need to be considered.

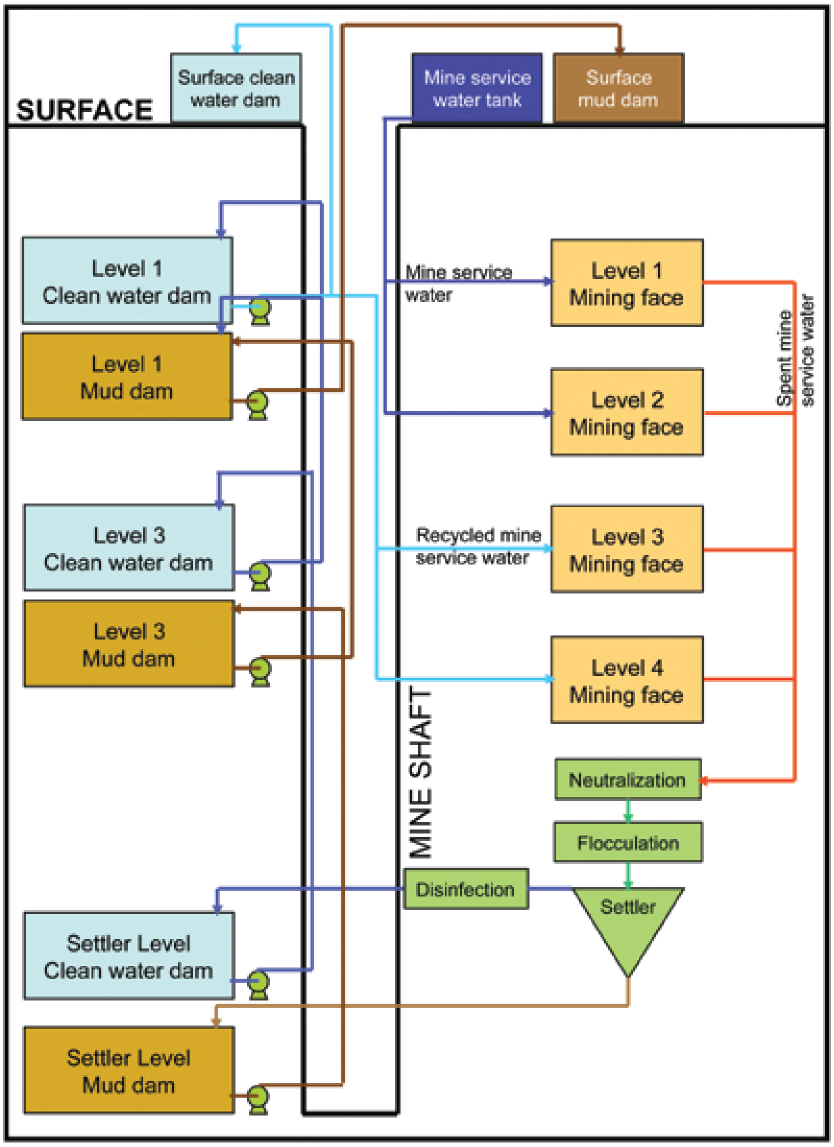
6.1.4 Mine service water systems

Typically, the mine service water systems comprise the following components:

1) Mine service water reticulation system with pressure piping to deliver the mine service water to the mining face where it can be used for machine cooling and dust suppression.
2) Drains and/or sumps with pumps to deliver spent mine service water from the mining face to the underground water treatment systems.
3) Underground neutralization systems to neutralize the acidity generated while the mine service water was in contact with sulphide minerals in the mining area, in order that the flocculants can function and to protect the clean water pumps from corrosion.
4) Application of coagulants/flocculants to the neutralized water.
5) Settling in underground settlers to remove the high suspended solids loading from the spent mine service water in order to enable multistage centrifugal pumps to pump the water out of the mine and to prevent silting of underground storage dams.
6) Disinfection systems wherever the cleaned and settled mine water is recycled back to the working face as mine service water in order to disinfect the water to reduce the health hazard if the water is inadvertently ingested.
7) Clean underground water storage dams to hold the settled water and to store water where water is pumped in multiple stages (as in very deep mines)
8) Large pump stations to pump the clean settled water up and out of the mine normally have very large multi-stage centrifugal pumps.
9) Mud storage dams to store mud removed from the spent mine service water in the underground settlers.
10) Mud pumps (normally positive-displacement pumps) to pump the mud out of the mine to the beneficiation plant as in gold and platinum mines, the mud is enriched with gold and platinum respectively.
11) Mud dewatering systems such as filter presses may be found at some mines to dewater the mud such that it can be hauled out of the mine with the ore, thereby removing the need for a mud-pumping system.

The abovementioned systems are shown schematically in Figure 6.2 below and discussed in more detail in the subsequent sections.

Figure 6.2: Schematic of typical underground mine service water circuit



6.1.4.1 Mine service water reticulation system

This typically consists of high pressure steel piping in the mine shaft, with lower pressure steel or HDPE piping through the haulages and to the mine face, with pressures depending on the water pressure requirements of the equipment using the water. A major deficiency in water management systems underground is that very few if any water flow meters are installed on these pipelines, making it very difficult to identify mine sections that use excessive volumes of water and making it difficult to implement water conservation measures. This deficiency should be rectified in order to improve water management in the underground systems.

6.1.4.2 Spent mine service water drains

Mine service water used at the mine working faces is removed from the working stopes into a drain system that ultimately delivers the water to the underground settlers. Different systems are employed to provide this function.

The most common system is to use gravity flow drains that drain the water back to the shaft area from where it then moves vertically down to the underground settlers. The problem with this system, is that although it is simpler, the suspended solids in the spent mine service water have a tendency to settle out in the drains, thereby requiring a high maintenance to remove the suspended solids material. Secondly, it has been shown in previous research that the suspended solids in the drains also contain elevated levels of sulphides and the long residence time of water in the drains leads to a reduction in water quality.

An alternative system is to build spent mine service water sumps close to the mine workings, where the water with suspended solids are pumped by suitable pumps to the shaft from where the water can flow down vertically to the settler level. This system does have a requirement for an additional spent mine service water reticulation system to be installed, together with the pumps, but the advantage is a reduction in maintenance costs and an improvement in spent mine service water quality.

6.1.4.3 Underground neutralization

The flow of water in the underground gold mines is very cyclical - mirroring the different mining cycles. The flow reaching the underground settler installations may increase by a factor of 10 within 30 minutes, when the water from the drilling operations arrives. This extreme variation in flow has negative consequences for the control and operation of the neutralization systems, flocculant dosing and settlers and requires overdesign to cope with peak loadings.

Although there are major benefits to be gained from flow balancing, there are inherent problems with mixing the dirty water to prevent the solids settling out ahead of the settlers. A flow balancing dam also needs to be quite large which may cause insurmountable problems with respect to the rock mechanics considerations and cost - particularly at the great depths (below 3000 metres) of the current mines.

Various treatment options exist for the removal of acidity or the neutralization of pH. Neutralization of spent mine service water is carried out ahead of the underground settlers in most gold mines. The underground processes are confined to chemical addition of lime, soda ash or caustic soda.

Some important characteristics of the various chemicals used for neutralization are shown in Table 6.2. Although lime is the cheapest and most widely used neutralizing chemical, it suffers from two major drawbacks:

- it leaves no residual buffer capacity (ability to absorb acids without a drop in pH) in the water; and
- it adds calcium to the water, thereby increasing the hardness and scaling properties – potentially limiting the degree of water reclamation that can be applied.

Table 6.2: Characteristics of common neutralization chemicals

Parameter	Lime	Soda Ash	Caustic Soda
Chemical formula	$Ca(OH)_2$	Na_2CO_3	NaOH
Solubility at 30 °C (g/l)	1,53	568	1 190
Consumption of pure product per g of CO_2	0,85	2,41	0,91
Consumption of pure product per g of H_2SO_4	0,76	2,16	0,82
Increase in hardness per g of CO_2 in g $CaCO_3$/l	1,1	0	0
Increase in hardness per g of H_2SO_4 in g $CaCO_3$/l	1,0	0	0
Product from reaction with CO_2	$Ca(HCO_3)_2$	$2NaHCO_3$	$NaHCO_3$
Product from reaction with H_2SO_4	$CaSO_4$	$Na_2SO_4 + 2NaHCO_3$	Na_2SO_4
Residual buffer capacity when neutralizing H_2SO_4	no	yes	no
Reaction time	slow	rapid	rapid
Cost	low	high	high

Additional information on neutralization chemistry and underground neutralization systems is given in Appendix C.

6.1.4.4 Coagulation and flocculation

The process of coagulation and flocculation is intended to condition the water and the suspended solids content therein, such that the formation of larger particles or flocs is encouraged. These larger, and consequently heavier, particles are then more easily settled by the downstream settling. The need for coagulation and flocculation is clear when a comparison of various particle settling times is made. Some of these are presented in Table D1 (Appendix D). This table indicates that it is not practical to settle particles smaller than 0.01 mm in diameter. This is particularly so in situations where the area available for settling is limited. This limitation occurs in the confined spaces of underground mines. The aim of coagulation is thus to reduce the required settling time of particles and thereby reduce the surface area required for a particular solid loading rate.

In underground mines, the coagulation and flocculation is undertaken with the use of added polymeric flocculants. Details on the coagulation and flocculation process are provided in Appendix D.

6.1.4.5 Underground settling

In gold mine water circuits, the suspended solids are primarily quartzitic in nature, although clay materials also occur. In underground water circuits, the solids are primarily due to the fines originating from blasting and cleaning of stopes. Where backfilling occurs, drainage from the backfill paddocks may contribute substantially to the suspended solids loading in the water.

All deep hard rock mines require underground settlers of one form or another to remove the suspended solids from the water before it can be pumped to surface with multistage centrifugal pumps. These settlers take various forms and include simple sumps, horizontal flow settlers, vertical flow settlers (rectangular or cylindrical), sludge blanket settlers and various types of high rate settlers. These settlers are preceded by pH adjustment and the addition of polymeric flocculants. These underground systems are typically poorly controlled and operated.

Apart from the particle settling velocities, the other critical parameters involved in the design and operation of any settling installation are:

- hydraulic or surface loading rate ($m^3/m^2.h$)
- solids loading rate ($kg/m^2.h$)

Due to the cyclical nature of underground mining operations these criteria fluctuate widely and often rapidly. The peak in the hydraulic loading can be up to 10 times the baseline flow. In addition, the maximum hydraulic loading corresponds to an increase in suspended solids content of between 100 and 400 times the normal concentration. This combination leads to peaks in the solids loading rate of up to 4000 times the baseline value. It is clear that with fluctuations such as these, good efficient control of settling is essential. Additional details on various underground settling systems are provided in Appendix E.

6.1.4.6 Disinfection

Chlorine disinfection is the standard disinfection technique applied on the mines. For surface installations, the chlorine may be dosed in the form of chlorine gas, although this is never applied underground for safety reasons. The most common form of chlorine dosing underground is by way of HTH tablets. In certain instances, chlorine generators have also been used in underground applications.

One of the primary problems with chlorine as a disinfectant in mine water circuits, is the high level of ammonia found in the water which interferes with the action of the chlorine. Another problem is the variation of pH which also affects the efficiency of the chlorine. For these reasons, alternative disinfection options have been investigated and are being used.

Chlorine dioxide has the advantage that it does not react with ammonia and, therefore, has a reduced demand in mine water systems. Chlorine/bromine combinations are increasingly being used within the gold mining industry to disinfect the underground mine service water circuits. Although bromine also reacts with ammonia to form bromamines, these are almost as effective as the hypobromous acid. Additionally, the bromine remains effective at much higher pH values and a chlorine/bromine combination disinfection programme is, therefore, effective over a wide pH range and tolerant of fairly poor pH control. Additional information on underground disinfection systems is provided in Appendix F.

6.1.4.7 Clean water storage dams

Clean water storage dams are normally located close to the settlers and also at different levels on the mine to cater for the fact that water cannot be pumped up from the bottom of the mine to the top in a single lift. Several stages are required and hence there are clean water dams on different levels. As shown in Figure 6.2, while these intermediate clear water dams serve a primary purpose of enabling water to be pumped all the way out of the mine, they can also be used as a source for recycling water back down as mine service water to the lower levels of the mine.

Clean water storage dams are also often sized to accommodate the full day's flow in order that water can be stored and then pumped up at night when energy costs are lower.

6.1.4.8 Clean water pump stations

Clean water pump stations are one of the primary users of energy on deep mines. These pumps are also very costly to purchase and maintain and complete overhauls are very difficult as it is not easy to dismantle these pumps and pull them back up the mine shaft. There is therefore a strong motivation to ensure that the neutralization and settling operations are done effectively in order to protect these pumps against the effects of corrosion and erosion respectively.

On most deep mines, the pumps used are multi-stage high pressure centrifugal pumps, capable of pumping water against a head of as much as 1000 m.

6.1.4.9 Mud dams

Settled mud removed from the settlers is typically enriched in gold or platinum (depending on the type of mine) and this mud is therefore a valuable product that needs to be delivered to the beneficiation plant. The mud is stored in mud dams that are normally agitated in order to prevent the mud dams from solidifying. Although not shown on Figure 6.2, there are also mud dams on intermediate levels as mud pumps can also not pump the mud from a deep mine to surface in a single lift.

6.1.4.10 Mud pumping stations

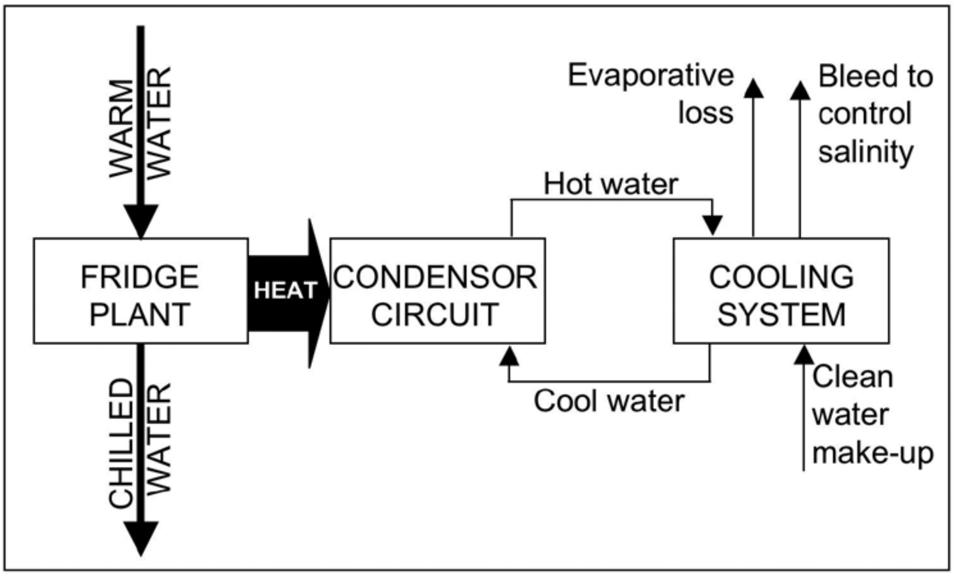
Mud pumping stations are normally located directly adjacent to the clean water pumping stations and also pump the mud up in various lifts as do the clean water pumps. Due to the nature of the material being pumped, the mud pumps are normally positive displacement type pumps specially designed and built to handle abrasive slurries.

6.1.5 Mine cooling systems

As shown in Figure 6.1, approximately 78 % of the water used in the gold mining industry is used for mine cooling and it is probable that a similar situation will prevail at other deep hard rock mines. Most of this cooling water (34 700 *l*/s) is circulated as condenser water for the refrigeration plants, while 9 800 *l*/s of water is circulated to bulk air coolers to cool the air underground. A further 4 800 *l*/s of chilled water is used as mine service water, which performs a supplementary cooling function in the stopes.

Condenser water is the hot water that circulates on the hot side of a refrigeration plant and absorbs the heat abstracted in the process of chilling the water – see Figure 6.3. This heated water is then sent to evaporative coolers where the heat is rejected and the water can then be returned back to the refrigeration plant to absorb more heat. The evaporation process results in concentration of salts and there is therefore a need to bleed high salinity water out of the condenser circuit and to add clean make-up water to balance the losses. The degree to which the condenser circuit can be closed and recycled is dependent on the quality of the make-up water and the higher the salinity of the make-up water, the lower the degree of recycling that can be applied and the higher the percentage of make-up water will be.

Figure 6.3: Detail of fridge plant water circuit



Chilled water is either sent directly to the working face where its use in the mining operations leads to environmental cooling or the chilled water is sent to evaporative coolers. In an evaporative cooler, the chilled water is sprayed into the path of incoming warm air, thereby cooling the air and allowing cold ventilation air to be pumped into the hot mine workings for mine cooling purposes. In this application, water is consumed as wind drift and as humidity if dry hot air is brought in.

The primary concerns with mine cooling water circuits are scaling, corrosion and biofouling and water quality needs to be controlled and anti-scalants are added to address this problem. Regular biofouling control programmes also need to be designed and implemented. Additional information is provided in Appendix G.

6.1.6 Other mine water uses

The other main users of water underground in the deep hard rock mines are the following:

Potable water: used for drinking purposes - insignificant in terms of water balance but significant in terms of health and safety risks. The potable water is often located too far away from the working face to be of practical value and is also often warm, making it more attractive to workers to drink the chilled mine service water, despite the health risks. Options do exist for small potable water treatment plants that tap into the chilled mine service water and convert this to chilled potable water. Alternatively, simple heat exchange systems can be constructed to chill the potable water using the chilled mine service water.

Sanitation: portable sanitation systems are available underground although they are not always used – hence the need to disinfect mine service water that is recycled from the settlers. This constitutes an insignificant flow of water in terms of the overall mine water balance.

Backfill: for those mines that place backfill (tailings) underground for rock support and rock mechanics reasons, backfill drainage can be a significant contributor to the underground spent mine service water system. The negative impacts of the backfill water are in terms of high concentrations of fine colloidal suspended solids that place an additional burden on the coagulation, flocculation and settling systems. Additionally, despite cyanide immobilization practices employed in the surface backfill preparation plant, free and complexed cyanide does find its way into the spent mine service water and may be recycled back as mine service water. Additionally, there are questions that need to be answered with regard to the long-term stability of the immobilized cyanide in the backfill if the mine had to become acidic and the backfill had to exposed to acidic leaching conditions.

6.2 WATER MANAGEMENT IN SHALLOW UNDERGROUND MINES

The most common example of the relatively shallow underground mines are the underground coal mines in South Africa, with water used underground primarily as mine service water to operate the mining machinery and for dust suppression. Mine cooling with chilled water is not necessary in these mines due to their shallowness and lack of heat in the surrounding rock matrix. The nature of the water use on underground coal mines is therefore quite different to gold mines and large underground neutralization and settling facilities are not necessary – dirty water can be pumped the relatively short distance up to surface without needing high-pressure multistage pumps with close tolerances.

Shallow underground mines (e.g. coal mines) are, due to their relatively shallow nature, more susceptible to water ingress problems associated with seasonal rainfall patterns as they are often located within or at least very close to the upper aquifer. The water ingress problems and the water balance are also closely linked to the type of underground mining method employed, i.e. bord and pillar mining or maximum extraction mining. Details on this are given in Chapter 5

The water management issues at underground coal mines are differentiated and discussed in the following manner:

- Mine life-cycle considerations
- Water ingress into underground coal mines
- Mine water balance considerations
- Mine water quality considerations
- Mine service water systems
- Mine water storage systems

6.2.1 Mine life cycle considerations

The same considerations and investigations as set out for deep underground hard rock mines will apply to shallow underground mines, although the outcomes, impacts and management options will be different. Refer to Section 6.1.1 of this report.

6.2.2 Water ingress into shallow underground mines

There are a number of potential sources of water ingress into shallow underground mines. A number of these water ingress pathways are specific to the type of underground mining that is applied and these pathways are discussed in Chapter 5. The generic pathways that are largely independent of the mining method are described in the following sections, together with strategies that should be considered to address these sources of water ingress.

6.2.2.1 Drill holes

The following lists typical drill holes used in underground mining which can allow ingress of surface and groundwater into the workings during the operation and post-closure phases.

- Geological drill holes.
- Electrical cable and communications holes.
- Stonedust holes.
- Rescue holes from underground rescue chambers.

Figures 6.4 and 6.5 are diagrams illustrating how holes should be closed after use to prevent water ingress

Geological boreholes must be accurately surveyed after completion and are to be shown on all survey plans of the mine. Mine planning can position pillars around boreholes so as not to intersect them during the mining operation.

Service boreholes will always be into mine workings where the services are delivered. These holes need to be plugged from the bottom where they intersect the workings and then grouted through to surface. It would be advantageous if the bord can be backfilled (e.g. with ash) to give further support to the roof to reduce the risk of bord failure which could destroy the plug and grouting thus allowing water to ingress into the workings.

