Series A: Activity Guidelines

A3

BEST PRACTICE GUIDELINE

Water Management in Hydrometallurgical Plants

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

DIRECTORATE: RESOURCE PROTECTION & WASTE

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DOCUMENT INDEX

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

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APPROVALS

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

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PREFACE

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

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

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

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

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

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

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

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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.

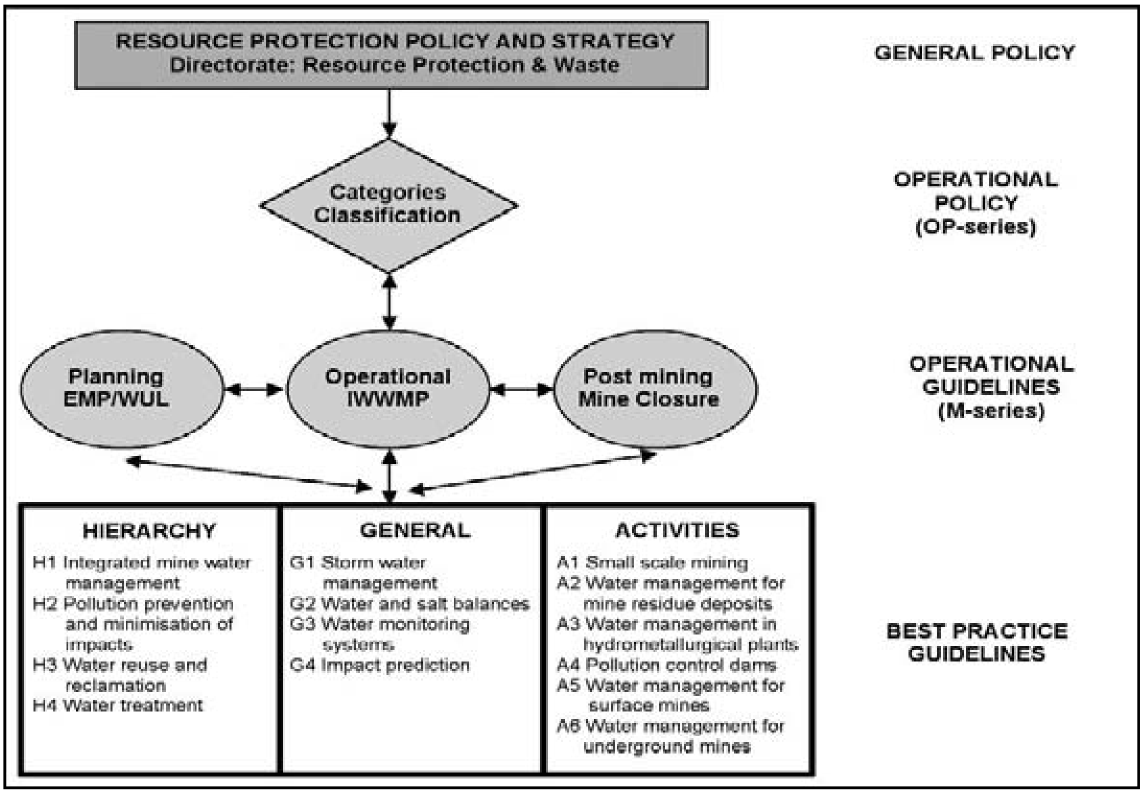
The overall Resource Protection and Waste Management Policy sets out the interpretation of policy and legal principles as well as functional and organisational arrangements for resource protection and waste management in South Africa.