Figure 6.4: Geological drill holes

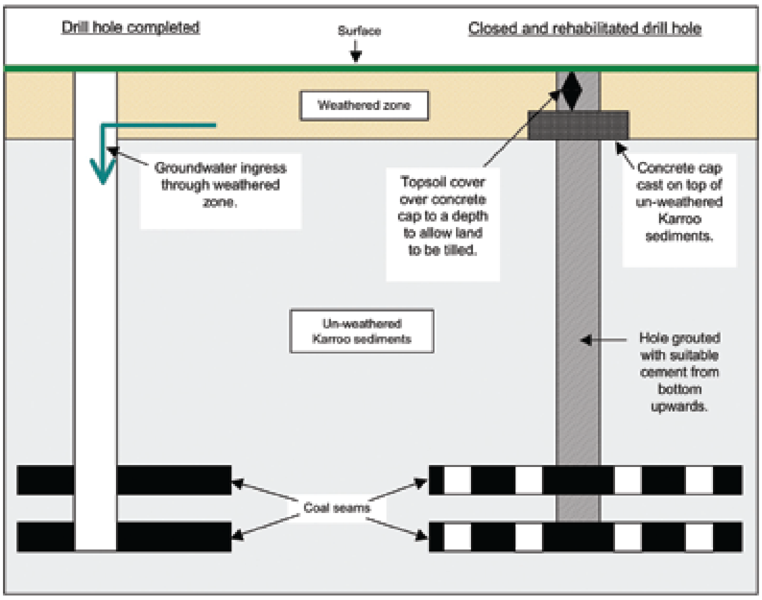
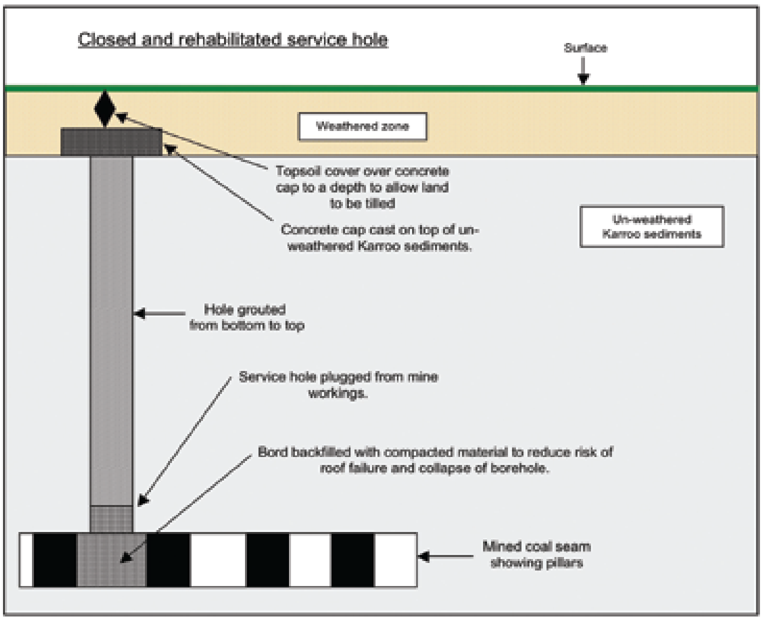


Figure 6.5: Service drill holes



6.2.2.2 Shafts

Shafts can be major sources of surface and groundwater ingress if not properly lined. Two typical shaft types are illustrated which are used on underground coal mines.

- Vertical shafts for men, materials and ventilation.
- Incline shafts for men, materials, coal conveying and ventilation.

Figures 6.6 and 6.7 are diagrams illustrating how shafts can be managed to reduce surface and groundwater ingress.

Figure 6.6: Vertical shaft closure

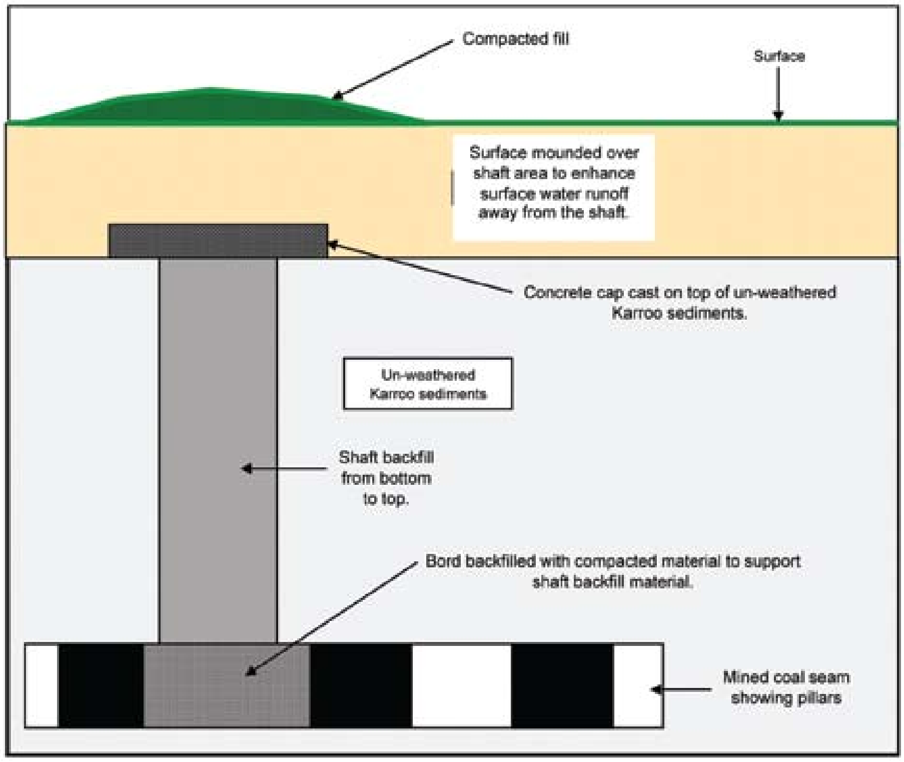
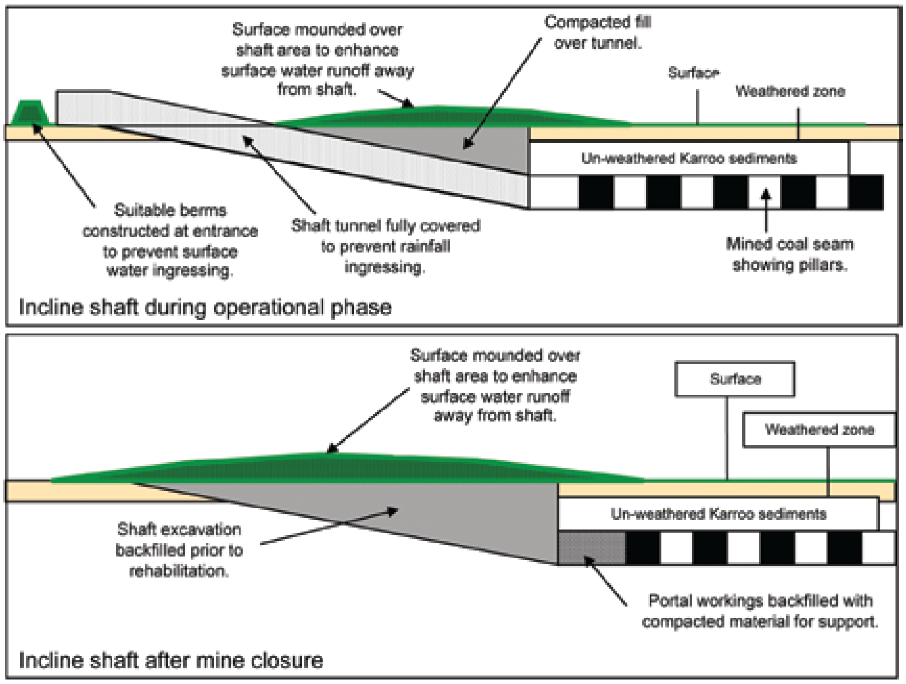


Figure 6.7: Incline shaft during operations and after mine closure



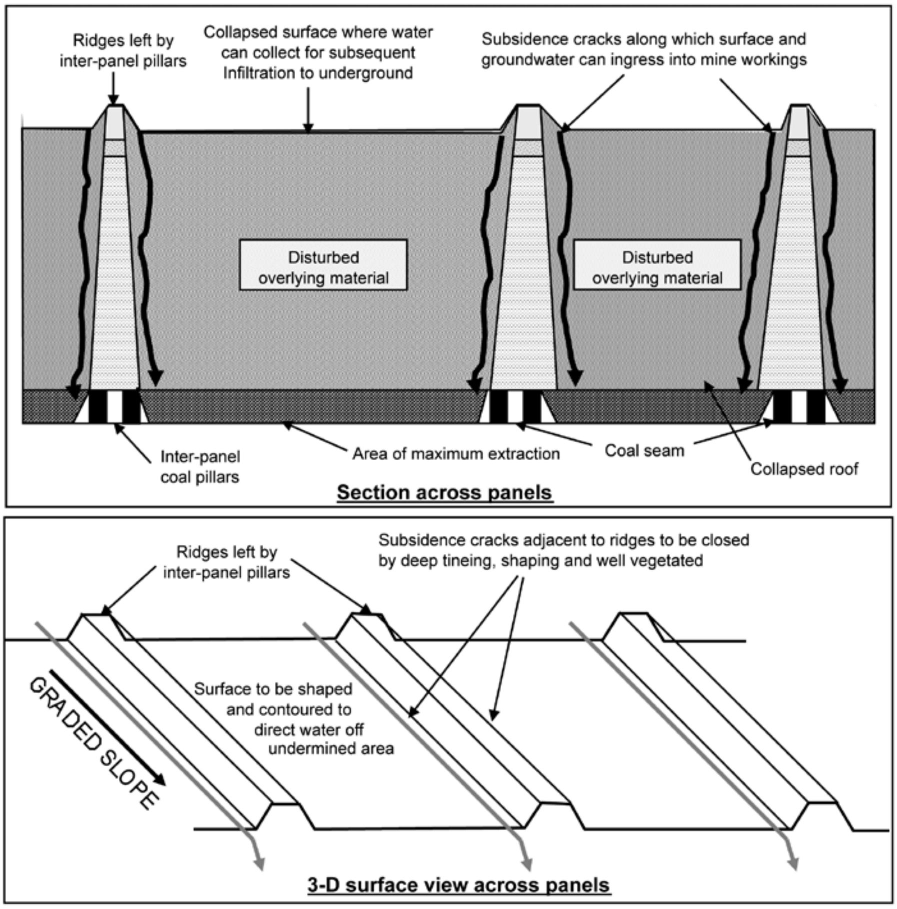
6.2.2.3 Flood protection

Flood protection dealt with here pertains to general protection of the workings as listed below.

- Observing 1:100 year flood lines.
- Surface water control over areas mined by maximum extraction methods.

Figure 6.8 illustrates how surface water can be managed over areas of maximum extraction.

Figure 6.8: Effects of and management of high extraction mining



6.2.2.4 Mining method

Well planned mining methods for bord and pillar mining can protect the surface from collapse during the operation and post-closure phases. Factors to be considered during all planning stages are listed below.

- Factors of safety for pillar design must not be less than 2.0 taking into account the strength of the coal, overlying strata, etc.
- Un-weathered and competent strata above the coal seam must not be less than 20 meters. This will reduce the chances of collapse of bords due to weathered and weak strata.

Details on the different mining techniques, associated water ingress problems and recommended management strategies are covered in detail in Chapter 5.

6.2.2.5 Geological features

While geological features such as faults, dykes, severe rolls, etc. are not normally conduits for water into underground workings, these can be opened up during and after mining whereafter they do become flow paths for both surface and groundwater.

6.2.2.6 Surface features

Surface features such as buildings, paved roads, paved areas (processing plants, workshops, offices) increase the rainfall runoff. Water from such areas needs to be directed into streams if not contaminated. Water management issues relating to these features are dealt with in detail in ***BPG A5: Water Management for Surface Mines.***

6.2.3 Mine water balance considerations

No recent industry-wide data sets are available to give reliable water balance data for the whole underground coal mining industry and water balance data varies too much between individual mines to be able to use any single mine water balance as illustrative of the whole industry. The most complete picture of the water balance within underground coal mines was obtained in a Water Research Commission project which was completed in 2001 (Pulles, 2001), although this study did find significant anomalies and gaps in the water balance data. Separate water balance data was collected and provided for bord and pillar mines and high (total) extraction mines as shown in Figures 6.9, and 6.10 below, although many mines apply both mining methods.

From a review of the specific water usage in litres/ton of coal produced, it is clear that the bord and pillar mining operations with a total usage of around 570 l/ton, perform much better than the total extraction mines with a total usage of around 13 600 l/ton. The general level of water management for the total extraction mines that were surveyed was by far the poorest, with 58% of water entering the circuit coming from unknown sources and 91% of water lost from the circuits reporting to unknown sinks. The very high levels of water usage within total extraction mining is most probably a consequence of the damage done to aquifers and to surface hydrology.

While the WRC report that was used to obtain the above information was prepared in 2001, and water management systems on mines have continued to improve, the information contained in this report does make useful reading and clearly suggests that there is a need for improved monitoring and water balance management in order that water sources and sinks are clearly understood and the specific water usage can be reduced.

A key consideration in developing mine water balances is to understand, define, quantify and incorporate calculations for inter-mine flow, both during operations and very importantly after mine closure as well.

Figure 6.9: Industry-wide water balance for operational underground B&P coal mines

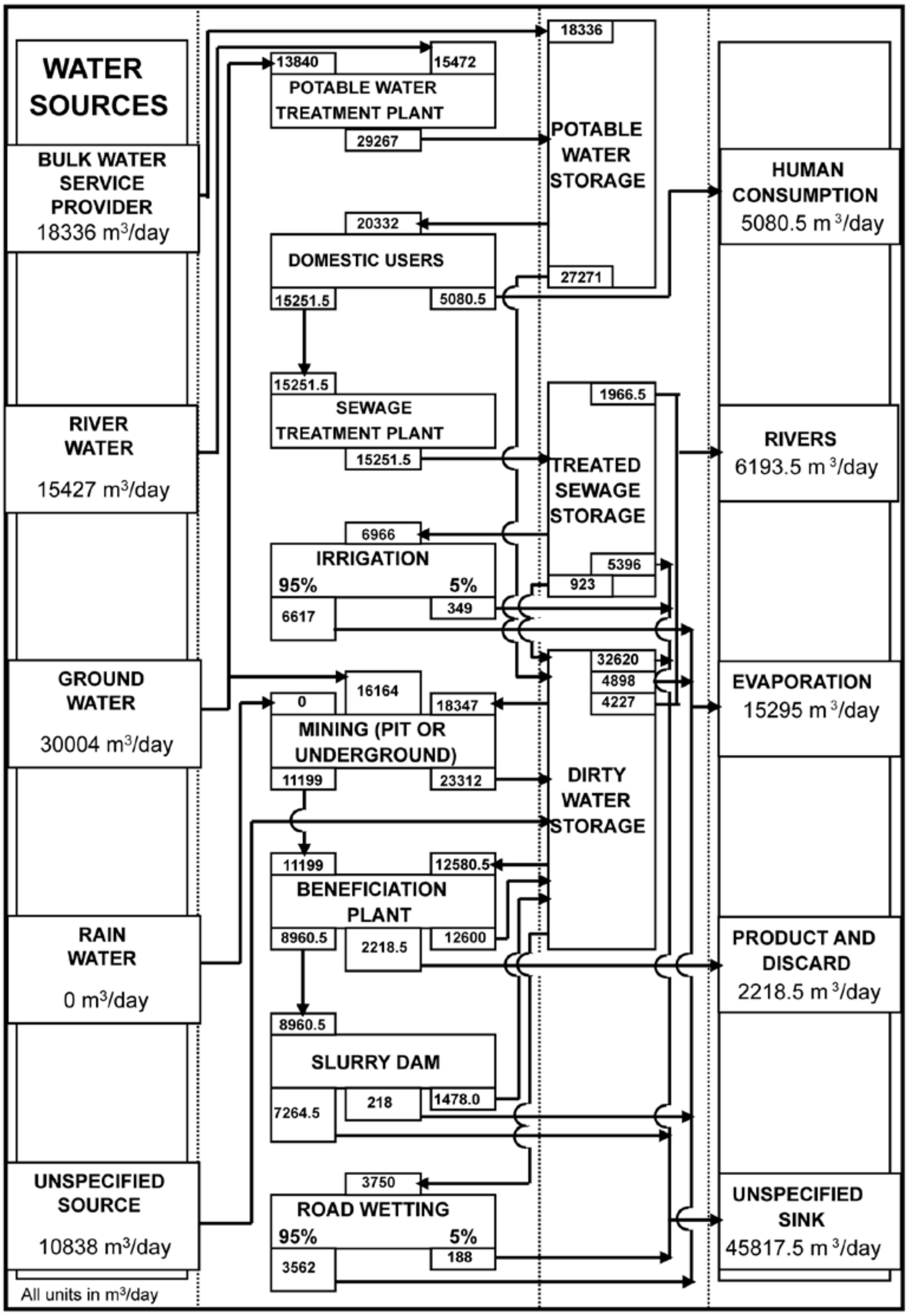
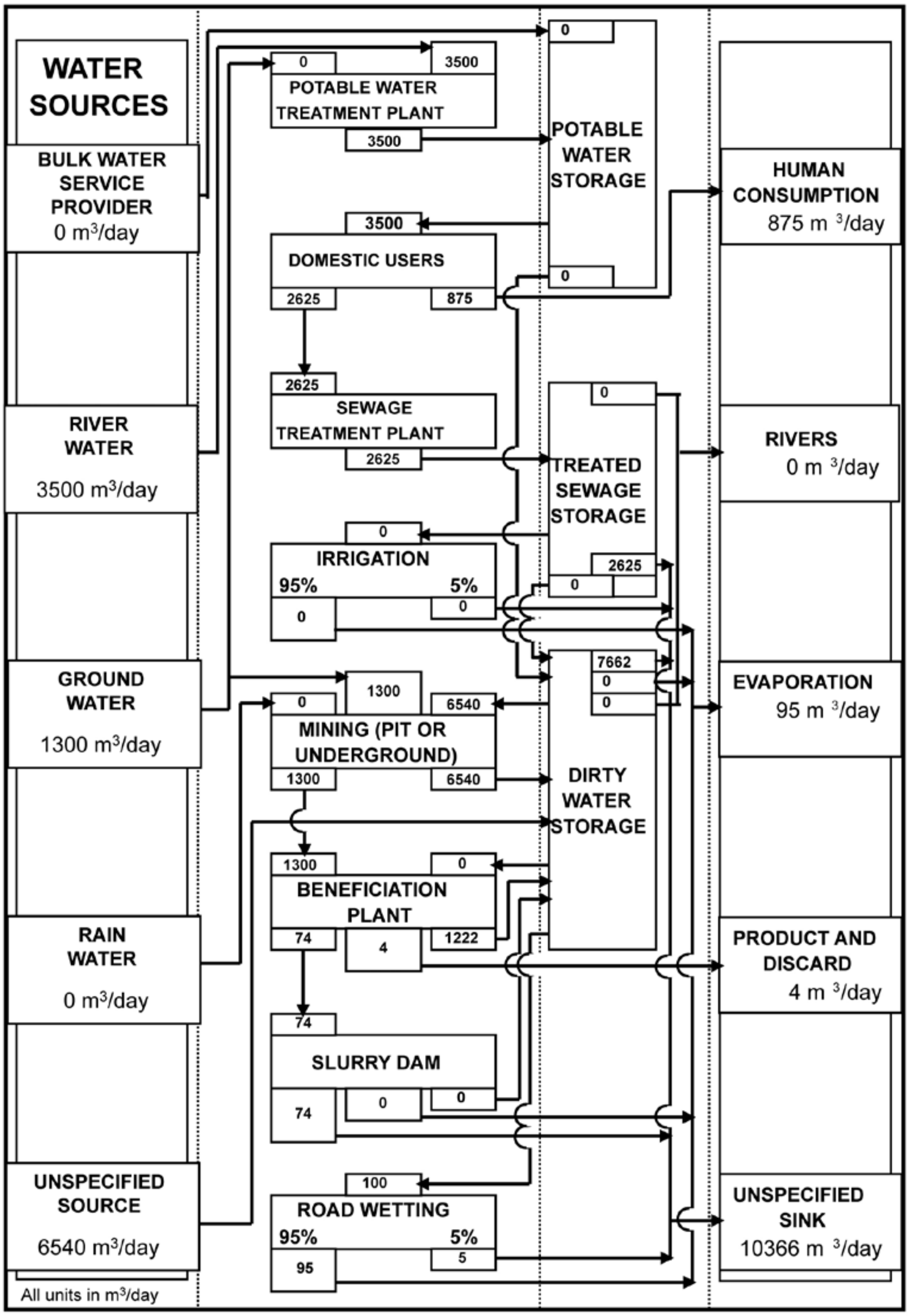


Figure 6.10: Industry-wide water balance for operational underground high extraction coal mines



6.2.4 Mine water quality considerations

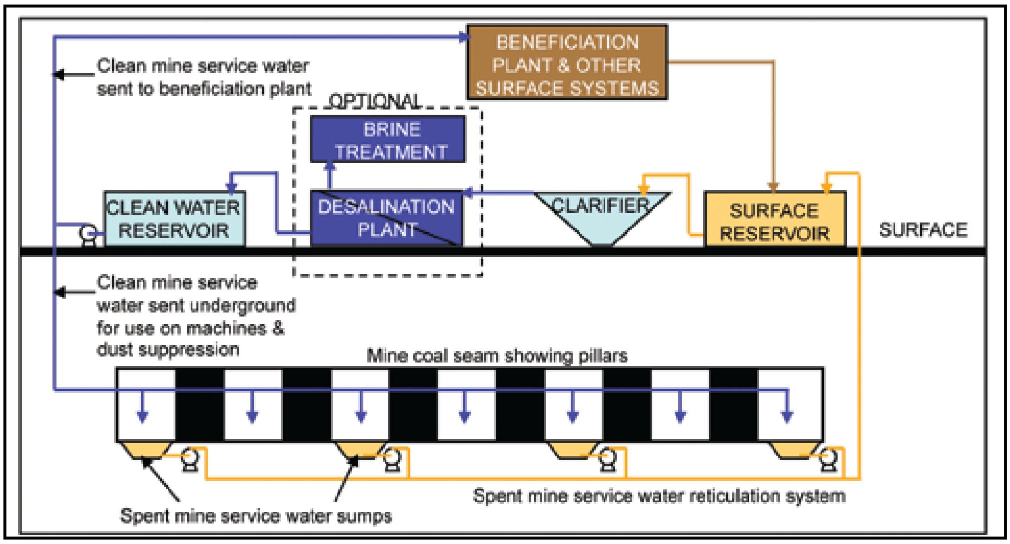
The water quality deterioration driving forces for underground hard rock and coal mines are similar, i.e. they derive from oxidation of sulphide minerals. Consequently, the nature of the contaminants found in mine service water in both hard rock and coal mines are similar and the reader is referred to Section 6.1.3 for the discussion on water quality issues. The main differences are that coal mines will not have problems with cyanide and radioactivity, although they may experience greater problems with oil and grease and other contaminants such as fluorides. Certain coal mines will also experience problems relating to elevated levels of sodium, originating from the host rock.