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

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

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

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



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

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

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

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

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

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

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

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

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

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

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

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

CONTENTS

FIGURES

APPENDICES

ABBREVIATIONS & TERMINOLOGY

AMD:	Acid mine drainage
Auxiliary inputs:	Materials added to the process to help or assist the process or increase the speed at which it occurs.
Berm:	A bank/border (raised or piled up area) constructed (from soil/cement) to prevent water flowing over it thereby forcing the water to flow along a specific path as directed by the berm.
BPG:	Best Practice Guideline (documents in this series)
Bund:	An artificial embankment to ensure containment in a desired area.
Classifier:	Process to arrange or distribute in classes.
COC:	Contaminants of concern
Chpt:	Chapter
DWAF:	Department of Water Affairs and Forestry
ECA:	Environment Conservation Act, 1989 (Act 73 of 1989)
Filters:	Filtration is the physical separation used for the removal of fine suspended solids. May be effected in granular media filters (e.g. sand filter) or membrane filters (e.g. Nanofiltration).
Flotation:	The physical separation and removal of suspended material that settles slowly by bubbling air through the solution and allowing particulates to float to the surface on air bubbles, where it is skimmed off.
Grinding:	The process through which the particle size is reduced by crushing between two hard surfaces. The physical characteristics are therefore changed (smaller particles/powder) but not the chemical characteristics.
Hydrometallurgical:	Includes milling and grinding circuits; separation circuits (magnetic or other); refining circuits; classifiers, hydrocyclones, screens, filters, thickeners, flotation processes, electro-winning, leaching, solvent extraction, metal recovery and precipitation
IWWM:	Integrated water and waste management
IWWMP:	Integrated water and waste management plan
Leaching:	To let liquid percolate through some material with the objective of removing soluble constituents from the material and capturing them in the liquid phase. Leachate is the resulting liquid containing the dissolved substance.
Milling:	See grinding. Using a mill for the grinding process.
NEMA:	National Environmental Management Act, 1998 (Act 107 of 1998)
NWA:	National Water Act, 1998 (Act 36 of 1998)
PGM:	Platinum Group Metal; includes platinum, palladium, rhodium, ruthenium, osmium and iridium
Precipitation:	The process during which a substance (the precipitate) is separated from

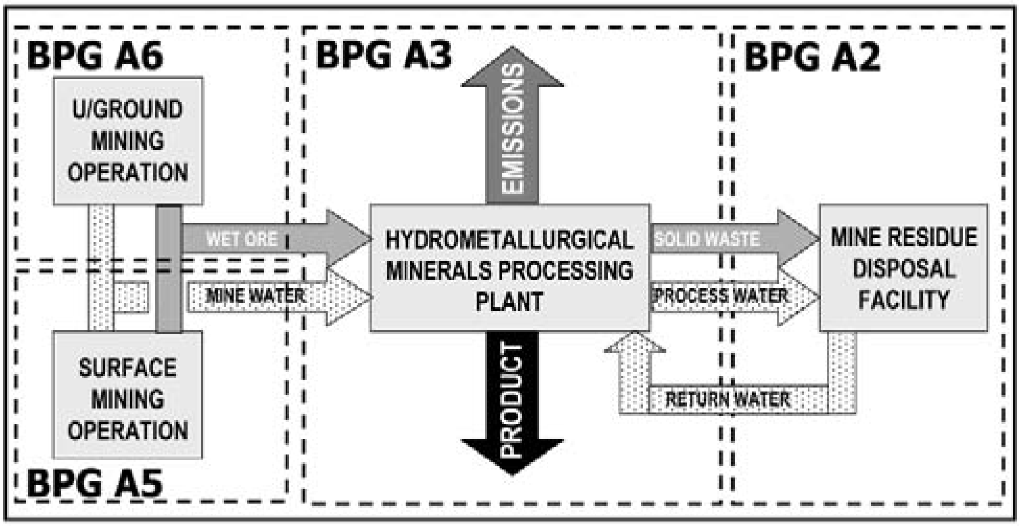
	the liquid (through the action of a chemical reagent or heat) in which it was previously dissolved and deposited in the solid state.
Pyrometallurgy:	The branch of extractive metallurgy in which processes employing chemical reactions at elevated temperatures are used to extract metals from raw materials, such as ores and concentrates, and to treat recycled scrap metal.
Raw water:	Water obtained from outside the operations; it may include water from the local service provider (municipality), bulk service provider or another water user and may be of a potable quality (drinking water supply from municipality) or water treated to a certain degree (treated sewage water)
Refining:	To free from impurities; to make purer or of a finer quality; to purify or cleanse.
Separation:	The separation of material into two streams based on some physical characteristic such as its magnetic properties of its specific gravity
Thickener:	It increases the density of the solution. A non-filter device for the removal of liquid from a liquid-solids slurry to give a dewatered (thickened) solids product; can be by gravity settling or centrifugation
Unreactive:	Materials that will not readily dissolve in water or react with water
WRC:	Water Research Commission