6.2.5 Mine service water systems

Figure 6.11 illustrates a typical mine water circuit for maximizing re-use of mine water for use on machines and for dust suppression. The majority of underground coal is mined by continuous miners and shearers. These machines need to operate on clarified neutral pH water with dissolved salt levels generally <400 mg/l. The water serves as a coolant for the motors and shearing drums and also for dust suppression.

A major difference between deep hard rock mines and shallower coal mines, is that for the coal mines, the dirty water can be pumped directly to surface, allowing the water treatment operations to be undertaken on surface. This makes the treatment systems and the reticulation systems much simpler and easier to manage.

Figure 6.11: Schematic representation of underground coal mine water circuit



6.2.6 Mine water storage systems

Mine water is stored in a variety of manners, most of which are conventional and will be covered by the **BPG A4: Pollution Control Dams** and relevant sections of the water licensing process. However, there are also a number of unique considerations that apply to storage of water underground in the mines and a number of coal mines use this to store vast volumes of contaminated water. A particular concern when storing water underground where it is likely to be in contact with sulphide minerals is to manage the storage systems in a manner that absolutely minimizes the potential for water quality deterioration to occur. This would imply that storage reservoirs must be filled as quickly as possible and that measures must be put in place to prevent regular fluctuation of the stored water level as it is this wetting and drying cycle on the exposed surfaces that will enhance the rate of sulphide oxidation and lead to water quality deterioration.

7

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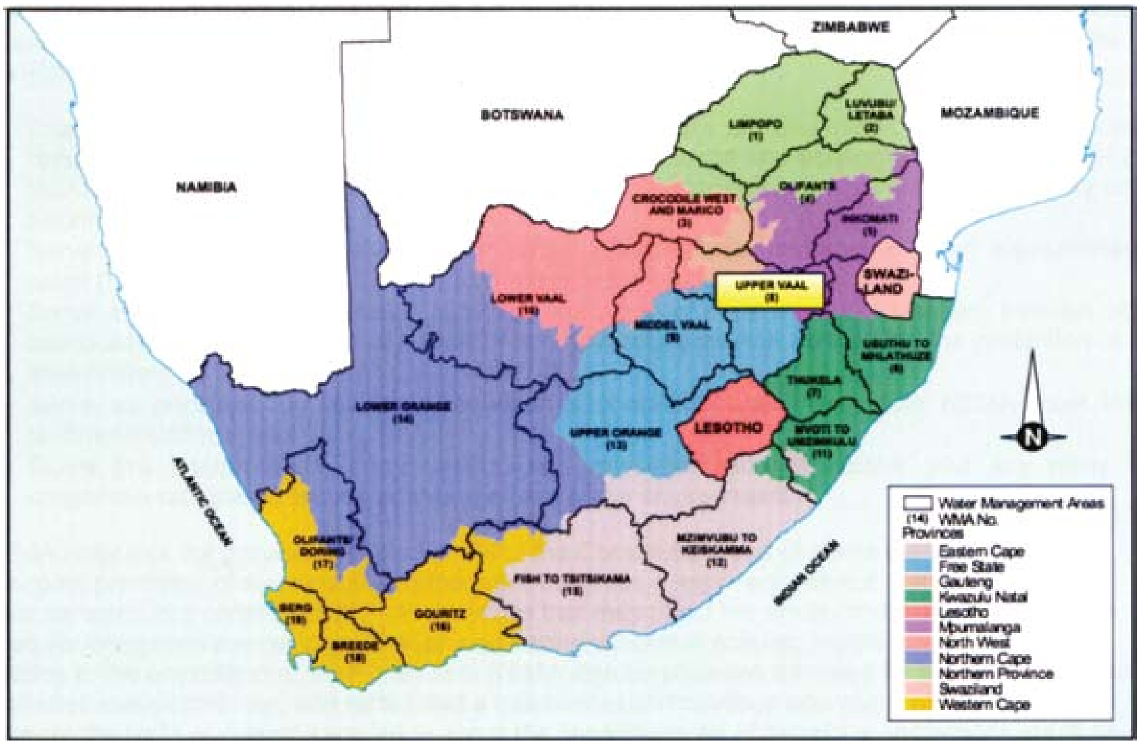
APPENDIX A
LEGAL FRAMEWORK

A.1 INTRODUCTION

The legal review provides an outline of the requirements for water management within the prevailing mining, water and environmental legislation in South Africa. The legal review focuses in two main areas, namely:

1) Section A.2 covers the water management requirements in the national legislation, including the National Environmental Management Act, 1998 (Act 107 of 1998), the Mineral and Petroleum Resources Development Act, 2002 (MPRDA) (Act 28 of 2002) and the National Water Act, 1998 (NWA), (Act 36 of 1998). The provisions included in other legislation are also considered
2) Section A.3 covers the policies, strategies and guideline documents that have been developed by DWAF at a national level to assist in effective water management throughout South Africa. These policies and strategies are required to be implemented regionally, or on a catchment basis in the case of DWAF. The guideline documents have been developed to assist the catchment-based implementation process. This implementation is currently being undertaken through DWAFs regional offices, but will in future be delegated to Catchment Management Agencies (CMAs) who will be responsible for all water management within a defined catchment areas.
3) Figure A1 indicates the division of the country into the 19 Water Management Areas (WMAs).

Figure A1: Water Management Areas in South Africa



Note that the regulatory environment is continuously being amended within South Africa. The legal framework and review included in this BPG thus covers the current legislative status.

A.2 SOUTH AFRICAN NATIONAL LEGISLATION

A.2.1 Constitution of the Republic of South Africa Act, 1996 (Act 108 of 1996)

Section 24 of the Constitution provides that *everyone has the right … to an environment that is not harmful to their health or well-being; and … to have the environment protected for the benefit of present and future generations through reasonable legislative and other measures that - (i) prevent pollution and ecological degradation; (ii) promote conservation; and (iii) secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development.*

Section 33 of the Constitution entitles everyone to administrative action that is lawful, reasonable and procedurally fair and, if one's rights have been adversely affected by administrative action, to be given written reasons for the decision.

Section 38 provides locus standi or the right to get involved to any member of public. This means that a member of public has the right to take appropriate action to prevent environmental damage. This may include taking action against the responsible authority for failing to perform its duties in preventing environmental damage or against an individual or authority who are in the process of undertaking a water use identified in the NWA without the necessary authorisation to undertake such water use.

A.2.2 National Environmental Management Act, 1998 (Act 107 Of 1998)

The National Environmental Management Act, 1998 (NEMA) contains certain principles in section 2. These principles apply throughout the country to the actions of all organs of state (as defined in the Constitution) that may significantly affect the environment and:

- Shall apply alongside all other appropriate and relevant considerations, including the State's responsibility to respect, protect, promote and fulfil the social and economic rights in Chapter 2 of the Constitution and in particular the basic needs of categories of persons disadvantaged by unfair discrimination
- Serve as the general framework within which environmental management and implementation plans (referred to in section 11 of NEMA) must be formulated
- Serve as guidelines by reference to which any organ of state must exercise any function when taking any decision in terms of NEMA or any statutory provision concerning the protection of the environment
- Serve as principles by reference to which a conciliator appointed under NEMA must make recommendations, and
- Guide the interpretation, administration and implementation of NEMA, and any other law concerned with the protection or management of the environment.

NEMA reiterates the provisions of section 24 of the Constitution, and contains the internationally accepted principles of sustainability. It therefore becomes a legal requirement that these principles must be taken into consideration in all decisions that may affect the environment. Furthermore, the need for intergovernmental co-ordination and harmonisation of policies, legislation, and actions relating to the environment, is emphasised. NEMA also emphasises the need for a mechanism that promotes sustainable use, and states that a risk-averse and cautious approach, which takes into account the limits of current knowledge about the consequences of decisions and actions, must be used in decision-making. It is also important to note that the Best Practical Environmental Option (BPEO) is defined in NEMA as the option that provides the most benefit or causes the least damage to the environment as a whole, at a cost acceptable to society, in the long term as well as the short term.

In the context of mining, these principles are given further effect through section 37 of the MPRDA, which stipulates that the principles set out in section 2 of NEMA:

- Apply to all prospecting and mining operations, as the case may be, and any matter relating to such operation, and
- Serve as guidelines for the interpretation, administration and implementation of the environmental requirements of the MPRDA.

Section 28 of NEMA further establishes a general duty of care on every person who causes, has caused or may cause significant pollution or degradation of the environment to take reasonable measures to prevent such pollution or degradation from occurring, continuing or recurring, or, in so far as such harm to the environment is authorised by law or cannot reasonably be avoided or stopped, to minimise and rectify such pollution or degradation of the environment.

New EIA Regulations, promulgated under NEMA, came into effect on 03 July 2006 (as covered in Government Notices R385, R386 and R387 of 21 April 2006 - the "NEMA EIA Regulations").

A.2.3 Mineral and Petroleum Resources Development Act, 2002 (Act 28 of 2002)

A.2.3.1 Mining Authorisation

Section 5(4)(a) of the MPRDA stipulates that no person may prospect for or remove, mine, conduct technical or reconnaissance operations, explore for and produce any mineral or petroleum or commence with any work incidental thereto (including the construction of any residue deposits) on any area without inter alia an approved environmental management programme or approved environmental management plan, as the case may be.

A.2.3.2 Prospecting rights

If the application for a prospecting right is accepted by the Regional Manager, the Regional Manager must within 14 days from the date of acceptance notify the applicant in writing to inter alia submit an environmental management plan (section 16(4)(a)). The granting of a prospecting right only becomes effective on the date on which the environmental management plan is approved in terms of section 39 of the MPRDA (section 17(5)). The application for renewal of a prospecting right must inter alia be accompanied by a report reflecting the extent of compliance with the requirements of the environmental management plan, the rehabilitation completed and the estimated cost thereof (section 18(2)(c)) and the Minister must grant the renewal of a prospecting right if the application complies with sections 18(1) and 18(2) and the holder of the prospecting right has inter alia complied with the requirements of the approved environmental management plan (section 18(3)(c)). The holder of a prospecting right must comply with the requirements of the approved environmental management plan in terms of section 19(2)(c). In the case of a retention permit, the environmental management plan approved in respect of the prospecting right remains in force as if the prospecting right had not lapsed in terms of section 32(2) (section 32(3)) and the holder of the retention permit must give effect to the approved environmental management plan (section 35(2)(a)).

A.2.3.3 Mining rights

If the application for a mining right is accepted, the Regional Manager must within 14 days from the date of acceptance notify the applicant in writing to inter alia conduct an environmental impact assessment and submit an environmental management programme for approval in terms of section 39 (section 22(4)). A mining right granted in terms of section 23(1) comes into effect on the date on which the environmental management programme is approved in terms of section 39(4) (section 23(5)). An application for renewal of a mining right must inter alia be accompanied by a report reflecting the extent of compliance with the requirements of the approved environmental management programme, the rehabilitation to be completed and the estimated cost thereof (section 24(2)(b)) and the Minister must grant the renewal of a mining right if the application complies with sections 24(1) and 24(2) and the holder of the mining right has inter alia complied with the requirements of the approved environmental management programme (section 24(3)(c)). The holder of a mining right must comply with the requirements of the approved environmental management programme in terms of section 25(2)(e).

A.2.3.4 Mining Permits

If the Regional Manager accepts the application for a mining permit, the Regional Manager must, within 14 days from the date of acceptance, notify the applicant in writing to inter alia submit an environmental management plan (section 27(5)(a)). The Minister must issue a mining permit if inter alia the applicant has submitted the environmental management plan (section 27(6)(b)).

A.2.3.5 Environmental management

Section 37 requires that the principles set out in section 2 of NEMA must apply to all prospecting and mining operations, and that the generally accepted principles of sustainable development must be applied by integrating social, economic and environmental factors during the planning and implementation phases of mining projects.

Section 38(1) requires that the holder of a reconnaissance permission, prospecting right, mining right, mining permit or retention permit:

- Must at all times give effect to the general objectives of integrated environmental management laid down in Chapter 5 of NEMA
- Must consider, investigate, assess and communicate the impact of his or her prospecting or mining on the environment as contemplated in section 24(7) of NEMA
- Must manage all environmental impacts in accordance with his or her environmental management plan or approved environmental management programme, as the case may be; and as an integral part of the reconnaissance, prospecting or mining operation, unless the Minister directs otherwise;
- Must as far as it is reasonably practicable, rehabilitate the environment affected by the prospecting or mining operations to its natural or predetermined state or to a land use which conforms to the generally accepted principle of sustainable development, and
- Is responsible for any environmental damage, pollution or ecological degradation as a result of his or her reconnaissance prospecting or mining operations and which may occur inside and outside the boundaries of the area to which such right, permit or permission relates.

Section 39 of the MPRDA deals with the requirements of an environmental management programme or plan, whichever is applicable. Section 40 allows for the consultation with other State departments that administers any law relating to matters affecting the environment.

Section 41 deals with the financial provision for remediation of environmental damage, and the requirement to maintain and retain the financial provision in force until the Minister issues a certificate in terms of section 43, which states that the holder of a prospecting right, mining right, retention permit or mining permit remains responsible for any environmental liability, pollution or ecological degradation, and the management thereof, until the Minister has issued a closure certificate to the holder concerned. In terms of section 43(5) no closure certificate may be issued unless the Chief Inspector (MHSA) and the DWAF (NWA) have confirmed in writing that the provisions pertaining to health, safety and management of potential pollution to water resources have been addressed.

Section 42 deals specifically with the management of residue stockpiles and residue deposits, and stipulates that these must be managed in the prescribed manner on any site demarcated for that purpose in the environmental management programme or plan in question only. Regulation 73 provides comprehensive supporting information for this section of the act.

In line with section 20 of the NWA and section 30 of NEMA, section 45 of the MPRDA allows the Minister to direct the implementation of urgent remedial measures in the case of ecological degradation, pollution or environmental damage which may be harmful to the health or well-being of anyone. If the holder of the relevant right, permit or permission fails to comply with this directive, the Minister may take the necessary steps to implement the required remedial measures and recover the cost for implementation from the holder concerned.

A.2.3.6 Mineral and Petroleum Resources Development Regulations

Government Notice No. R.527 (R527), dealing with the mineral and petroleum resources development regulations was published in the Government Gazette of 23 April 2004 (GG No. 26275, Volume 466). In particular, Part III of R527 deals with environmental regulations for mineral development, petroleum exploration and production.

In terms of regulation 48, an environmental impact assessment contemplated in section 39(1) of the MPRDA is a process which results in the compilation of a:

- Scoping report, the contents of which is described in regulation 49, and
- An environmental impact assessment report, the contents of which are described in regulation 50.

The contents (framework) of an environmental management programme or plan, whichever is applicable, is described in regulations 51 and 52, respectively, while the requirements for monitoring and performance assessments of these programmes/plans are described in detail in regulation 55. The methods and quantum of financial provision for the rehabilitation, management and remediation of negative environmental impacts (including those associated with mine residue deposits) are given in regulations 53 and 54.

Regulations 56 deals with the requirements for mine closure, including the principles for mine closure, closure objectives and the contents (framework) of the environmental risk assessment report and closure plan.

Part IV of R527 deals with pollution control and waste management regulation and stipulates a number of requirements specific to the management of mine residue stockpiles and deposits (regulation 73). Regulation 73(1) stipulates that the assessment of impacts relating to the management of residue stockpiles/deposits must form part of the environmental impact assessment report (regulation 50) and environmental management programme or plan, as the case may be. Other requirements with respect to the design, operation and maintenance, and decommissioning and closure of a mine residue deposit include:

- Characterisation of mine residue, by a competent person, to identify any significant health or safety hazard and environmental impact that may be associated with the residue when stockpiled or deposited at the site(s) under consideration (regulation 73(2))
- Classification of residue stockpiles/deposits, by a competent person, in terms of the safety and environmental hazard/impact thereof. The classification will determine the level of investigation and assessment required, the requirements for design, construction, operation, decommissioning, closure and post-closure maintenance, and the qualifications and expertise required of person undertaking the necessary investigations and/or assessment (regulation 73(3))
- Selection and investigation of a site, following the prescribed process, with specific requirements for geotechnical and groundwater investigations (regulation 73(4))
- Incorporations of prescribed considerations during the design of residue stockpile/deposits (regulation 73(5))
- Implementation of a monitoring system for residue stockpiles/deposits with respect to potentially significant impacts (regulation 73(7)), and
- Management requirements for residue deposits during the decommissioning, closure and post-closure phases (regulation 73(8)).

A holder of any right or permit must further ensure that (regulation 73(6)):

- The residue deposits, including surrounding catchment paddocks, are constructed and operated in terms of the approved environmental management programme/plan
- The residue deposit is constructed strictly in accordance with the design, and if not, that the necessary approvals are obtained and the environmental management programme/plan amended accordingly
- All residue transported to and the surplus water removed from the site are recorded as part of the monitoring system
- Appropriate security measures are in place to limit unauthorised access to the site
- Specific action is taken in respect of any sign of pollution
- Adequate measure are implemented to control dust pollution and erosion of the slopes, and
- Details of the rehabilitation of the residue deposit are provided in the environmental management programme/plan.

Other requirements which could apply to mining are stipulated, namely:

- Regulation 64: Air quality management and control
- Regulation 65: Fire prevention
- Regulation 66: Noise management and control
- Regulation 68: Water management and pollution control
- Regulation 69: Disposal of waste material, including mining waste, and
- Regulation 70: Soil pollution and erosion control.

A.2.4 National Water Act, 1988 (Act 36 of 1998)

A.2.4.1 Water use

Section 21 of the NWA stipulates the following water uses:

(a) taking water from a water resource
(b) storing water
(c) impeding or diverting the flow of water in a water-course
(d) engaging in a stream flow reduction activity contemplated in section 36
(e) engaging in a controlled activity identified as such in section 37(1) or declared under section 38(1)
(f) discharging waste or water containing waste into a water resource through a pipe, canal, sewer, sea outfall or other conduit
(g) disposing of waste in a manner which may detrimentally impact on a water resource

(h) disposing in any manner of water which contains waste from, or which has been heated in, any industrial or power generation process
(i) altering the bed, banks, course or characteristics of a watercourse
(j) removing, discharging or disposing of water found underground if it is necessary for the efficient continuation of an activity or for the safety of people, and
(k) using water for recreational purposes.

Note that in the above, waste includes *any solid material or material that is suspended, dissolved or transported in water (including sediment) and which is spilled or deposited on land or into a water resource in such volume, composition or manner as to cause, or to be reasonably likely to cause, the water resource to be polluted.*

In terms of section 4 of the NWA, water may only be used if it is a Schedule 1 use, a continuance of an existing lawful use (ELU), or authorised in terms of a general authorisation (GA) or licence. A water use may therefore not be implemented unless it is properly authorised through one of these types of authorisations. The circumstances that will determine the type of authorisation to be issued for a specific water use that is not a Schedule 1 use, and the different possibilities for regulating particular water uses are briefly discussed below.