1 INTRODUCTION AND OBJECTIVES

The Hydrometallurgical Processing Plant is an integral part of the mining operation on many mines, including gold, coal and platinum. Hydrometallurgical processing plants typically feature as a central component of the mining operation in that these receive 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 hydrometallurgical processing plant are integrally linked with the preceding mining operation and the subsequent residue disposal facility and its associated return water systems, there are particular features that relate to water management within the hydrometallurgical processing plant itself. This Best Practice Guideline (BPG) focuses specifically on water management issues within the hydrometallurgical processing plant, while water management issues within the mining operations are covered in *BPG A5: Water management for Surface Mines and BPG A6: Water Management for Underground Mines* and water management associated with a residue disposal facility is covered in *BPG A2: Water Management for Mine Residue Deposits*.

This BPG (*BPG A3: Water Management in Hydrometallurgical Plants*) therefore only deals with water management issues within the boundary fence of the hydrometallurgical processing plant (see Figure 1.1 below) and excludes water management associated with the mining process/operation and the residue disposal activities. This BPG thus starts when ore (including water/moisture) and water from the mining operation arrives at the hydrometallurgical processing plant for processing and finishes when residue (tailings) leaves the processing site (generally via a pipeline) for disposal.

Figure 1.1: Best practice guidelines



The type of hydrometallurgical processing plant that is addressed in this BPG is one that focuses on the unit processes typically encountered in such a plant and would include: milling and grinding circuits; separation circuits (magnetic or other); refining circuits; classifiers, hydrocyclones, screens, filters, thickeners, flotation processes, electro-winning, leaching, solvent extraction, metal recovery and precipitation.

Hydrometallurgical processing plants 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, with their hydrometallurgical processing plants have 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 used 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, hydrometallurgical processing plants are required to tighten up the degree of water reuse and reduce the amount of wastewater discharged. This obviously has significant implications for water quality within the hydrometallurgical processing plants' water circuits, both in terms of potential effects on the efficiency of various unit processes within the plant, as well as on the equipment that makes up the plant in terms of scaling and corrosion. To ensure that improved water management within hydrometallurgical processing plants 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 plants 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.

Hydrometallurgical processing operations, if not managed correctly, have the potential to negatively impact on the surrounding environment and cause environmental damage on numerous fronts. Beginning with the exploration of prospective sites, through to the refining and beneficiation of minerals, many contaminating wastes are generated both directly and indirectly. If not managed correctly, these waste streams may pose serious threats to ecosystems and to human quality of life, and could also deteriorate resources, particularly water and soil. It is therefore important to minimize all pollutants, including air emissions, wastewater discharges and solid wastes as well as energy and water consumption.

An integrated water and waste management (IWWM) approach is based on the DWAF water management hierarchy for decision-taking and focuses firstly on waste and pollution prevention/avoidance. If complete prevention is not possible, waste and pollution minimization becomes the next area of focus and this may include the economic reduction of waste stream volumes and use of chemicals via process design. Thereafter reuse (recycling) and reclamation (recovery) becomes important and lastly, if all of the above have been considered, treatment (reduction of volume or hazardousness) and environmentally safe disposal remain the only options left to ensure the minimisation of the environmental impact.

Waste creation needs to be controlled during the production processes by integrating a series of highly effective pollution prevention measures, state-of-the-art environmental management practices and efficient treatment technologies/strategies in the polluting sections of the operation. Individually and/or collectively, these minimization strategies will reduce the quantities of pollutants released to small, manageable amounts, and will also enable treatment and removal of any toxic chemicals that may otherwise have been destined for discharge into the environment. In addition to preserving the environment, liabilities and operational cost will be reduced through such practices.