A.2.4.1.1 Existing Lawful Water Uses (Sections 32 to 35)

Section 32 identifies water uses that were authorised under legislation, which was in force immediately before the date of commencement of the NWA (such as the 1956 Water Act), as ELUs. This is subject to the requirement that such water use took place at any time during the two years prior to the date of commencement of the NWA. Should a person have had such authorisation to use water but have not exercised this authorisation in the two years prior to this date, that person may apply to have the water use declared as an ELU in terms of section 33 of the Act. The section on ELU is designed to enable existing economic activities based on the use of water to continue until such time as compulsory licensing is called for in a particular catchment management area.

A.2.4.1.2 General Authorisations (GAs) (Section 39)

The aim of GAs is to set a cut-off point below which strict regulatory control is not necessary. If a water use is not described under Schedule 1, but authorised under a GA as published in the Government Gazette, such water use does not require a licence, unless the GA is repealed or lapses, in which case licensing will be necessary. For example, Government Notice No. 399 (GN399) of 26 March 2004 provides for GAs with respect to various water uses in terms of section 21of the NWA.

A.2.4.1.3 Licences (Sections 40 to 52)

A person who wishes to use, or who uses water in a manner that is not a Schedule 1 use, not covered under a GA, or in a manner that is not regarded or declared as an ELU, may only use that water under the authority of a license (section 4). The NWA makes provision for two types of applications for water use licences, namely individual applications and compulsory applications. The provisions applicable to an individual application for a water use license are described in sections 40 to 42 of the NWA. These sections also provide that a responsible authority may require an assessment by the applicant of the likely effect of the proposed water use on the resource quality, and that such assessment be subject to the Environmental Impact Assessment (EIA) regulations promulgated under section 26 of the Environment Conservation Act, 1989 (Act 73 of 1989) (ECA). In terms of sections 43 to 48 of the NWA, compulsory applications for licences will be required under certain circumstances (e.g. in catchment management areas which are under water stress) from all water users using a particular water resource or in a specific geographical area, irrespective of whether or not their water use has been authorised by a GA or an ELU. Compulsory applications for the authorisation of these water uses are subject to the development of a Water Allocation Plan, which needs to be prepared by the responsible authority.

In the event that the purpose of the NWA will be met by the granting of a license, permit or other authorisation under any other law, the licensing authority may either dispense with the requirement for a license in terms of section 22(3), or may combine the various license requirements of other organs of state into a single license (section 22(4)). These provisions are of particular importance with regard to certain multiple water uses (section 22(4)), such as may occur for underground mining, e.g. a mine may require water use licenses under sections 21(a), (b), (c), (f), (g) and (j).

Section 27 of the NWA specifies some factors that must be taken into consideration when considering a water use authorisation, including:

(a) existing lawful water uses
(b) the need to redress the results of past racial and gender discrimination
(c) the efficient and beneficial use of water in the public interest
(d) the socio-economic impact of the water use or uses if authorised of the failure to authorise the water use or uses
(e) any catchment management strategy applicable to the relevant water resource
(f) the likely effect of the water use to be authorised on the water resource and on other water users
(g) the class and the resource quality objectives of the water resource
(h) investments already made and to be made by the water user in respect of the water use in question
(i) the strategic importance of the water use to be authorised
(j) the quality of water in the water resource which may be required for the Reserve and for meeting alignment with the catchment management strategy
(k) international obligations, and
(l) the probable duration of any undertaking for which a water use is to be authorized.

These decision-making considerations are important when contemplating the prioritisation of a particular application, and when establishing preferences when evaluating competing applications for specific water uses.

Section 148(1)(f) of the NWA makes provision for an appeal to the Water Tribunal against a decision on a license application under section 41 by the applicant or any other person who has lodged a written objection against the application. If applicable, appeals against decisions on license applications may also be taken to the High Court.

A.2.4.2 Water use regulations

Government Notice No. 704 (GN704), regulations on use of water for mining and related activities aimed at the protection of water resources, was promulgated in terms of section 26 of the NWA on 4 June 1999. These regulations are covered in detail in **BPG AS: Water Management for Surface Mines** and are not covered here.

A.2.4.3 Dam safety requirements

Chapter 12 of the NWA contains measures aimed at improving the safety of new and existing dams with a safety risk so as to reduce the potential for harm to the public, damage to property or to resource quality. A dam with a safety risk means any dam which can contain more than 50 000 m^3 of water (irrespective whether such water contains substances or not) and which has a wall of a vertical height of more than 5 metres, or which has been declared as a dam with a safety risk under section 118(3)(a). Dam Safety Regulations published in Government Notice R.1560 of 25 July 1986, which are still in force under the NWA, require that dams with a safety risk must be classified into categories, and that licenses must be issued before any task relating to a specific category of dam may commence. These regulations also prescribe the conditions, requirements and procedures to classify, register, obtain a license to construct a new dam, impound a dam, or alter an existing dam. It further stipulates the requirements and responsibilities in respect of dam safety inspections, emergency procedures, recording and reporting.

A.2.4.4 Other important requirements in the NWA

Section 19 of the NWA further stipulates the general duty of care on persons who own, control, use or occupy land on which any activity or process is or was performed or undertaken, or any other situation exists which causes, has caused or is likely to cause pollution of a water resource, to take all reasonable measures to prevent any such pollution from occurring, continuing or recurring.

Section 20 deals with the reporting, containment and remedying of any incident or accident in which a substance pollutes or has potential to pollute a water resource or have a detrimental effect on a water resource. It further states that the CMA may take the necessary measures, if the remedial measures fail or inadequately comply, at the expense of the responsible person(s). Section 30 of the National Environmental Management Act, 1998 (Act 107 of 1998) (NEMA) stipulates similar requirements.

Sections 56 to 60 deals with water use charges and allows the Minister to establish a pricing strategy with charges for any water use to fund the direct and related costs of water resource management, development and use, and for achieving equitable and efficient allocation of water. These charges may be used to ensure compliance with prescribed standards and water management practices according to the user pays and polluter pays principles.

Provision is made for incentives for effective and efficient water use and could therefore be used as a means of encouraging reduction in waste and water wastage.

The Department of Mineral and Energy Affairs (DME) administrates the Mineral and Petroleum Resources Development Act, 2002 (MPRDA), but due to the major impact that mining can have on the environment, especially the water environment, DME is obliged to consult with DWAF with regard to certain decisions made in terms of this Act.

A.2.5 Mine Health and Safety Act (MHSA), 1996 (Act 29 of 1996)

Section 2(1) stipulates that the owner of a mine that is being worked must ensure, as far as reasonably practicable, that the mine is designed, constructed and equipped to provide conditions safe for operations and a healthy working environment and that the mine is commissioned, operated, maintained and decommissioned in such a way that employees can perform their work without endangering the health and safety of themselves or of any other person. Section 2(2) further stipulates that the owner of a mine that is not being worked, but in respect of which a closure certificate has not been issued, must take reasonable steps to prevent injuries, ill-health, loss of life or damage of any kind from occurring at or because of the mine. The Chief Inspector of Mines has the power to monitor and control those environmental aspects at mines that affect, or may affect, the health or safety of employees or other persons and is required to consult with the Director: Mineral Development concerning the exercise of those powers.

The above is reiterated in Section 5 which states that every manager must, to the extent that it is reasonable practicable:

- Provide and maintain a working environment that is safe and without risk to the health of employees
- Identify the relevant hazards and assess the related risks to which persons who are not employees may be exposed, and
- Ensure that persons who are not employees, but who may be directly affected by the activities of the mine, are not exposed to any hazards to their health and safety.

Regulation 2.10.15, promulgated in terms of the MHSA, stipulates that the appointed manager must ensure that in the construction of any dump or any slimes dam in the neighbourhood of any building, thoroughfare or other public road, railway or public place, no danger to life or limb or damage to property can result there from.

In terms of Section 9, a manager must prepare and implement a code of practice on any matter affecting the health or safety of employees and other persons who may be directly affected by activities at the mine if the Chief Inspector requires it. These codes of practices must comply with guidelines issued by the Chief Inspector.

According to section 11(1) every manager must:

- Identify the health and safety hazards to which employees may be exposed while at work
- Assess the health and safety risks to which employees may be exposed while at work, and
- Record the significant hazards identified and risks assessed and make these records available for inspection by employees.

Sections 11(2) and 11(3) states that the manager must determine and implement all measures necessary to:

- Eliminate the risk
- Control the risk at source
- Minimise the risk
- Provide protective equipment, and
- Institute a programme to monitor the risk.

A.2.6 Atmospheric Pollution Prevention Act, 1965 (Act 45 of 1965)

Part II of the Atmospheric Pollution Prevention Act, 1965 (APPA) describes the control of noxious and offensive gases, as described in sections 9 to13 and summarised below:

- Schedule 2 of APPA contains a list of scheduled processes
- Any operator of a scheduled process shall apply for a registration certificate from the Chief Air Pollution Control Officer (CAPCO) before operation to register the premises on which the scheduled process will be carried on
- Maximum allowable ambient level control measures and apparatus will be included as the conditions of the registration certificate
- The CAPCO will firstly issue a provisional certificate, valid for a certain period

- If the measures, apparatus and controls implemented are effective, the CAPCO will issue a final registration certificate which will be valid until changes to the process, plant or building takes place or until it is withdrawn by the CAPCO, and
- The holder of the certificates shall at all times comply with provisions of all certificates (provisional and final certificates).

Part IV of APPA deals with dust control and states that the owner or occupier shall take steps (prescribed) or if not prescribed, adopt the best practicable means to prevent the dust dispersion from causing a nuisance (Section 28). Further, if the CAPCO is of the opinion that any other dust generation, apart from that described in Section 28 (1) is causing a nuisance, an abatement notice may be served on the owner/occupier to take prescribed steps or to adopt best practicable means to abate such nuisance (Section 29).

Finally, according to Section 32, if a mine has received a notification of the Chief Inspector of Mines that the mine is likely to cease operations within 5 years, the owner of the mine may not dispose of any assets without a certificate issued by the CAPCO to the effect that that all necessary dust control measures has been taken, or without the consent of the Minister of Health in consultation with the DME. Any such disposal in contravention with above constitutes an offence.

A.2.7 Environment Conservation Act, 1989 (Act 73 of 1989)

Waste is defined in section 1 of the Environment Conservation Act, 1989 (ECA) as *any matter, (whether gaseous, liquid or solid, or any combination there-of) which from time to time may be proclaimed by the Minister (of Environmental Affairs and Tourism) by notice in the Government Gazette as an undesirable or superfluous by-product, emission, discharge, excretion, or residue of any process or treatment.*

Government Notice No. 1986 in Government Gazette 12703 of 24 August 1990 describes what is meant by waste in this context. This definition specifically excludes (and is therefore not applicable to mine residue deposits):

- Water used for industrial purposes as governed under the 1956 Water Act
- Any matter discharged into a septic tank or french drain sewerage system
- Building rubble used for filling or levelling purposes
- Any radio-active substances
- Any minerals, residue, waste rock or slimes produced at a mine, or
- Ash produced by or resulting from the generation of electricity.

Section 19 and 20 of the ECA deal specifically with waste management and pollution prevention.

A.2.8 National Heritage Resources Act, 1999 (Act 25 of 1999)

Section 34 stipulates that a permit is required from the relevant provincial heritage resources authority to alter or demolish any structure or part of a structure which is older than 60 years. Various other forms of protection may also apply.

A.2.9 National Nuclear Regulator Act, 1999

The National Nuclear Regulator Act, 1999 (NNR) is applicable to "facilities specifically designed to handle, treat, condition, temporarily store or permanently dispose of any radioactive material which is intended to be disposed of as a waste material". The following sections of the NNR are relevant to surface mines:

- Chapter 3 provides details on authorisations of facilities and the responsibilities of holders of nuclear authorisations. A licensing guide (LG-1032) has been published by the Council for Nuclear Safety (CNS). This guide provides details on the methodology for the assessment of nuclear hazards and guidance on submissions to the CNS
- Chapter 4 details the financial securities and liabilities that are applicable to holders of nuclear authorisations, and
- Chapter 5 provides information on safety and emergency measures.

A.2.10 Other Acts

The Conservation of Agricultural Resources Act, 1983 (Act 43 of 1983) and the Biodiversity Act, 2004 (Act 10 of 2004) are also relevant for mining.

A.3 SUMMARY OF APPLICABLE WATER MANAGEMENT POLICIES AND STRATEGIES

A.3.1 National Water Resource Strategy (NWRS)

The National Water Resources Strategy, 2004 (NWRS) is the implementation strategy for the NWA and provides the framework within which the water resources of South Africa will be managed in an integrated manner in the future. This strategy sets out policies, strategies, objectives, plans, guidelines, procedures and institutional arrangements for the protection, use, development, conservation, management and control of the country's water resources. The NWRS sets out the current government objectives for managing water resources in South Africa as follows:

- To achieve equitable access to water, that is, 1) equity of access to water services, 2) equity to the use of water resources, and 3) equity to the benefits from the use of water resources
- To achieve sustainable use of water, by making progressive adjustments to water use to achieve a balance between water availability and legitimate water requirements, and by implementing measures to protect water resources and the natural environment
- To achieve efficient and effective water use for optimum social and economic benefit.

The NWRS also lists important principles to facilitate achievement of these policy objectives, such as:

- Water will be regarded as an indivisible national asset. The Government will act as the custodian of the nation's water resources, and its powers in this regard will be exercised as a public trust
- Water required to meet basic human needs and to maintain environmental sustainability will be guaranteed as a right, whilst water use for all other purposes will be subject to a system of water use authorisation.
- The responsibility and authority for water resource management will be progressively decentralised by the establishment of suitable regional and local institutions, with appropriate community, racial and gender representation, to enable all interested persons to participate.

Water use for mining activities will be subject to the requirements of a water use authorisation. The benefits and need for this water use will be assessed in the context of the water availability and spread of water use in the catchment.

A.3.2 Catchment Management Strategies (CMS)

The country has been divided into 19 WMAs (see Figure A.1). The delegation of water resource management from central government to catchment level (as proposed above) will be achieved by establishing Catchment Management Agencies (CMAs) at WMA level. The NWRS requires that CMAs progressively develop a Catchment Management Strategy (CMS) for the protection, use, development, conservation, management, and control of water resources within its WMA(s). The Department's eventual aim is to hand over certain water resource management functions to CMAs. Until such time as the CMAs are established and are fully operational, the Regional Offices (ROs) of the Department will continue managing the water resources in their areas of jurisdiction.

The water management and water licensing issues for an underground mine will thus be dealt with by the Regional Office of the Department of Water Affairs and Forestry, until the CMAs are established and operational.

A.3.3 Internal Strategic Perspectives (ISP)

The objective of the Internal Strategic Perspective (ISPs) is to provide a framework for the management of the water resources in each WMA, until such time as the ROs can hand over the management functions to the established CMA. The ISP provides details on the Department's view on how Integrated Water Resource Management (IWRM) should be practiced in each WMA. This will ensure consistency when answering requests for new water licences, and informing existing water users (including authorities) on how the Department will manage the water resource within the area of concern. Stakeholders must be made aware of the bigger picture as well as the management detail associated with each specific water resource management unit.

The ISPs for each WMA provide details on the available water resources and the current and future use of the water resource. The ISPs thus provide useful catchment-based information to the planning and water management team on a mine.

A.3.4 Water Resource Availability and Utilisation in South Africa

This report provides an overview of South Africa's available water resources for 1996 and the current patterns of utilisation. This availability and utilisation has then been projected to 2030, based on the present trends in water use and population growth, indicating that South Africa will reach the limits of its economically usable, land-based fresh water resources during the first half of the century.

The report indicates that these trends can be changed to ensure the secure and adequate supply of water and to sustain the prosperity and natural environment of South Africa. Key recommendation made in the report in this regard include a) coordination of water allocation priorities with national development objectives and strategies for the country as a whole, b) greater emphasis be placed on water conservation and c) comprehensive programme to install a new appreciation of the value of water and the importance of the changed approach to the utilisation of water.

The details in the report include:

- A summary of the water requirements and resource potential for the various regions within the country
- Future options on availability and utilisation of water, and
- Recommendations on the way forward.

A.3.5 The Philosophy and Practice of Integrated Catchment Management: Implications for Water Resource Management in South Africa

The Department of Water Affairs and Forestry, through the NWA and the National Water Policy, have identified that naturally occurring water usually can be effectively and efficiently managed only within a river basin or catchment area, because of the need to manage, or at least account for, all aspects of the hydrological cycle. Thus, the Department recognises and accepts that an integrated catchment management (ICM) approach will be adopted in South Africa (DWAF, 1986). This approach is seen to facilitate the achievement of a balance between the interdependent roles of resource protection and resource utilization.

The document identifies the role of central government in Integrated Catchment Management (ICM) as being one of leadership, aimed at facilitating and co-ordinating the development and transfer of skills, and assisting with the provision of technical advice and financial support, to local groups and individuals. Where specific areas of responsibility fall outside the mandate of a single government department, appropriate institutional arrangements are required to ensure effective inter-departmental collaboration. At a lower level in this process, individual landholders and communities must be recognized as competent partners. Where these individuals may lack the necessary skills for full participation, the lead agencies must take responsibility for assisting with their development and application.

The document identifies five basic principles for effective ICM as follows:

- A systems approach which recognizes the individual components as well as the linkages between them, and addresses the needs of both the human and natural systems
- An integrated approach, rather than a comprehensive approach, in which attention is directed towards key issues of concern identified by all stakeholders in the process
- A stakeholder approach which recognizes the importance of involving individual citizens and landowners, as well as government agencies, in a participatory process to define all decisions around the conservation and use of natural resources which affect their lives
- A partnership approach which promotes the search for common objectives, and defines the roles, responsibilities and accountabilities of each agency and individual who participates in the process of decision making, and
- A balanced approach where close attention is given to decisions designed to achieve a sustainable blend of economic development, protection of resource integrity, whilst meeting social norms and expectations.

A.3.6 A Strategic Plan for the Department of Water Affairs and Forestry to Facilitate the Implementation of Catchment Management in South Africa

The Strategic Plan provides the Department of Water Affairs and Forestry with a strategic plan to facilitate the implementation of the concept of ICM. The philosophy of managing water resources on an ICM approach is taken as a guiding principle in the strategic plan.

The strategic plan document is divided into two parts, namely part I which is designed to meet urgent management interests in the form of an Implementation Strategy, a Programme of Activities and a Schedule of Human Resources, and Part II which provides the motivation and context for individual proposals in Part I.

The strategic plan provides details on the concepts, functionalities and institutional structures surrounding "Integrated Water Resource Management on a Catchment Basis", as follows:

- Framework for IWRM in RSA which will evolve in a three-tiered framework comprising a National Water Resources Strategy (NWRS), a Statutory Framework for CM and CM Processes/ Strategies/ Plans in particular catchments
- CM Functions: Three classes of CM Functions are distinguished, namely Core, Physical Development and Administrative functions, and
- Institutional Context and Evolution of CM: the Department is foreseen to play a leading role regarding CM, both through a National CM Facility (Directorate), and through the Regional Offices.

A.3.7 Towards a Strategy for Waste Discharge Charge System (WDCS)

The Waste Discharge Charge System (WDCS) forms part of the Pricing Schedule for Water Use Charges established in terms of section 56 of the NWA and will be introduced to address the particular issue of excessive water pollution.

The resource quality objectives (RQOs) form the integral basis and fundamental principle of the WDCS. Water resource management in South Africa links the acceptable level of impact to the concept of RQOs, which balance the need to protect water resources with the need to develop and use these resources. The setting of RQOs is catchment specific, based on the social, economic and political drivers for development and utilisation of a specific water resource. RQOs are to be set as part of the classification system for water resources, through a process of consensus seeking among water users and other stakeholders, in which the government is responsible for ensuring that environmental interests are represented. The WDCS will therefore focus on reducing discharge loads in order to achieve or maintain RQOs in a catchment. Where RQOs are being met, the WDCS is not applied. Where RQOs are exceeded or in threat of being exceeded, the WDCS may be applied as part of water quality management in the catchment. The WDCS applies to surface water and groundwater resources where RQOs have been defined and an adequate understanding of the resource supports the implementation of the system.

The WDCS will be applied to a particular catchment area in which a water quality problem exists. This could be a whole catchment in which a widespread water quality problem occurs or a sub-catchment within a larger water basin.

Where downstream RQOs are more stringent than upstream RQOs, and downstream RQOs are exceeded or threatened, the WDCS may be applied in the upstream catchment even if the upstream RQOs are achieved.

The implementation of the WDCS will achieve the following supportive and additional objectives:

- To encourage efficient resource utilisation (incentive objective)
- To recover costs of activities aimed at pollution abatement and damage caused by pollution (financial objective)
- To discourage excessive pollution (deterrent objective), and
- To promote sustainable water use (social objective).