The prevention and management of pollution from hydrometallurgical processing plants is based on the environmental and water management systems in place on these sites as well as the production processes. These management systems should include a practical environmental policy, organizational procedures, research and development programmes, environmental responsibilities, allocation of dedicated resources and support, training, monitoring, management and treatment and operational adjustments and control.

This BPG is specifically aimed at water containing waste within hydrometallurgical processing plants associated with all types of mines and can also be applied to small-scale mines if simplified (refer to *BPG A1: Small-scale Mining*). Pyrometallurgical and smelter operations are not considered, although many of the principles and procedures covered in this BPG may be applicable to such operations. This BPG will also draw extensively on other BPGs that have already been produced and will cross-reference to these BPGs wherever it is appropriate to do so.

The primary objectives of this document are formulated as follows:

- To promote a strategic water management approach at hydrometallurgical processing plants that views and manages water as a key business asset with social, cultural, environmental and economic value.
- To provide a practical and logical process whereby water management within hydrometallurgical

processing plants can be optimized.

The first 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 second objective addresses the practical issues and guidance that will be required to give effect to the first objective.

The layout of the document is as follows:

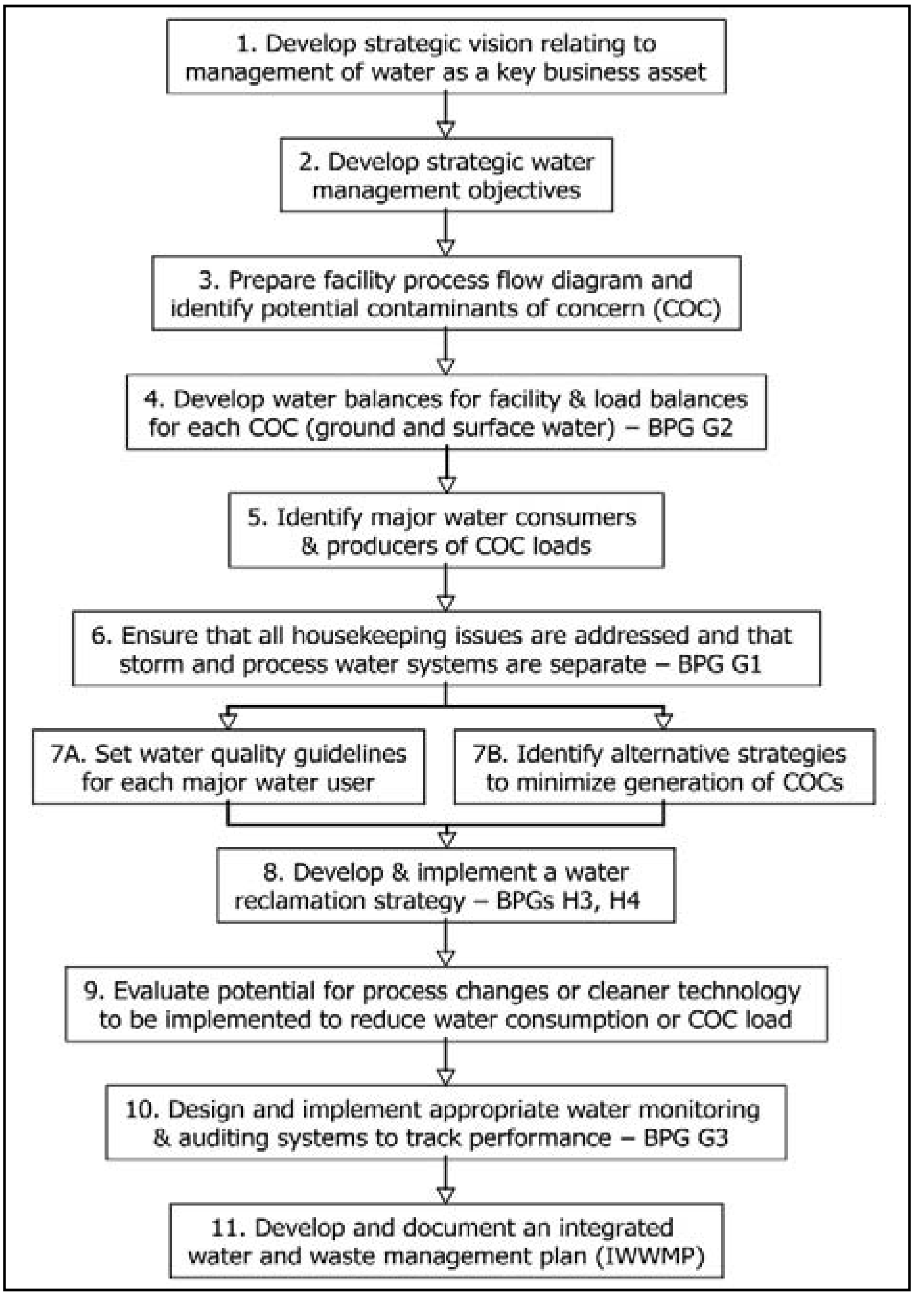
- *Chapter 2: General principles and considerations* for water management on a hydrometallurgical processing plant and the stepwise procedure to follow for efficient and effective water management on a hydrometallurgical processing plant.
- *Chapter 3: Legal framework* and legislation to consider in terms of water management at a hydrometallurgical processing plant.
- *Chapter 4:* Considerations within the different phases of the *mine life-cycle* and the importance to incorporate considerations into the planning and design phases already.
- *Chapter 5: Financial considerations* assessing the true cost and value of water as well as looking at water as a key business asset.
- *Chapter 6: Information gathering* to gain knowledge of the site and process, do water and salt balances and understand the mine/plant water users' requirements.