Four levels of discharge charges are envisaged in the strategy, as follows:

- Tier 1: Basic/Administrative charge: this charge will cover the administrative and management functions in the catchment,
- Tier 2: Load-based charge, for pollution loads higher than the Recommended Resource-Directed Value (RRDV) for the catchment, and
- Tier 3 and 4: Deterrent charges for pollution loads higher than the Maximum Allowable Resource-Directed Value (MARDV).

The Department will use the WDCS as a tool for source control and management, which will provide the following benefits:

- A strong financial incentive to reduce pollution loads to the water resource, particularly if the pollution loads discharged are in excess of the RRDV and the MARDV, and

- The revenue from the WDCS will be ring-fenced to cover water quality management work within the Department. This work will include rehabilitation and remediation projects, waste abatement work (such as regional treatment facilities or on-site pollution prevention or treatment) and investigative studies.

A.3.8 Water Conservation and Water Demand Management (WC/WDM)

The management of water resources and the provision of water services culminated in a new approach which Water Conservation and Water Demand Management (WC/WDM) plays a crucial role in ensuring environmental sustainability, socio-economic equity and efficiency. The NWA and Water Services Act, Act 108 of 1997, (WSA) has provided an enabling environment in which all relevant institutions could be required to integrate WC/WDM into their strategic roles and responsibilities. It is thus a requirement that mines (and other water use sectors) consider WC/WDM during all life cycle phases and strategies. In this instance the DWAF has compiled three sectoral strategy documents, complementary to the present National Water Conservation and Water Demand Management Strategy, namely:

- Agriculture
- Water Services, and
- Industry, Mines and Power Generation.

These documents provide detailed information in terms of strategic outputs, prioritised activities and key role-players. The NWC/WDMS objectives to be achieved by each sectoral strategy include:

- To facilitate and ensure the role of WC/WDM in achieving sustainable, efficient and affordable management of water resources and water services
- To contribute to the protection of the environment, ecology and water resources
- To create a culture of WC/WDM for all consumers and users
- To create a culture of WC/WDM within all water management and water service institutions
- To support water management and water services institutions to implement WC/WDM
- To promote the allocation of adequate capacity and resources by water institutions to WC/WDM
- To enable water management and water services institutions to adopt integrated planning, and
- To promote international co-operation and participate with other Southern African countries, particularly basin-sharing countries in developing joint WC/WDM strategies.

The Industry, Mining and Power Generation sector, because of its diversity, is considered to offer numerous opportunities for contributing towards WC/WDM. Such opportunities include the efficient use of water during industrial production, re-use of water, recycling of water from other sectors and improved quality of effluent discharge.

A.3.9 Water Allocation Reform

As custodians of the national water resource, the DWAF is obliged to promote the beneficial use of water in the best interests of all South Africans.

In order to do this, water allocations must be carried out in a manner that promotes equity, addresses poverty, supports economic growth and provides opportunities for job creation. The allocation process recognises that redressing the effects of previous discriminatory legislation is necessary for social stability and to promote economic growth. Moreover, the water allocation process must allow for the sustainable use of water resources and must promote the efficient and non-wasteful use of water.

However, allocating water without ensuring that all users have the capacity to use this water productively will limit these benefits. Water allocations should, therefore, not only aim at realising the above goals, but must work closely with all spheres of government and other institutions to promote the productive and responsible use of water. Likewise, where possible, water reallocations should try to minimise possible negative impacts on existing productive lawful water users who are contributing to social and economic stability, growth and development. Water allocations must promote shifts in water use patterns that are equitable but also phased and carefully considered.

These objectives go well beyond the Department's primary mandate and require the active pursuit of cooperative governance arrangements to support the productive use of water. Accordingly, approaches to reallocating water between users will initially be rolled out in areas experiencing shortages of water. However, in order to address the urgent short-term need for equity across the country, rollout will also be fast-tracked in areas where there are less serious water availability concerns. These implementation approaches take into account the prevailing resource and capacity constraints within the Department and our country.

A.3.10 Water Classification System

The water classification system using A to F ecological categories has been used for preliminary Reserve determinations. A need had been expressed for a classification system that integrates ecological and user requirements into management classes and which allows for the examination of the socio-economic and ecological implications of water management decisions. The National Water Resource Classification System (NWRCS) is a set of guidelines and procedures for determining the desired characteristics of a water resource, as represented by a Management Class (MC). The MC outlines the attributes that the responsible authority and society require of different water resources. The NWRCS will be used in a consultative approach with all relevant stakeholders to classify water resources in order to facilitate a balance between protection and the utilisation of the water resource.

The outcome of the water classification process incorporating economic, social, ecological and stakeholder consent will be promulgated by the Minister or her delegated authority setting the MC for every significant water resource, which will be binding on all authorities or institutions when exercising any power, or performing any duty under the NWA. The MC of a resource sets the boundaries for the volume, distribution and quality of the Reserve as well as Resource Quality Objectives. The MC ranges from Natural to Heavily Used/Impacted and essentially describes the desired ecological condition of the resource, and conversely, the degree to which the resource could be utilised.

A.3.11 The National Groundwater Strategy

The groundwater quality management strategy forms part of the DWAFs National Water Resource Strategy. South Africa's water resources are very unevenly distributed across the country, and in arid or water-scarce areas. The value and vulnerability of groundwater represent a strategic component of the water resources of South Africa. Security of groundwater supplies is thus essential and protection of groundwater has become a national priority.

It is common for groundwater to be poorly managed. It takes a long time to detect that it has become polluted and groundwater has only limited ability to purify itself. It is difficult, often impossible, and also very expensive to restore polluted groundwater to its original quality. The major reason for poor management of groundwater resources, however, has been a lack of a structured approach to management as well as a lack of knowledge and information about groundwater.

In order to manage groundwater quality in an integrated and sustainable manner within the context of the National Water Resource Strategy and thereby provide an adequate level of protection to groundwater resources and secure the supply of water of acceptable quality, the DWAF has identified the following policy goals:

- To implement source-directed controls to prevent and minimise, at source, the impact of development on groundwater quality by imposing regulatory controls and by providing incentives
- To implement resource-directed measures in order to manage such impacts as do inevitably occur in such a manner to protect the reserve and ensure suitability for beneficial purposes recognized, and
- To remedy groundwater quality where practicable to protect the reserve and ensure at least fitness for the purpose served by the remediation.

Principles that will guide the implementation of this strategy include subsidiary and self-regulation, pollution prevention, integrated environmental management, equity, sustainability, the polluter pays, and public participation.

APPENDIX B
WATER MANAGEMENT MODELING FOR UNDERGROUND MINES

This Appendix has been taken from BPG A5: Water Management for Surface Mines as it is also directly relevant and applicable to underground mines.

B.1 BASELINE INFORMATION

Table B.1 identifies the likely information requirements for water management modeling and design of the water management measures.

Table B.1: Baseline information requirements

Design area	Information Requirements
Mine planning	• Layout of the mine and supporting infrastructure • Location of shafts, underground workings, processing plants and water and waste management facilities
Hydrology and stormwater	• Climate data: Patterns of temperature, rainfall, evaporation and atmospheric moisture for the area • Reports, documents and maps on the hydrology of the area • All available river flow data • Surface water quality information • Downstream water users and their quality criteria • Resource quality objectives for the affected catchment(s).
Water balance	• Reports and documents on the mine water balance • Water flow and water quality measurements or predictions • Ambient water qualities
Geotechnical	• Reports and documents on the geology and geotechnical conditions for the area
Hydrogeology	• Published and unpublished geological and hydrogeological reports, maps and documents • Borehole positions, logs and well construction details • Details of groundwater abstractions and groundwater users in the area • Conceptual and/or detailed groundwater models • Recharge estimations • Groundwater quality information • Any available monitoring data
Mine residue	• Annual anticipated tonnage and overall total tonnage • Life of mine • Results of any testwork on the mine residue • Residue characteristics, such as particle size distribution, dry density, etc. • Mine residue deposit details, e.g. footprint area, rate-of-rise
Geochemical	• Reports and document on the geochemical properties of the residue, e.g. particle size distribution, porosity, moisture content including soil moisture retention tests, mineralogy, acid base accounting, kinetic data, etc. • Geotechnical conditions for the area • Ambient water quality
General	• Archaeological sites within the mine area • Wetlands and ecologically sensitive areas

The baseline information that is collected should meet the following objectives:

- Provide an understanding of the regional water resource context in which the mine is to operate
- Identify the potential sources of water for the project
- Delineate the study area for the water management
- Determine the hydrological and groundwater data availability
- Identify gaps in the database and implement monitoring to fill these gaps
- Prepare base maps for use in the study, and
- Identify the water courses that could be impacted by mining.

The baseline information that should be collected is likely to include the following:

- The location of mine working, mine lease and surface rights areas as well as towns, roads, rivers and water supply infrastructure
- Determination of the water volume and water quality mine water requirements
- Topographical map of the area (1:50 000 and 1:250 000 scale)
- Land use, geological and soil maps of the area
- The mine plan
- A definition of study area, which is the area of potential impact of the mine. During the conceptualisation and planning phase, the available information should be used to provide an estimate of the study area. A conservative estimate should be made at this stage. The extent of the area can be revised as baseline data becomes available
- Discussions with the regional offices of DWAF should also be held so that the water situation, in particular the regional context and the possible sources of water for the project can be obtained. Information on the catchment management strategy, future water resource developments, ecological Reserve data and reports should be collected and reviewed
- Identification of flow and water quality sampling points in the study area and collection of data from the DWAF databases
- Collection of data from the groundwater databases of DWAF
- Establish the location of rainfall gauges and weather stations that could be used in the development of water management measures. Any data from these monitoring stations should be collected and assessed
- A hydrocensus of boreholes in the study area should be undertaken. The information collected includes location of boreholes, borehole yield, borehole owner, type of pump, water level, water quality data and use of water abstracted from the borehole
- A surface water user survey in the study area
- Collection of surface water samples for water quality analysis and flow measurements of streams in the area
- Establishment of closure objectives for the mining operation
- The available data should be reviewed and a gap analysis undertaken. The following could be the result of this analysis:
  - Ongoing groundwater data collection for water levels and water quality
  - Drilling of further boreholes. These boreholes can be linked to the geotechnical and mineral resource studies.
  - Required pump tests on boreholes to determine yields and determine the aquifer properties for use in the groundwater modeling
  - Surface water flow monitoring program. This may require the installation of weirs to characterise the rainfall - runoff characteristics of the catchments and the flow regimes. This data can be used to calibrate a rainfall – runoff model for use in the water management modeling for the mine
  - Surface water quality monitoring program. This program should be designed to capture the seasonal variation in water quality of the water courses and water supply to users that could be impacted on by the planned mining operations. If the local water resource is to be developed as a source of supply for the mine then the program should be sufficiently detailed to supply the mine's needs. An iterative process should be used to determine the water quality variables that need to be included in the analysis. This process starts with analysing for a comprehensive set of variables. The initial set tested for will be revised depending on the results of the analysis
  - A weather station and a rain gauge system should be installed if needed. The rain gauges should be located to provide information for use

in conjunction with the flow measurements for rainfall-runoff model calibration
  - Soil surveys of area to quantify the types and quantities of soil in the area, and
  - Biomonitoring of the river ecology.
- The available hydrological and climate data should be analysed. The following information is needed from the database
  - The Mean Annual Precipitation of the site should be determined as well as the average monthly rainfall depths, and
  - The average monthly pan evaporation depths.
- A representative daily rainfall record at least 50 years long should be synthesised from the available rainfall data records.

B.2 INTEGRATED WATER MANAGEMENT MODELING

B.2.1 Conceptualisation and Planning Phase

B.2.1.1 Objective

The objectives of the water management modeling at this phase are to establish the following:

- Preparation of an initial water management layout and sizing of the water management system
- The mine water requirements for processing
- Potable water requirements
- Initial layout of mine infrastructure
- Initial layout of waste facilities
- Clean and dirty water catchment areas
- Identify sources of water supply
- Establish the hydrological database for use in the water management modeling. The main elements are rainfall and evaporation.

B.2.1.2 Preparation of hydrological database

The water management modeling for this phase will involve an assessment of the rainfall data to produce the following:

- Monthly average rainfall depths and mean annual precipitation. The dry, median and wet years should be identified from the record and the average rainfall depths identified for each of these years
- A statistical analysis of the daily rainfall depth time series to produce the 2 year, 5 year, 10 year, 20 year, 50 year, 100 year and probable maximum precipitation (PMP) information. This information is required for the tailings dam and pollution control dam safety assessments
- Intensity-duration-frequency curves developed for the site
- A daily and monthly time series of rainfall depths for the site. These are required to drive the water management models. A rainfall time series in excess of 50 years is ideally required
- Monthly average evaporation depths are needed for the water management modeling to determine evaporation from pollution control dams and in soil moisture budgets for catchment runoff modeling and covers for rehabilitated surfaces.

B.2.1.3 Determination of flood lines

The 1:50 and 1:100 year flood lines for the water courses passing over the mine site should be determined. The 50m and 100m exclusion zones should also be determined and located on the mapping.

B.2.1.4 Water management modeling

The contour mapping of the area showing the layout of the mine infrastructure will be used to identify the clean and dirty catchment areas. The catchment areas should be measured and the locations of pollution control facilities and diversion channels and berms should be provisionally located on the maps. The process plant design team should provide an estimate of the water volume and water quality requirements of the process plant and the mass and characteristics of the waste streams.

At this stage there could be a number of teams involved in the project. The battery limits of the different teams as far as water management is concerned should be clearly established. The type of information and level of analysis that is required from each team should also be established. A design criteria and assumption register should be established for the project.

The water management modeling at this stage of the project is best done at a monthly time step using the average monthly rainfall depths for the dry, median and wet years. A spreadsheet model can be set up for the mine system. The model should include the major elements making up the system. A number of the elements change in size over the life of the mine. Sizes of these elements at specific points in time over the life of the mine can be used in the model. Simple algorithms such as the use of runoff factors should be considered for application to catchment areas.

The preliminary waste stream characteristics will be used to determine the entrainment volumes in the waste management facilities and water volumes returned. At this stage, with the absence of any geochemical data, water quality is likely not to be considered in the analysis.

The water management model will be applied for the different years at a monthly time step to determine the preliminary sizes of pollution control dams, return volumes available from the dams and the make-up water requirements for the project over the life of the project. The need for a discharge from the mine must also be identified. The results of the analysis will be used to revise the layout where necessary and locate the pollution control facilities. A source of water supply to meet the water needs of the mine should be identified.

The possibility of developing a groundwater or surface water source, abstracting from existing infrastructure and/or receiving water from adjacent mines should be investigated. The most likely source should be identified and a preliminary analysis undertaken on the feasibility of supply from the source and the type of infrastructure needed to supply the required water.

The information gaps should be identified and studies or monitoring programs put in place to fill the gaps. At this stage the progress with the water management study should be communicated to the regulator.

B.2.2 Pre-Feasibility Phase

B.2.2.1 Objective

The objective of this phase of the study is to further refine the output from the water management model developed during the conceptualisation and planning phase, based on the information generated during this phase.

B.2.2.2 Water management modeling

The information that should be available at this stage of the project, which will be used in the water management modeling, will include the following:

- A pre-feasibility mine plan, including details on the mining methods and other mines in the vicinity to cover aspects such as intermine flow considerations and demands/pollution of the same water sources
- Updated process plant water requirements
- Revised layouts of the plant infrastructure
- Results of the groundwater investigations and modeling, including the results of the pit dewatering assessments
- Initial geochemical results
- Water quantity and quality information from the baseline monitoring, and
- Updated characteristics of waste streams.

The water management model should be progressed to a higher level of accuracy during this phase, using the above information. A daily time-scale for the model would be appropriate at this stage in the mine development. The model should include the details from the pre-feasibility mine plan and the revised infrastructure plot plan. The different elements of the prospective mine water balance for the underground workings should be included, specifically water ingress into the mine, water usage and quality for mine cooling and mine service water, projected water quality deterioration through the different uses, inclusion of any distinguishing geochemical data that has been obtained for the orebodies to be mined. Other water requirements, such as potable water use, should also be included in the model.

The water requirements for the process plant should be reviewed at this stage, including water quantity, any water quality constraints and the interaction with the mine service water. The results of the groundwater studies will provide input to the assessment of water make in the undergound mine. The water quality model should be developed at this stage, using the first round of geochemical results, the water quality information from the baseline monitoring and the updated characteristics of the waste sources and management requirements. Any results from rainfall-runoff modeling should also be used to calibrate the model.

With the input data updated, the model should be run so as to size the water management infrastructure to meet the design criteria of Government Notice No. 704 (GN704), regulations on use of water for mining and related activities (See also ***BPG A4: Pollution Control Dams*** for guidance on spill criteria). Details of the sizing should be sent to the design team to confirm the location and layout of this infrastructure. Some iteration may be required to optimise the size, location and layout of the infrastructure to suit local conditions.

The output of the water management model should be used to identify the need and quantity of water supply to the mine and the need to discharge to a watercourse. Pre-feasibility level design of the water supply, and an impact assessment of any discharge, should be undertaken at this stage.

The design team should also liaise with the regulator to start preparing the water use licence application for the various water uses, e.g., water abstraction, water storage, discharge, etc.

B.2.3 Feasibility Phase

B.2.3.1 Objective

The objective of this phase will be to revise the water management model with the latest information from the feasibility study work.

B.2.3.2 Water management modeling

The water management modeling will follow the same approach as covered above with the new information. The water use licence application should be prepared and submitted during this phase.

B.2.4 Design Phase

B.2.4.1 Objective

The objective of this phase will be to prepare water monitoring programmes for the construction and operations phase.

B.2.4.2 Water management modeling

The infrastructure plot plan will be updated during the mine design phase. Using this information and the water management model, the design team should:

- Develop operating rules for the water infrastructure,
- Identify and design the water supply system for the construction phase,
- Undertake detailed design of the water management infrastructure
- Develop a water quantity and quality monitoring programme for the construction and operations phases of the mine. Further information on developing such a programme is provided in ***BPG G3: Water Monitoring Systems***, and
- Identify and design (at a preliminary level) the water management measures required for mine closure.

B.2.5 Construction and Commissioning Phase

B.2.5.1 Objective

The objective of this phase will be to develop water management programmes for the construction phase.

B.2.5.2 Water management modeling

The water management model will be used during this phase to prepare and implement water management measures during construction. These will be implemented to manage the quantity and quality of the water supply for construction, as well as the management of any waste stream from construction.

B.2.6 Operational Phase

B.2.6.1 Objective

The objective of this phase is to update and/or amend the water management model developed at the design stage to an operational model.

B.2.6.2 Water management modeling

The water management model should be updated to reflect the “as-built” conditions on site, following the construction phase. The model will thereafter be regularly updated during the mine operational phase, as changes are made in the mine plan and the infrastructure layout and additional water-related information become available.

The generic steps that will be followed during the operations phase are as follows:

- Collection of data from the monitoring programme (water quantity, water quality, volumes in the raw water dams and process water dams and meteorological data)
- Input of the collected data into the water management model. This data will be used to check the assumptions made in the model and to calibrate the model
- Apply the water management model, using monthly predictions, to assess the short-term operations of the water management system
- Use the water management model to manage the water on the mine site to meet the regulatory requirements, and
- Update the water management measures required for mine closure.

Consideration should be given during operations to managing the water systems on the mine using real-time data collection and use of information in the model.

B.2.7 Closure Phase

B.2.7.1 Objective

The objective of this phase will be to confirm the design of the water management measures for mine closure.

B.2.7.2 Water management modeling

The calibrated water management model should be used to:

- Confirm the predictions of water management used in preparing the mine closure plan
- Undertake an assessment of the water management requirements for mine closure
- Design the water management measures required for mine closure, and
- Develop cost estimates of the water management measures, to include in the overall quantum of financial provisions for closure to be made by the mine.

APPENDIX C
UNDERGROUND
NEUTRALIZATION

C1. INTRODUCTION

Neutralization is the process whereby the pH of acid or alkaline water is corrected, usually by chemical addition, towards a neutral pH of 7. The phenomenon and mechanisms of acid mine drainage (AMD) are well documented and the occurrence of acid water is one of the biggest water management problems in the mining industry. Neutralization may be applied to this water for any of the following purposes:

- treatment of effluent prior to its discharge to the environment.
- adjustment and control of pH as pretreatment for a downstream unit process, such as flocculation for underground settling.
- pH and carbonate correction to reduce scaling or corrosion characteristics.

The chemistry of neutralization is complex but an elementary understanding is essential if the various neutralization techniques are to be understood.

C2. CHEMISTRY AND RELATED CONCEPTS

In order to understand the process of neutralization it is useful to explain the chemistry and theory of pH. Although the control of scale and corrosion is only one objective of neutralization, the concepts are included in this section as an understanding of the chemistry is essential in implementing successful treatment processes. The concepts are also discussed, at various levels of detail, in the numerous texts which are available on the subject[(1),(2),(3)].

C2.1 pH Chemistry

Pure water consists of H_2O molecules as well as the dissociated ions, H^+ (hydrogen ion) and OH^- (hydroxide) which result from the reversible reaction

$$H_2O \longleftrightarrow H^+ + OH^- \tag{1}$$

When a reversible reaction is at equilibrium, the rates of the forward and reverse reactions are equal and for the example of water dissociation (1), the following expressions can be written.

$$\text{Rate of forward reaction} = k_1[H^+][OH^-] \tag{2}$$

$$\text{Rate of reverse reaction} = k_2\,[H_2O] \tag{3}$$

where k_1 and k_2 are rate constants. At equilibrium, and according to the Law of Mass Action, equations (2) and (3) become

$$[H^+][OH^-] = k_2/k_1 = K \tag{4}$$

where K is known as the thermodynamic dissociation constant. This factor can also account for the concentration of water molecules, $[H_2O]$ which can be considered as constant, due to the fact that the dissociation of water is weak. The value of K at 23 ˚C is 1×10^{-14} mole litre^{-1} and in a neutral water this implies that

$$[H^+] = [OH^-] = 10^{-7} \text{ mole litre}^{-1}$$

From the definition of pH as pH = $-\log_{10}[H^+]$ it follows that a neutral water will have a pH of 7 and an acidic water, with a high concentration of H^+ ions, will have a pH < 7. This is, however, a simplified interpretation of neutrality as there are other complicating factors which are discussed below.

C2.2 Carbonate Chemistry

Water contains various dissolved species and ions, the most important of which, from a neutralization aspect, include CO_2, H_2CO_3, HCO_3^-, CO_3^{2-}, Ca^{2+}, $CaCO_3$, H^+ and OH^-. These species comprise the carbonate system, the intricate balance of which is governed by complex chemistry, beyond the scope of this review. It is necessary however, to include a discussion on the role of carbon dioxide, CO_2 and bicarbonate, HCO_3^- in particular, in order to gain a full understanding of acidity and alkalinity.

Carbon dioxide is present in the atmosphere and is a product of fuel combustion processes and respiration. The concentration in soil is much greater as a result of soil organism respiration. Dissolved CO_2 reacts with water to form the weak acid, carbonic acid, which then dissociates into the hydrogen and bicarbonate ions according to reaction (5).

$$CO_2 + H_2O \longleftrightarrow H_2CO_3 \longleftrightarrow H^+ + HCO_3^- \qquad (5)$$

This water is able to dissolve magnesium and calcium from dolomite, which is a combination of calcium carbonate and magnesium carbonate as shown below.

$$CO_2 + H_2O + MgCO_3 \longrightarrow Mg(HCO_3)_2 \longleftrightarrow Mg^{+2} + 2(HCO_3^-) \qquad (6)$$

$$CO_2 + H_2O + CaCO_3 \longrightarrow Ca(HCO_3)_2 \longleftrightarrow Ca^{+2} + 2(HCO_3^-) \qquad (7)$$

The calcium and magnesium ions are responsible for the hardness of the water and the bicarbonate ions, along with carbonate ions, CO_3^{-2}, give the water most of its alkalinity.

C2.3 Alkalinity and Acidity

Alkalinity is the acid neutralizing capability of water. It is equal to the amount of standard strong acid which would be required to take the water to a defined end point. This end point may be the methyl-orange end point, which is approximately pH 4.5 depending on the initial condition of the water, and this alkalinity is then termed M alkalinity. P alkalinity is determined by titration to the phenolphthalein endpoint of pH 8.4. The relationship between these two values gives an indication as to the quantities of alkaline hydroxides, carbonates and hydrogen carbonates in the sample according to Table C1.

Table C1: Contributions of various ions to alkalinity

Dissolved Salts	P Alk = 0	P Alk < M Alk/2	P Alk = M Alk/2	P Alk > M Alk/2	P Alk = M Alk
OH^-	0	0	0	2 P Alk - M Alk	M Alk
CO_3^{2-}	0	2 P Alk	M Alk	2(M Alk - P Alk)	0
HCO_3^-	M Alk	M Alk - 2 P Alk	0	0	0

The buffering capacity is closely related to the amount of alkalinity in the water where buffer capacity is the ability of the water to absorb acid without a substantial decrease in pH.

Acidity is defined as the base neutralizing capacity of the water and is determined by the following expression:

$$\text{Acidity} = CO_2 + H_2CO_3 + HCO_3^- + H^+ - OH^- \qquad (8)$$

where these terms are usually expressed in mg/*l* as $CaCO_3$. This end point is more difficult to determine and acidity is thus seldom measured.

C2.4 Scale and Corrosion

The term saturation pH which is denoted as pH_s, refers to that pH value of a water in which the product $[Ca^{2+}][CO_3^{2-}]$ is equal to the solubility product constant for the precipitation reaction of $CaCO_3$. In the over saturated condition, there is a tendency for the precipitation to form and the water is known as scale forming or protective. In this condition the distribution of CO_2 within the water is such that the concentration of free CO_2 is lower than that required at equilibrium. The formation of scale is prevented by treatment which is aimed at decreasing the pH, softening or removal of carbonates.

Conversely, at a pH value less than pH_s, the water tends to be corrosive and is known as an aggressive water. The low pH is due to an excess of CO_2, which is in excess of that required for the saturated condition. Neutralization treatment aims either to remove or transform this excess CO_2.

There are several graphical methods available to determine whether a water is aggressive or scale-forming, the simplest of which is the Langelier diagram which accounts for temperature, ionic strength and alkalinity concentrations. Langelier also established the Langelier Saturation Index (LSI) which is simply the difference between the actual pH and the saturation pH, denoted pH_s.

$$LSI = pH - pH_s \qquad (9)$$

From the preceding discussion, it is can be deduced that a negative LSI implies a condition in which any calcium carbonate, which has been precipitated, is stripped away. A positive LSI implies a scale-forming, protective condition. Under certain conditions this may be an over-simplification and in 1944 Ryznar proposed a new index known as the Ryznar Stability Index (RSI).

$$RSI = 2pH_s - pH \qquad (10)$$

where the following relationships hold:

RSI = 6,0 (water stable)

RSI > 7,5 (corrosion is marked)

RSI > 9,0 (corrosion may be serious)

RSI < 6,0 (scale forming condition)

The determination of pH_s is complex and various simplifying methods of calculation and interpretation of calcium carbonate saturation[4, 5, 6] exist. Computer programs are also available to facilitate these calculations.

C3. OBJECTIVES OF NEUTRALIZATION

Neutralization treatment is applied with the objective of correcting pH, either as pretreatment for a downstream process, or prior to final discharge to the receiving environment, or as a stabilization process for scaling or corrosive waters.

C3.1 pH Correction for General Use or Discharge

According to the general effluent standard, the pH of highly alkaline or acidic waters needs to be corrected before it is discharged to the environment. The standards are fairly lenient in terms of pH and the permissible range is between 5.5 and 9.5. If the water is intended for other use, then different standards apply. In terms of mining applications, these ranges are specified in the COMRO guidelines for various end-uses. These values are summarized in Table C2 below.

Table C2: Recommended pH limits for various applications

Application or end use	Recommended pH range
SABS Drinking water	6 - 9
General Effluent Standard	5,5 - 9,5
COMRO (Mine service water)	5,5 - 8,5
COMRO (Hydropower - carbon)	6 - 8,5
COMRO (Hydropower - galvanised	7 - 8,5
COMRO (Cooling water -copper)	5,5 - 8,5
COMRO (Cooling water - stainless)	3,0 - 8,5
COMRO (Cooling water - titanium)	1,0 - 8,5

C3.2 pH Correction as Pretreatment

Many processes such as coagulation, flocculation, sedimentation and filtration are directly or indirectly affected by the pH of the influent water. In particular, the upstream flocculant dosing of underground settling and surface thickening is susceptible to pH. Effective control thereof is essential in reducing both chemical dosing costs as well as the indirect costs due to abrasion, through high suspended solids contents. Flocculants, particularly the commercial polymer varieties, are expensive and the payback time of an effective pH control system can be very short. The control is however, dependant on which neutralization process is used and particular problems are discussed in the relevant section. The effect of neutralization on floc generation is discussed in the literature[7] and the subject of flocculation and settling is discussed more fully in a separate literature review.

C3.3 Stabilisation of Scaling or Corrosive Waters

The conditioning of waters which are scaling or corrosive is perhaps the most important of neutralization objectives in terms of possible cost savings. The problems of scale formation in the mining industry are well studied[8],[9] and the direct costs of scaling type waters are due to the increased pumping costs as well as increased maintenance required for the periodic removal of scale and pipe cleaning. However, these costs are negligible in comparison to the replacement costs of pipelines, vessels and pumps which are subjected to corrosive conditions. These problems are well documented for both the mining industry[10, 11, 12, 13] as well as other sectors[14, 15]. It is clear from the brief chemistry background given in Section C2 that the scaling and corrosion tendencies of the water are dependant on the carbonate balance, which is pH dominated. The choice of neutralization process is therefore not as straightforward as that for simple pH correction treatment.

C4. METHODS OF NEUTRALIZATION

There are both chemical and physical methods of adjusting the carbonate balance and achieving a more stable water, although only chemical methods are employed in underground mines.

Neutralization can be achieved through the addition of alkaline or alkaline-earth based reagents. Some of the properties, advantages and disadvantages of the three most common neutralization chemicals are summarized in Table C3. A fuller discussion of the neutralizing capacities of sodium and calcium based products is given in the literature[16]. These and other properties are discussed below.

C4.1 Lime

Lime may be bought in a variety of forms depending on the quantities required and local availability. Commercial, hydrated lime ($Ca(OH)_2$) is expensive and will only be used where small quantities are required. Usually, it is bought in the pebble form called quicklime (CaO) which may be railed or trucked to the mine and stored in large silos. This quicklime is prepared by slaking which essentially involves the addition of water into a slurry form. Slaking has the additional advantage of rendering the lime more manageable by eliminating dust problems.

Although lime is the cheapest of the neutralization chemicals, this advantage is often negated by poor management underground. There is a longer reaction time which is often overlooked in the design of settler feed launders, for instance. In this case, the aim of neutralization is to raise the feed pH to a level at which the chosen flocculant operates optimally. The pH is often measured too close to the dosing point, with the result that the lime has either not mixed completely or, has not reacted completely. The measured pH is then observed as being too low and additional, unnecessary lime is dosed upstream. Factors such as insufficient mixing due to lime's low solubility, poor baffle and launder design compound this problem. Many mines have installed automatic lime dosing control systems with feed back from continuously monitoring pH probes. The problems of insufficient reaction time and mixing are however, still applicable to automatic control systems. Such a system is further disadvantaged however, by the hostile conditions encountered underground. Humidity and lack of maintenance of the pH probe are the major problems which have too often resulted in failure of the control system and subsequent abandonment.

A further problem with neutralization as pretreatment for flocculant dosing is the massive variations encountered in feed flowrate to the settlers. Although proportional weirs as described by various authors[17,18] alleviate this problem to some degree, manual dosing, as a response to some downstream pH measurement, is inadequate. The ideal control set-up would include a feed forward loop anticipating variations in flow and pH and adjustment of lime dosage accordingly.

Table C3: Characteristics of common neutralization chemicals

Parameter	Lime	Soda Ash	Caustic Soda
Chemical formula	$Ca(OH)_2$	Na_2CO_3	$NaOH$
Solubility at 30 ^{0}C (g/ℓ)	1,53	568	1 190
Consumption of pure product per g of CO_2	0,85	2,41	0,91
Consumption of pure product per g of H_2SO_4	0,76	2,16	0,82
Increase in hardness per g of CO_2 in g $CaCO_3$/ℓ	1,1	0	0
Increase in hardness per g of H_2SO_4 in g $CaCO_3$/ℓ	1,0	0	0
Product from reaction with CO_2	$Ca(HCO_3)_2$	$2NaHCO_3$	$NaHCO_3$
Product from reaction with H_2SO_4	$CaSO_4$	$Na_2SO_4 + 2NaHCO_3$	Na_2SO_4
Residual buffer capacity when neutralising H_2SO_4	no	yes	no
Reaction time	slow	rapid	rapid
Cost	low	high	high

C4.2 Soda Ash

Because the reaction time of sodium carbonate or soda ash (Na_2CO_3) is more rapid than that of lime, and because of the high solubility many of the dosing and control problems associated with lime are not apparent. However, consumption per gram of aggressive CO_2 and H_2SO_4 is nearly three times that of lime and the actual cost of the reagent is high. The combination of these two factors make soda ash a very expensive method of neutralization. A distinct advantage of soda ash is that it imparts a residual buffering capacity to the flow. The inability of lime to add buffering capacity is often overlooked and the low cost is the only basis for reagent choice, which can prove to be simplistic and short-sighted. Where water is extensively reused and recirculated, the advantage of the buffer capacity, imparted by soda ash, may compensate for the added cost of soda ash.

C4.3 CAUSTIC SODA

As with soda ash, reaction time of caustic soda (NaOH) is quick and solubility is high, both factors which facilitate dosing control and mixing. Consumption of pure product per gram of aggressive CO_2 and H_2SO_4 is similar to that of lime but the cost of the raw reagent is high enough to limit the application. An additional disadvantage is the inability to add buffering capacity. Caustic soda is also a hazardous chemical which has logistic and cost implications.

C5. CONCLUSION

Neutralization is used as a water treatment process for the correction of pH generally, as well as adjustment of the carbonate balance which is aimed at stabilising scaling or corrosive waters. Simple pH adjustment may be required for release of the water to the environment or as a pretreatment for a downstream process.

Correct and well controlled neutralization affords opportunities for significant cost savings through longer equipment life, reduced maintenance or reductions in reagent consumption. However, the chemistry involved in neutralization is complex and a misinterpretation of this chemistry often results in ineffective process control. This in turn leads to excessive neutralization chemical costs and the potential benefits are transformed into unnecessary losses.

The application of neutralization in underground mine water treatment is mainly in the field of conditioning prior to flocculant dosage in the settling processes and to protect the water reticulation system against corrosion. Chemical dosage, in the form of slaked lime, is the most common method of neutralization, due to its cost effectiveness.

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**APPENDIX D
COAGULATION AND
FLOCCULATION**

D1. INTRODUCTION

One of the most common problems in process and service water is the suspended solids content. The separation of the solid and liquid contents is required for several reasons, depending on the application. In South Africa as in most arid countries, there is a high degree of water reuse and recycle. Solids will accumulate during each cycle until the resultant slurry becomes unfit for use. In addition the abrasive nature of solid particles imparts additional wear on piping, pumps and process equipment. The removal of the solids becomes essential if the quality and usefulness of the water is to be maintained. In other applications, it is the solids content which is valuable and the further treatment thereof requires it to be in a relatively dry form.

The mining industry encompasses various aspects of separation but most involve the recovery of a clean water product. Underground operations require large volumes of water for dust suppression, cooling, hydro-power and in some cases water-jetting. There is a high degree of solids accumulation in these processes and the water reports to underground sumps for delivery to surface with a high suspended solids content. In order to protect the pumps and water columns, it is necessary to remove a large portion of the solids content.

Although it is often measured and interpreted as a single contaminant, this is an oversimplification and the suspended solids usually comprise a variety of individual species and particle types and sizes. A knowledge of this makeup is essential in the development of treatment systems aimed at the efficient separation of the solid and liquid fractions. Colloidal particles, apart from being small enough to pass through conventional filtration media, have the added disadvantage of stability. This prevents the collision and agglomeration which would render the resultant larger particles, settleable by gravity. Efficient coagulation and flocculation requires a knowledge of the type of colloidal particles so that the stabilizing properties may be suppressed or even overcome. The principles involved in coagulation and flocculation are discussed in a separate section.

Once a degree of particle aggregation has been achieved, it becomes possible to separate liquid and solid contents under the influence of gravity or other applied forces. This is achieved in a variety of processes including thickeners, clarifiers, settlers or settling dams. The correct design of such facilities must allow for the protection of the particle flocs and must create suitable conditions for these flocs to settle.

D2. COAGULATION AND FLOCCULATION

It is useful at the outset to define the terms coagulation and flocculation as they are often used interchangeably, which is not strictly accurate. The overall process of floc formation aims at the creation of suitable conditions for particle aggregation. Initially, the stabilizing repulsive charges on the particles must be neutralized. The particles must then be brought into contact with each other so that flocs may form and settling is enhanced. It is common to refer to the first step as coagulation and this may include the processes of double layer compression and charge neutralization. Flocculation describes specifically the aggregation of particles through mechanisms such as bridging and enmeshment. These processes are described more fully below.

D2.1 OBJECTIVES

The process of coagulation and flocculation is intended to condition the water and the suspended solids content therein, such that the formation of larger particles or flocs is encouraged. These larger, and consequently heavier, particles are then more easily settled by downstream processes such as thickening, clarification and settling. The need for coagulation and flocculation is clear when a comparison of various particle settling times is made. Some of these are presented in Table D1. The settling times are based on Stokes' Law.

This table indicates that it is not practical to settle particles smaller than 0.01 mm in diameter. This is particularly so in situations where the area available for settling is limited. This limitation occurs in the confined spaces of underground mines. The aim of coagulation is thus to reduce the required settling time of particles and thereby reduce the surface area required for a particular solid loading rate. The principles of the settling process itself are described in Section D3.2 below.

Table D1: Settling times of various particles and particle sizes

Particle diameter, mm	Particle type	Time to settle through 1m depth	Particle specific area, m^2/m^3
10	Gravel	1 second	$6x10^2$
1	Sand	10 seconds	$6x10^3$
10^{-1}	Fine sand	2 minutes	$6x10^4$
10^{-2}	Clay	2 hours	$6x10^5$
10^{-3}	Bacteria	8 days	$6x10^6$
10^{-4}	Colloid	2 years	$6x10^7$
10^{-5}	Colloid	20 years	$6x10^8$
10^{-6}	Colloid	200 years	$6x10^9$

D2.2 Mechanisms of Coagulation and Flocculation

Coagulation, as defined above, is aimed at the destabilization of solid particles. This destabilization involves the elimination or reduction in inter-particle repulsive forces. Once the particles are destabilized, natural or induced motion will move particles together and the aggregation can occur.

D2.2.1 Coagulation

There are two main mechanisms of particle destabilization. Both involve the reduction of the surface potential which is responsible for the repulsive forces.

D2.2.1.1 Double-Layer compression

Particles possessing a fixed surface electrical charge also require a counter charge to balance and neutralize the surface potential. This counter charge is comprised of a number of ions which are concentrated in a diffuse layer, called the double layer, surrounding the particle. When an electrolyte, in the form of a coagulant, is added to the colloidal dispersion, the density of the charge in the double layer is increased. This has the effect of reducing the necessary volume for charge neutralization. The implication is that the depth of the double layer is reduced or compressed. The van der Waals attractive forces between particles then become more dominant and aggregation is enhanced. The net attractive force is a sum of these van der Waals forces and the electrical double layer repulsive forces. At high concentrations of electrolyte, the double layer is reduced dramatically and the van der Waals forces are correspondingly extremely dominant. Aggregation thus occurs very rapidly. The practical implication of this observation is that increasing the electrolyte concentration causes an increase in the rate of aggregation.

D2.2.1.2 Charge neutralization by adsorption

Certain chemical species may be adsorbed directly onto the surfaces of colloidal particles. If the adsorbed species has an opposite charge to that of the particle, then charge neutralization will occur.

The knowledge of which mechanism is responsible for coagulation is important as it has implications for the concentration and dosing of the coagulant. It is clear that the mechanism of adsorption destabilization is stoichiometric which implies that as the concentration of colloids, or colloid surface area increase, so the required dosage of electrolyte increases. Overdosing in the case of double-layer compression causes an increase in the rate of particle aggregation, while overdosing of adsorbable species can actually retard the aggregation process. This is due to the restabilization of particles when the surface charge is reversed to that of the adsorbed species.

D2.2.2 Flocculation

Aggregation of the destabilized colloids can only occur if there is contact between the particles. This can occur naturally or may be induced mechanically. The thermal or Brownian motion present in a liquid gives rise to perikinetic flocculation. Particle contact induced by stirring or differential settling is termed orthokinetic flocculation.

An analysis of the flocculation rates obtainable via the two mechanisms shows that perikinetic flocculation is dominant at particle sizes < 1 µm. It is also clear, however, from Table D1 that particles of this diameter do not settle very quickly. These two factors imply that some form of orthokinetic flocculation is required for effective settling. Usually this is achieved by baffles, mechanical mixing or agitation with compressed air.

The degree of mixing or agitation in a flocculation basin can be quantified by measurement of the mean velocity gradient which is a function of the basin volume, fluid viscosity and power input to the basin. The velocity gradients need to be high enough to allow sufficient particle contact but must not be so high as to cause the shearing of the newly formed flocs. This is particularly problematic in the case of organic polymer flocculants because once the long polymer chains become detached, they may fold back around the particle and restabilize it.

Although the flocs formed by iron(III) and aluminium(III) salts are not as strong as the polymer flocs, it has been found that velocity gradients of between 25/sec and 100/sec are suitable for the metal salt flocs while lower values such as 15/sec are optimum for the polymer floc formation.

Another important criterium in the design of flocculation systems is the detention time as this is a measure of the opportunity for contact to occur.

D2.2.3 Other mechanisms

Another mechanism which combines coagulation and flocculation and which does not involve charge neutralization is the sweep-floc process in which colloids become enmeshed in metal salt precipitates. In some cases the colloids form the nuclei for the precipitation of the insoluble metal hydroxides.

Some large molecule natural compounds such as starch and cellulose are also known as coagulating agents. Various theories have been developed to explain the mechanism and it is accepted that the long chain molecules act as a bridge between two or more colloidal particles to form the beginning of a floc.

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APPENDIX E UNDERGROUND SETTLING

The process of settling is used in various applications for the separation of solid and liquid contents. The degree of separation may range from the recovery of water from process slurries to the clarification of colloidal waters for potable use. The main mining applications include the thickening of plant residue, prior to the disposal on slimes dams and the removal of suspended solids from underground service water before delivery to surface. Underground settling forms the focus of this discussion since it incorporates many of the general principles involved as well as presenting special difficulties, as discussed below.

E1 OBJECTIVES

The general objective of any settling process is the separation of suspended solid material from the aqueous media. Although it is essentially a physical process relying on the force of gravity, there are chemical considerations involved in the coagulation step as well as in the control of the overall process. This is discussed further in Section E4.

The specific objectives of settling underground service water are two-fold:

- Removal of solid material from the water prior to pumping, in order to reduce the abrasion of pipes and pumps.
- Separation and collection of sludge content for delivery to surface and treatment in the metallurgical plant. Typically the sludge has a high grade of gold.

It is difficult to quantify the cost of increased wear on process equipment due to the presence of suspended solids, but it was estimated in 1994 that costs which can be ascribed to poor settling alone were approximately R140 million. Combined with the increase in gold recovery from the sludge, the importance of efficient underground settling becomes clear.

E2 THEORY AND DESIGN OF SETTLERS

The velocity, V, at which a particle, of diameter d, will settle in a fluid is given by Stoke's Law as follows:

$$V = \frac{2gd^2 (p_1 - p_2)}{9\eta} \qquad (1)$$

Where p1 = density of particle
p2 = density of the fluid
η = coefficient of fluid viscosity

Application of this law for various particle sizes yields the settling times presented in Table E1.

Table E1: Settling times of various particles and particle sizes

Particle diameter, mm	Particle type	Time to settle through 1m depth	Particle specific area, m^2/m^3
10	Gravel	1 second	$6x10^2$
1	Sand	10 seconds	$6x10^3$
10^{-1}	Fine sand	2 minutes	$6x10^4$
10^{-2}	Clay	2 hours	$6x10^5$
10^{-3}	Bacteria	8 days	$6x10^6$
10^{-4}	Colloid	2 years	$6x10^7$
10^{-5}	Colloid	20 years	$6x10^8$
10^{-6}	Colloid	200 years	$6x10^9$

Apart from the particle settling velocities, the other critical parameters involved in the design and operation of any settling installation are:

- hydraulic or surface loading rate ($m^3/m^2.h$)
- solids loading rate ($kg/m^2.h$)

Due to the cyclical nature of underground mining operations these criteria fluctuate widely and often rapidly. The peak in the hydraulic loading can be up to 10 times the baseline flow. In addition, the maximum hydraulic loading corresponds to an increase in suspended solids content of between 100 and 400 times the normal concentration. This combination leads to peaks in the solids loading rate of up to 4000 times the baseline value. It is clear that with fluctuations such as these, good efficient control of settling is essential. This aspect is discussed further in Section E4.

The flowrate to any underground settler is usually a factor of the total tonnage of rock mined per unit time, T. The volume of water required per mass of rock mined, W_T, differs for various operations but an industry average figure of approximately 2 m^3 per ton is applicable. The maximum design flowrate, Q_m, should allow for double this calculated flow and this gives the expression:

$$Q_m = 2(W_T)(T) \qquad (2)$$

Calculation of the settling velocities from equation (1) will give a minimum required settler surface area, As , as follows:

$$As > Q_m/V \qquad (3)$$

This surface area excludes that required for feed and overflow launders.

E3 TYPES OF SETTLERS

The variables of design in settler systems are the hydraulic and solids loading rates and these are dependant on the choice of settler type and configuration. A summary of the typical hydraulic or surface loading rates for various configurations is presented in Table E2. The various types of settler configuration are then discussed.

Table E2: Surface loading rates for various types of settlers

Settler Type	Loading rate, $m^3/m^2.h$
Conventional shallow rectangular	1 - 4
Conventional deep conical	5 - 8
Conventional sludge blanket	5 - 10
High rate sludge blanket	15 - 20
Inclined plate or lamella	15 - 20
High rate tube	50 -60

E3.1 Horizontal Flow

The simplest form of settlers consist of shallow cells in which the dirty water moves very slowly in a horizontal direction from inlet to outlet. The basis of design is to allow sufficient detention time for particles to settle before the outlet is reached. The bottom is slightly inclined to allow for the collection and removal of sludge. This type of settling installation is usually found at the older shafts. These installations may operate in a batch manner in stagnant sumps or with continuous introduction of influent and removal of sludge.

E3.2 Lamella or Inclined Plate

Lamella plate type separators consist of a number of parallel closely spaced inclined plates over which the dirty water is fed. Gravitational separation occurs and the clarified water collects under each plate and continues to flow towards the top. Settled sludge collects along the bottom of each plate and flows down the incline to be collected in the underflow. The lamella separators have wide application in wastewater treatment but are not particularly suited to the wide fluctuations in solids and hydraulic loading encountered in underground settling operations. There is also a tendency for plates to block.

E3.3 Vertical Flow

The more modern settlers operate on a vertical flow basis with the introduction of the influent dirty water occurring at some depth below the settler surface level. Originally the idea was developed for use in the sewage treatment industry and later developed for mine water treatment. The various types of configuration include double-V, cylindro-conical, high rate tube and sludge blanket settlers. Conventional vertical flow settlers operate on the basis that the rising velocity of the water is lower than the settling velocity of the flocs, giving a net settling out of the solids. Vertical flow settlers require substantially less surface area than horizonatal flow settlers. The principle of operation for the double-V, the high rate tube and sludge blanket settlers makes use of orthokinetic flocculation as described previously. Influent water is introduced at some depth below the settler surface which must be below the floc or sludge blanket which forms in the settler body. This water then rises to the surface and the associated suspended solids encounter the fluidised sludge blanket. Orthokinetic flocculation occurs and a portion of the flocs increase in size, thus increasing their settling velocity and they fall out of the sludge blanket, to be collected at the bottom of the settler cell.

The important aspects of such settler arrangements are the uniformity of the influent feed and clear water withdrawal as well as sludge removal. Ideally, there should be no local velocity gradients or short circuiting which tend to disturb the sludge blanket. This is achieved by introducing the dirty water and withdrawing the clear effluent across the entire surface area of the settler. A uniform upward flow over the settler area is thus created.

E3.4 Ideal characteristics of underground settlers

The progress in development of underground settlers has been necessitated by the unique conditions and restrictions encountered underground. The ideal underground settler should have the following characteristics:

- High rate which reduces the required surface area
- Ability to cope with wide and rapid fluctuations in feed flow and solids loading
- Low maintenance and operator skill requirements
- Robust and correct control of lime and flocculant dosing.

These aspects are discussed briefly in Section E4

E4 OPERATION OF SETTLING SYSTEMS

As with any process the operation and control of settling systems is facilitated by a knowledge of the principles and mechanisms involved. The settler cell cannot be controlled in isolation and aspects such as feed launder flow, pH adjustment, flocculant dosing, mixing and influent introduction are integral components of any efficient settling operation.

In cases where the settler system has been overdesigned, the control and distribution of flow during peak periods is easily achieved with the use of gate valves in the feed launders. Ideally, each settler should be maintained under constant conditions and fluctuations in feed flow should be smoothed out where possible.

The adjustment of pH by the addition of neutralising chemicals is often required for conditioning prior to flocculant addition. The control of this neutralisation step is often poor. The target pH is thus seldom achieved and this results in the poor performance of the dosed flocculant. The problems of underground neutralisation are discussed more fully in that particular literature review.

The problems related to flocculant dosing are similar to that of neutralisation in that there is seldom a correlation between flocculant dosage and dirty water flowrate or suspended solids concentration. The design of the feed launders from the dosing point is critical since excessive turbulence causes flocs to shear. The launder should be designed so as to allow a period of initial mixing and gradual turbulence reduction until the point of introduction into the settler cell.

E5 CONCLUSION

The importance of water and solid separation in industry and wastewater treatment is well understood. Settling under the influence of gravity provides a relatively inexpensive method of solids removal from large flowrates of turbid water and slurries.

Flocculants and coagulants are added to waters containing particles with very low settling velocities. The knowledge of coagulation and flocculation mechanisms is important if the optimum conditions are to be created.

Underground settling of dirty service water is carried out in order to reduce abrasive wear on pipes and pumps as well as to recover the high gold grade solids content which is washed down from the working areas of the shafts. Underground conditions are particularly hostile and the high cost of development limit the space available for settling. This fact has prohibited the use of horizontal flow settlers and recent trends are towards vertical flow configurations such as cylindro-conical and high rate tube settlers.

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APPENDIX F
DISINFECTION

F1 INTRODUCTION

Underground mine service water in South Africa is used for dust suppression, drilling, cooling and cleaning. Although the chilled water is not intended for potable use, it is often used as drinking water by mining personnel and atomised droplets may be inhaled. The water is recirculated within the mining circuits where it may be infected with intestinal organisms or water borne diseases such as cholera or typhoid. In order to protect the health of the underground work force it is customary to disinfect the service water.

Although a regulation is in force that all water used underground shall be free of bacterial contamination, in practice it is often very difficult to accomplish this (2).

Industry, utilities and municipalities have relied on chlorine gas as the principal method for microbiological control of cooling waters and disinfection of waste treatment applications. Today the concerns for the environment, operator safety, and liability issues have caused many plants to reconsider their use of chlorine and look at alternative biocides that meet environmental discharge requirements and minimise safety and liability issues. Bromine chemistry has proven to be a simple, cost effective, alternative to chlorination/dechlorination for these applications.

Chlorine gas cannot be used underground for safety reasons and chlorine compounds such as calcium or sodium hypochlorite have traditionally been used.

F2 PATHOGENS

Disinfection refers to the selective destruction of disease-causing organisms as opposed to sterilisation, which is the destruction of all organisms.

The bacteriological quality of the water is monitored by enumerating total aerobic bacteria (TAB), total coliforms (CC) and *Escherichia coli (E. coli)*. *E. coli* is an indicator of human faecal contamination(13). The bacteriological standard specified by Anglo American Corporation for mine service water is less than 3 000 TAB per 100 ml, less than 2 CC per ml and the total absence of *E. coli* (1).

The pathogens can be divided into different groups of organisms(8) and more detail on this is given in the literature review on microbiological contamination.

There are several disinfecting agents available for use. Among these are the use of UV irradiation, ozone, micro-filtration, chlorine dioxide and compounds that produce hypobromous and hypochlorous acids.

F3 CHLORINE BASED DISINFECTION

Historically the methods of treatment have been chlorine based and include the use of gaseous chlorine (surface installations only), calcium hypochlorite granules or tablets, chlorinated cyanurate tablets, sodium hypochlorite solutions and hypochlorite produced by electrolysis. These compounds all produce hypochlorous acid which is the primary sanitiser in all chlorination procedures(1).

The standard method of disinfection in South African mines is treatment with calcium hypochlorite, although liquid sodium hypochlorite is used at a few sites(2). Gaseous chlorine is invariably considered to be so toxic and hazardous that chlorine cylinders are not taken underground. Solid or liquid chemicals that are easier to transport and safer to handle are used instead. Several chemicals such as sodium hypochlorite, chloride-of-lime, lithium hypochlorite, and granular calcium hypochlorite can be utilised.

Important variables affecting the efficiency of chlorine disinfection are: contact time; initial mixing; pH; temperature; concentration of disinfectant; concentration of ammonia; types of organisms; and nature of suspending liquid.

F3.1 Effect of Contact Time

Effect of contact time is indicated by the following equation:

$N_t/N_o = kt^m$

N_o = number of organisms at time t = 0

N_t = number of organisms at time t

t = time (sec)

k = constant (sec^{-1})

m = constant

The equation results from the analysis of chlorination data that have been found to plot as straight lines on log-log paper.

F3.2 Effect of Initial Mixing

It has been shown that the addition of chlorine in a highly turbulent (Re > 10 000) regime resulted in kills two orders of magnitude greater than for addition under low turbulence.

F3.3 Effect of pH

The common chlorine compounds form hypochlorous acid on reaction with water. The hypochlorous acid (HOCl) is in equilibrium with the hypochlorite (OCl^-) ion, and the equilibrium changes with pH as shown in Table F1 below.

Table F1: Effect of pH on chlorine

pH	5	6	7	8	9	10
%HOCl	100	93	70	22	4	0
%OCl^-	0	7	30	78	96	100

The pH is important because the HOCl has a disinfection power 40 - 80 times higher than OCl^-.

F3.4 EFFECT OF TEMPERATURE

The effect of temperature on rate of kill is given by the van't Hoff-Arrenhius relationship as follows:

$$\ln t_1/t_2 = (E(T_2 - T_1)/(R.T_1.T_2)$$

E = activation energy (J/mol)

t_1, t_2 = time for given percentage kill at temperatures T_1 and T_2 respectively

T_1, T_2 = temperature (°K)

R = gas constant (8,314 J/mol.°K)

where the activation energy E varies for different chlorine compounds at different pH values as shown in Table F2 below. Increased temperature results in a more rapid kill.

Table F2: Effect of temperature on chlorine

Parameter		Chlorine		Chloramines		
pH	7,0	8,5	9,8	7,0	8,5	9,5
E (J/mol)	34 332	26 796	50 242	50 242	58 615	83 736

F3.5 Effect of Disinfectant Concentration

Depending on the type of chemical agent, it has been observed that, within limits, disinfection effectiveness is related to concentration by the following empirical relationship:

$$C^n.t_p = \text{constant}$$

C = concentration of disinfectant

^{n} = constant

t_p = time required to effect a constant percentage kill

The constants in this equation can be determined by plotting on log-log paper, the concentration versus time required to achieve a given percentage kill. In general, if n is greater than 1, contact time is more important than dosage; if n = 1, the effect of time and dosage are about the same.

F3.6 Effect of Ammonia Concentration

Ammonia reacts rapidly with hypochlorous acid to form monochloramine (NH_2Cl) and dichloramine ($NHCl_2$). An excess of chlorine will form nitrogen trichloride (NCl_3). The dichloramine is about 120 - 150 times less effective than hypochlorous acid, while the monochloramine is about 1 000 times less effective for killing bacteria. Relative ratios of mono- to dichloramine are dependent on pH, temperature, contact time and initial concentration of chlorine. Dichloramine predominates at pH 5 and below and monochloramine predominates at pH 7 and above.

Free chlorine can only be obtained once all the ammonia has been oxidised to chloramines. This is referred to as breakpoint chlorination and requires 8 - 10 mg/ *l* chlorine per mg/l ammonia. Chloramines are just as effective in disinfecting water, provided sufficient contact time is available

F3.7 Types of Organisms

Effectiveness of disinfectants is influenced by the nature and condition of the micro-organisms. Viable growing bacteria cells are killed easily, while bacterial spores are extremely resistant. Chlorination is less effective for viruses than for bacteria. In general high free chlorine residuals are required to inactivate viruses.

F3.8 Nature of Suspending Liquid

The nature of the liquid has an important effect on disinfection efficiency. Ammonia will react with chlorine to produce the less effective chloramines. Turbidity will reduce the effectiveness of disinfectants by absorption and by protecting entrapped bacteria.

It has been shown in the past sixteen years, particularly in warmer climates, that there are disease-producing pathogenic organisms in the service water (*Salmonella* strains, *Entamoeba hystolytica* etc.), which are more resistant to chlorination than E. coli. Hence, the absence of E. coli after chlorination is not always an indication that all potentially harmful pathogens have been eliminated.

In mine service water, it is important that disinfectant maintains an active residual in the water to prevent the growth of bacterial slimes in the distribution network and refrigeration units[5].

On site chlorine generators are available on the market, and the production of chlorine by electrolysis of a saturated brine solution is an established method being used.

Chlorine generation is achieved as follows;

Dissociation	$2NaCl \rightarrow 2Na^+ + 2Cl^-$
Anodic reaction	$2Cl^- \rightarrow Cl_2 + 2e^-$
Cathodic reaction	$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$
Reassociation	$2Na^+ + 2OH^- \rightarrow 2NaOH$.
Chlorine dioxide manufacturing	$2NaClO_2 + Cl_2 \rightarrow 2ClO_2 + 2NaCl$

Chlorine is produced at atmospheric pressure, making the plant safer, and only salt is stored as chlorine is produced on demand.

For a considerable number of years, kits for the in situ electrical generation of chlorine water (in the form of sodium hypochlorite) have been available commercially.

These units are not practical for industrial use since the carbon electrodes have an active life of only about three to six months.

Early in 1976 it was learnt that industrial units with platinized titanium electrodes, guaranteed for a minimum life of five years, were being manufactured to produce chlorine from sea water. These chlorinators consist essentially of a transformer that supplies direct current to platinized titanium anodes and titanium cathodes arranged in the form of tubes. The chlorine is generated as sodium hypochlorite during a 'once through' passage of sea water through the tube cell(2).

The system appeared to have considerable potential if it could be adapted for underground use. It was realised that in these circumstances, a manufactured brine solution would have to be recirculated relatively rapidly through the chlorinator while a slight controlled discharge from the circuit into the mine service water was allowed.

The assembly has sophisticated controls to prevent overheating, and has cut-outs for excess currents and low liquid flow, a leak detector and automatic reset and level controls switches. Its power supply is designed to convert a standard three-phase 50/60 Hz supply into the high current, low-voltage power required to perform this function as follows: a step-down transformer, a saturable reactor assembly, a variable controller, an auxiliary transformer, and a rectifier assembly. These components are housed in a lockable power-supply enclosure.

The electrolysis of salt water releases hydrogen at the rate of 0.25 m^3/kg of sodium hypochlorite generated. The hydrogen remains entrapped in the pipe work and is released into the atmosphere over the recycle tank. Measures should be taken to provide continues forced-draught ventilation at the location to sweep away the hydrogen. This draught also assists in cooling the circulation brine.

To ensure that all, or as much as possible of the underground service water is chlorinated, the site of installation must be carefully chosen. In most cases an appropriate site is either into, or at the outlet from, the dam feeding the machine water to the working levels below. Four units were tested at Western Holdings, President Brand, Vaal Reefs and Western Deep Levels.

The ideal characteristics of a disinfectant are compared with actual characteristics of some common chlorine-based disinfectants in Table F3 below.

Table F3: Ideal and actual characteristics of chlorine-based disinfectants

Characteristic	Ideal	Chlorine gas	Sodium hypochlorite	Calcium hypochlorite	Chlorine dioxide
Toxicity to micro-organisms	Highly toxic at low conc.	High	High	High	High
Toxicity to man	Non-toxic	Highly toxic	Toxic	Toxic	Toxic
Solubility	Soluble in water	Slight	High	High	High
Stability	Effective after kept in storage	Stable	Unstable	Stable	Unstable - generate on site
Interaction with ammonia	Should not interact	Strong interaction	Strong interaction	Strong interaction	No interaction
Penetration	Must penetrate through scale	High	High	High	High
Corrosivity	Should not corrode metals	Highly corrosive	Corrosive	Corrosive	Highly corrosive
Availability	Available in large quantities and low cost	Low cost	Moderately low cost	Moderately low cost	Moderate cost
Handling	Safe to handle	High hazard	Medium hazard	Medium hazard	High hazard

F4 CHLORINE DIOXIDE-BASED DISINFECTION

The effectiveness of ClO_2 to disinfect poliovirus and indicator bacteria in clean water and sewage was determined during various studies. *Clostridium perfringes* was the most resistant to disinfection by ClO_2, followed by poliovirus, *S. faecalis* (faecal streptococcus) and *E. coli*. The results suggest that reduction in concentrations of *C. perfringens*, but not faecal coliform or faecal streptococcus can be used as a simple monitoring assay to determine if ClO_2 treatment conditions to disinfect human enteric viruses had been achieved. Some resistance to disinfection has been detected and is usually associated with suspended matter that hinders disinfection. Settling of mine service water should eliminate this problem, see literature review on flocculation and settling.

Chlorine continues to be the disinfectant of choice to treat both drinking and waste waters. However the USEPA (1976) task force report concluded that the standard practice of treating waste waters with chlorine resulted in the formation of toxic as well as potentially carcinogenic products and was also ineffective in disinfecting human enteric viruses. Of the alternative disinfectants tested, chlorine dioxide is one of the most promising since:

- it does not react with hydrocarbons to form carcinogens;
- remains an effective disinfectant even in the presence of ammonia
- and organics in water;
- remains a residual in the water[14].

The presence of organic nitrogen and ammonia in underground mine water often results in inadequate disinfection being achieved. A case study at a mine on the Witwatersrand Reef indicated that chlorine dioxide could be an economically viable alternative to chlorine, especially for underground applications. Disadvantages of using this disinfectant are that sodium chlorite used for its generation has to be imported from overseas, and a somewhat more sophisticated generation-dosing system than chlorine[5].

Minimizing the inorganic by-products, chlorite ion and chlorate ion, in drinking water may be important if chlorine dioxide is used for potable water treatment. Sulphur dioxide, sulphite and free chlorine are used to do this in America as the USEPA has limits on the concentrations of these ions in drinking water.

F5 BROMINE BASED DISINFECTION

Bromide can be delivered for water treatment applications in three practical forms:

1) *Bromochlorodimethylhydantoin* (BCDMH) (solid tablets or granules)

   Reaction: $C_5H_6BrClN_2O_2 + 2H_2O \rightarrow C_5H_8N_2O_2 + HOBr + HOCl$

   Feed system: Brominator

2) *Activated Bromide* (Br^-) (liquid)

   Reaction: $HOCl + Br^- \rightarrow HOBr + Cl^-$

   Feed system: Positive displacement pump

3) *Bromine Chloride* (BrCl) (liquid in bulk)

   Reaction: $BrCl + H_2O \rightarrow HOBr + H^+ + Cl^-$

   Feed system: Bromine Chloride Feeder

The reactions above show how bromine, in its various forms, hydrolyses in water to form the weak acid, hypobromous acid (HOBr). Regardless of the form in which bromine chemistry is delivered, the principal mechanism for biocidal activity is the formation of hypochlorous and hypobromous acid in the chlorination of water. Both hypohalous acids are powerful oxidising agents which combine readily with protoplasm in an organism forming stable nitrogen-halogen bonds with the proteins. The formation of these halogen bonds interrupts the metabolic processes and is, therefor, toxic to all living organisms[3].

Since both bromine and chlorine are in the same chemical family known as halogens, there are many similarities in how the two elements react in water treatment applications. However, there are some key distinctions.

F5.1 Nitrogen Environment

Since various levels of ammonia and/or nitrogen are encountered in most mine water (due to explosive residue), it is important to consider the effect of these substances on biocidal activity and final effluent residuals of bromine and chlorine in treated systems.

Halomines are quickly formed when the biocidal active agent, hypohalous acid (HOBr or HOCl), comes in contact with nitrogen based compounds.

Chloramines are formed upon chlorination and are relatively poor biocides. Monochloramine is predominant at the pH of typical water treatment applications. At a pH of 8.5 monochloramine formation is virtually complete. The biocidal activity of monochloramine is eighty times less than that of free chlorine[(3)].

Mono- and dibromamines are formed during bromination, and are very active biocides. These bromamines show disinfection properties that are comparable to that of free bromine. In some systems, breakpoint chlorination is required to maintain microbiological control when ammonia is present. Typically breakpoint chlorination requires 10 mg/*l* of chlorine for every 1 mg/*l* of ammonia. Since bromamines are very effective biocides, breakpoint bromination is not relevant.

In summary, effective microbiological control and disinfection can be achieved at much lower halogen dosages when bromine chemistry is applied.[(10)]

Alternative halogen-based disinfection methods were studied and a dramatic effect of a low level nitrogen (2 mg/*l*) on biocidal activity of bromine and chlorine chemistries against three bacterial genera. Chlorine was effective against E. coli but was less effective against the *Pseudomonas*, and *Streptococcus* genera. Pseudomonas is known for its relative resistance to biocides and is the predominant slime forming bacterial genus of concern in condenser and heat exchanger biofouling.

F5.2 Kinetics

The kinetics of halogen-based disinfection methods were also studied and bromine chemistry achieved kill levels of at least four orders of magnitude in less than four minutes. These results take on particular significance in applications that require rapid disinfection. The disinfection kinetics of bromine chemistry make it possible to reduce contact time in these applications. This reduction in exposure not only benefits the environment, but can result in lower condenser corrosion rates.

F5.3 Environment

An analysis of the relative decay ratios of bromamines vs. chloramines helps explain why bromine chemistry has a positive impact on the environment. Bromamines decayed to low levels in less than half an hour while chloramines required many hours to decay to the same levels.

Several fish survival studies have confirmed that the environmental impact is reduced significantly through the application of bromine chemistry[(4)].

F5.4 Alkaline Waters

With the decline of chromate treatments in recirculating cooling systems, there has been a trend toward alkaline corrosion control programs. It has been well documented that the effectiveness of chlorine is reduced significantly in an alkaline environment. As the pH of the water rises, hypochlorous acid (HOCl) and hypobromous acid (HOBr) dissociate to form the hypohalite ions (OCl^- and OBr^-). The hypohalite ions are not active biocides at typical use levels. Disinfection performance in an alkaline environment shows that bromine chemistries continued to achieve kill levels of 4 to 6 orders of magnitude at a pH of 8.2.

In mine service water systems, the effects of fluctuating pH values and high levels of ammonia and suspended solids create many problems with chlorine based disinfection compounds. Many mines have service water systems with pH values above 7.5 - 8, due to poor neutralisation control, and ammonia levels as high as 100 mg/l or more. Under these conditions, effective chlorination is almost impossible.

Over the last few years a number of mines have evaluated and implemented bromine based disinfection systems, using the chemical bromo-chloro-dimethyl-hydantoin (BCDMH) which releases both active chlorine and bromine compounds. The bromine portion remains an active and effective disinfectant at much higher pH values than chlorine as shown in the Table F4 below.

Table F4: Effect of pH on chlorine and bromine

pH	Chlorine	Bromine		
	% HOCl	% OCl	% HOBr	%OBr
7,5	50	50	100	0
8,5	10	90	60	40

NOTE : Both HOCl and HOBr are almost 2 orders of magnitude more effective as disinfectants than OCl and OBr.

F5.5 Field Trials

Trials using BCDMH were conducted at two shaft sites, one in the Free State and one in the North West Province. The BCDMH was used in tablet form and was dosed by means of a dispenser which had a 35 kg capacity.

Results from both trials showed that the BCDMH had been successful in maintaining low bacterial counts. Cost comparisons were calculated for both HTH and BCDMH in both trials.

A 41% cost saving was calculated for the trial run in the Free State. However in order to ensure proper biological control, it has been agreed that the dosage rate be increased to 1 mg/*l*, which would still represent a cost saving of 34.4%.

The cost of the trial run in the North West Province was calculated at an average monthly cost of 29% saving.

F6 POTENTIAL PROBLEMS ASSOCIATED WITH DISINFECTION

Primarily because the standard method of disinfection depends on human control for the addition of hypochlorite and the regulation of its flow, it is frequently found difficult to disinfect mine water adequately and continuously[2].

Gaseous chlorine is invariably considered to be so toxic and hazardous that chlorine cylinders are not taken underground. Although widely employed, calcium hypochlorite is not the ideal additive for use underground. One of the main disadvantages is the difficulty in feeding the solid, or a relatively concentrated solution of it, at a constant dosage rate. Apart from chlorine gas, it is the cheapest form of available chlorine but it is still expensive to use. The hypochlorite increases the pH value of the service water, which in practice decreases the disinfecting activity of the hypochlorous acid solution formed; additional calcium is added to the water, increasing its scaling tendencies, which are probably already high[2].

The optimum procedure for effective disinfection requires sufficient contact time between micro-organisms and disinfectant to allow for proper kill, followed by a level of residual biocide to prevent bacterial regrowth.

It is often difficult to maintain the optimum procedure as factors such as fluctuating pH, the presence of ammonia and a high level of organics in water all interfere with the biocidal action of hypochlorous acid[1].

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**APPENDIX G
COOLING WATER
TREATMENT**

G1 INTRODUCTION

The South African gold mining industry has, since 1982 reduced its use of water purchased from bulk water service providers by about 30%. This reduction has been achieved by increasing mine service water recycling and reducing domestic uses[1].

The use of mine service water without any form of pretreatment or in-service treatment can lead to various problems. These include corrosion, scaling, fouling and microbiological activity. These mechanisms will all seriously reduce heat transfer efficiency and in extreme cases, result in equipment failure. These problems can be identified individually, but are often inter-related; microbial activity can lead to the destruction of the treatment chemical which could result in corrosion or scaling; dirt ingress into the system if uncontrolled can deposit on heat exchange surfaces leading to corrosion and bacterial activity[2].

Untreated cooling tower water contains suspended solids which become concentrated and cause fouling and microbial growth. Cooling water treatment technology has advanced to a stage where most of the problems discussed can be overcome. Practices include solid/liquid separation (clarification), desalination, softening, disinfection, corrosion, scaling and fouling prevention[3].

G2 COOLING WATER SYSTEMS

The following types of cooling water systems are used industrially:

- open recirculation system.
- closed recirculation system.
- once-through system.

A closed recirculation system is used to transport heat from a heat source to a radiator which is normally air cooled. The mines use these systems for internal combustion engines and the closed cooling loops of some air compressors. Chemicals are added to these systems to protect against corrosion[3].

Once-through systems require large volumes of water and are used where such supplies are available e.g. the sea or large rivers or dams. The temperature of the water is raised slightly in the process, which can result in a heat pollution problem. Chemicals are not used for water treatment and corrosion protection is achieved by correct materials of construction[3].

The open recirculation system is used most widely in the gold mining industry. The circulating water transports heat from the heat exchange equipment to a cooling tower. The cooling is achieved by the evaporation of a portion of the circulating water. The quantity of water lost by evaporation is approximately 2 % of the rate of circulation per 10°C cooling obtained in the tower[3] .Water is also lost through windage which is a loss of fine droplets of water entrained by air. Whereas evaporation loss causes an increase in the concentration of dissolved solids in the circulating water, windage tends to limit the degree of concentration. As the dissolved solids concentrate by evaporation the solubility of some of the salts in the water is exceeded and a scale is deposited on the heat exchange surface. The term used to indicate the degree of concentration of the circulating water as compared with the make-up water is cycles of concentration[2].

There are a variety of approaches for reducing the increased total dissolved solids (TDS) level which results from recycling, and controlling the level of salts and other variables within acceptable ranges to ensure satisfactory cooling system operation.

G2.1 Scaling

The factors which influence scaling are pH, alkalinity, calcium, magnesium, sulphate, phosphate, temperature, dissolved solids and silica. Hence typical scales found in cooling systems can be controlled by [(2)] :

- reducing the alkalinity of the water by dosing acid.
- adjusting the design and mechanical operation of the system to ensure a minimum water flow velocity of 1 m/s.
- using non-adherent material in heat exchangers to reduce the number of nucleation sites.
- air rumbling.
- installing larger heat exchangers with more surface area.
- using chemical inhibitors which reduce the growth of crystalline scale.

Inhibitors such as polyphosphates, phosphates and polycarboxylic acids are normally used to prevent scale formation[(2)]. They are highly active and are strongly attracted to surfaces, this provides competition between the inhibitor and the crystallising substances for active growth sites. If the inhibitor is successful, crystal growth or scaling ceases.

Very small amounts of inhibitor can prevent scale formation even if the scaling salts are present in high concentrations. If insufficient inhibitor is present to render the growth sites inactive, the presence of the inhibitor distorts crystal growth and adhesion so that the formation of hard scale is prevented.

When scale inhibitors are added to the circulating water the water can be allowed to concentrate further without resulting in scaling. If calcium carbonate, calcium sulphate, calcium silicate or magnesium silicate become over saturated in the circulating water however, economic dosages of scale inhibitor will not prevent scale formation[(3)]. The oversaturation of dissolved salts is prevented by limiting the cycles of concentration of the circulating water to within the effective range of the scale inhibitor used. This may be achieved by bleeding some of the circulating water from the system. An alternative method is side stream softening of the circulating water using lime-soda softening, reverse osmosis, ion exchange or electrodialysis. In these processes, a side stream of cooling water is treated to remove sufficient materials so that scaling and corrosion can be controlled to acceptable levels. With the exception of the lime-soda process, these technologies are expensive and produce brines that must be disposed of by solar or mechanical drying methods[(5)].

The lime-soda softening process removes calcium, magnesium and silica in the form of a sludge discharged from the softener. This process is most suitable for makeup waters that are not high in chlorides or dissolved solids concentrations[(5)]. Lime (calcium hydroxide) is added to the system to raise the pH to about 11. At this pH, calcium carbonate and magnesium hydroxide are precipitated. Ions such as sodium, potassium, sulphate and chloride are not removed in the softening process.

G2.2 Fouling

Although the terms fouling and scaling are often used synonymously, foulants are softer non-crystalline deposits originating from suspended material in the circulating water. These materials include silica, iron oxide, organic contaminants and microbiological slime[(2)]. Fouling may also result from overdosing of scale and corrosion inhibitors which then stick together and settle out of the water.

Fouling in cooling water systems can be controlled by increasing the rate of blowdown, by the installation of side stream softening, by the use of the air rumbling procedure (the use of high pressure air to increase the turbulence of a water stream for mechanical descaling), or the use of chemical fouling inhibitors. Increasing the blowdown rate means increasing the make-up water rate, which can be expensive. Side stream softening by means of the hot lime-soda process reduces the suspended magnesium in the circulating water by precipitating magnesium hydroxides which aid in silica removal[(6)]. Iron is precipitated by oxidising it to yield insoluble ferric hydroxide. The oxidation is normally carried out with oxygen/air, chlorine or potassium permanganate[(6)].

There are essentially two types of fouling inhibitor; charge reinforcement dispersants and wetting agents[(2)]. The dispersants keep foulants in suspension, preventing them from settling onto the metal surfaces.

Microbiological fouling in cooling water systems are potentially the most dangerous, the slime-like deposits occur throughout the system. The slime deposits act as a filter to remove suspended solids from the water which leads to other forms of fouling. Cooling tower temperatures are well within the range in which these organisms survive and thus provide an ideal environment. There is also sufficient nutrient matter in the form of organic matter, nitrogen, phosphorus, ammonia, sewage and oxygen dissolved in the water[(2)].

In addition to the formation of deposits these organisms can be responsible for extreme forms of corrosion under these deposits by anaerobic bacteria. Chemicals available for the control of microbiological growth in cooling systems are[(2)] :

- oxidising biocides
- non-oxidising biocides
- biodispersants

Chlorine is one of the most widely used oxidising biocides. Non-oxidising biocides can be toxic and are not suitable for potable water. Biodispersants are used as aids to oxidising agents, they loosen deposits, thereby making destruction easier and more effective[(2)].

G2.3 Corrosion

Corrosion is the end result of scaling, fouling and microbiological activity. In a corrosion cell the corrosion process is made up of four components[(2)] :

- the pure metal donates electrons at the anode.
- the cathode accepts electrons from the anode.
- the oxygen and the water combine with the electrons to form hydro-oxides.
- the cooling water containing dissolved minerals provides the link to complete the corrosion circuit.

The main factors contributing to corrosion are the following[(2)]:

- water pH; if the pH is too low the water will be aggressive, if the pH is too high scaling will occur[(7)].
- the attachment of dissimilar metals.
- system deposits.
- dissolved gases; the presence of ammonia with oxygen increases the rate of corrosion of copper and its alloys.
- water temperatures; corrosion proceeds more quickly in hot water.
- dissolved solids; an increase results in a higher conductivity of the water.
- microbiological matter; increases corrosion by depositing on surfaces and generates highly corrosive by-product wastes such as hydrogen sulphide[(8)].

Corrosion and scaling in open recirculating systems can be effectively controlled by chemical means[(9,10)] :

- chromate programs.
- alkaline zinc programs.
- stabilised phosphate programs.
- all organic programs.
- synthetic anionic polymers and organophosphorous compound programs.

The type of program chosen will depend on the water chemistry as well as environmental considerations.

Chromates would not generally be considered in the mining environment, especially if the water is discharged underground, due to environmental problems associated with effluent containing chromates.

The alkaline zinc program operates in alkaline conditions in open recirculating systems. These programs are blends containing zinc, scale inhibitors and general dispersants which act to inhibit scale, corrosion and deposit formation. This program requires precise control and is sensitive to pH upsets. The stabilised phosphate program is a blend of polyphosphate which minimises corrosion of mild steel, an inhibitor to prevent corrosion of copper and copper alloys and an inhibitor to minimise fouling. This program is also very pH sensitive and is therefore seldom recommended for mine service water which is susceptible to wide fluctuations in pH and alkalinity.

All organic programs are non-metallic multifunctional treatments which prevent corrosion and scaling. The all organic chemical treatment is able to operate at pH, alkalinity and hardness levels beyond those normally tolerable in antiscalant programs, and therefore provides an excellent choice of treatment for systems using mine service water. If persistent low pH and alkalinity levels are experienced caution should however be exercised in the use of this program.

Synthetic anionic polymers and organophosphorous compound programs consist of anionic polymers which are strong dispersants assisting in the prevention of scale and fouling deposits and organophosphorous compounds which are effective in the stabilisation of scale forming species. Due to the fact that these programs operate at alkaline pH's, the corrosion potential is lowered but the program itself offers no corrosion inhibition. Low pH and alkalinity levels of the circulating water will cause corrosion to occur at increased rates when compared to other programs.

In order to prevent system deposits from dirt which will cause anode sites resulting in pitting corrosion, various techniques such as settling, filtering and chemical treatment are used to clean or purify water. From a chemical point of view clarification is the oldest and most widely used technique. It is a process applied to water for the removal of suspended solids, finer solids and colloidal material[2]. This process incorporates coagulation, flocculation and sedimentation.

G2.4 Biological Control

Different types of habitat within cooling systems encourage the growth of a variety of organisms:

- the daylight illumination of open cooling towers allows algae to develop.
- the anaerobic conditions which occur in dead legs and slime layers favours the growth of sulphate reducing bacteria which result in microbially induced corrosion.

Cooling water systems harbour two distinct microbial populations:[11]

- planktonic (free-floating) micro-organisms present in the circulating bulk fluid.
- sessile (surface attached) micro-organisms growing in biofilms.

These two micro-organisms differ very significantly in their sensitivity to biocides. In treating a cooling system, a biocide should be chosen for its ability to specifically control or remove sessile micro-organisms and biofilms as these are responsible for most biofouling problems.

Biofilm development is affected by the following cooling water system parameters[11] :

- ambient temperature affects biofilm thickness.
- water flow rate; an increase in flow rate results in an increase in biofilm thickness unless shear forces remove attached biomass.
- nutrient availability as low as 1 ppm can lead to biofilm development.
- surface material/ roughness; a rough surface biofouls more quickly.
- system temperature; a thicker biofilm forms at more favourable temperatures.
- pH; neutral is optimal.
- concentration of inorganic particles; these provide additional attachment sites.
- bleed rate; an increase reduces nutrient concentration.
- biocide type and quantity; effectiveness of the treatment will affect the biofilm.

The major groups of microbes found in cooling systems are green algae, diatoms, blue-green algae, fungi, protozoa and heterotrophic bacteria.[12] The algae and diatoms use carbon dioxide as their carbon source, the fungi, protozoa and heterotrophic bacteria use organic material as their carbon source. Organisms that may exist under deposits in cooling systems, in poorly oxidised closed loops and cooling systems with high concentrations of ammonia are sulphate reducing bacteria and fermentative bacteria, denitrifying bacteria and nitrifying bacteria respectively.

Microbiological fouling is controlled using chemical treatment which incorporates both biocides and biodispersants. Chlorine, an oxidising biocide, is commonly used for general bacteriological control[9]. Chlorine treatment is supplemented with non-oxidising biocides which contain dispersants since it has no penetrating or dispersant properties. The elevated pH conditions under which most recirculating cooling systems operate will adversely affect the chlorine's performance.

Other oxidising biocides include ozone, bromine, hydrogen peroxide, permanganate, chloramines, chlorine dioxide and certain hydantoins that donate hypobromous and hypochlorous acid[12]. Non-oxidising biocides include a variety of proprietary organic molecules e.g. carbonates, thiosulfanate, propyl diamine. The following factors must be considered when using non-oxidising biocides:

- required contact time.
- minimum concentration necessary to achieve kill.
- compatibility with scale/ corrosion inhibitors.
- half life at the pH and temperatures of the cooling system.

Additional information is given in Appendix F.

G3 CONCLUSIONS

Various methods exist to treat mine service water for cooling water applications:

- scale protection may be achieved through the use of scale inhibitors, side stream softening, reverse osmosis, ion exchange and electrodialysis.
- fouling can be controlled by increasing the rate of blow down, side stream softening, the air rumbling procedure or chemical fouling inhibitors.
- microbiological growth can be controlled using oxidising biocides, non-oxidising biocides and biodispersants.
- corrosion and scaling protection may be achieved through the use of various chemical addition programs. Dirt deposits can be prevented by using coagulation, flocculation and sedimentation.

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