- *Chapter 7:* Housekeeping and water management systems aiming to:
  - conserve water;
  - segregate water of different qualities;
  - store material in the correct manner;
  - deal with high contamination risk areas;
  - manage storm water;
  - clean spillages efficiently and effectively;
  - maintain and repair equipment; and
  - make the operation sustainable.
- *Chapter 8: Water quality and constituents of concern* specifically preventing the deterioration of water quality by minimizing the generation of contaminants and establishing the water quality requirements of the mine/plant water users.
- *Chapter 9: Water reuse and reclamation* summary as per details contained in BPG H3: Water Reuse and Reclamation.
- *Chapter 10:* The need and significance of *process changes or cleaner technology,* the implementation of changes or technologies, barriers preventing implementation and how to overcome these barriers.
- *Chapter 11: Integrated water and waste management plan* compilation from information collected and strategies implemented by following the process stipulated in this BPG.

2

GENERAL PRINCIPLES AND CONSIDERATIONS

Figure 2.1 below shows an effective stepwise procedure that should be followed in a hydrometallurgical processing plant to ensure the efficient management of water. Details pertaining to the diagram are discussed further on in the document in the different Chapters as indicated.

Figure 2.1: Stepwise procedure for water management at a hydro-metallurgical processing plant



In order to support the two primary objectives of this BPG as listed in Chapter 1, a number of key principles or considerations are identified that need to be considered when implementing best practice water management within hydrometallurgical processing plants.

Understand the true cost and value of water: (Chapter 5)

The true cost and value of water includes all direct costs of water use on site as well as its value as a business asset required for continued operation, for example:

- Cost of exploration and extraction of groundwater;
- Social, cultural, environmental, and economic feasibility study costs;
- Waste stream disposal costs;
- Cost of water supply;
- Reticulation costs such as pumping, storage, power consumption;
- Water treatment costs;
- Mitigation and remediation costs in the event of spillage;
- Construction and rehabilitation costs of engineering works e.g. river diversions, clean/dirty water diversions etc;
- The value of ecosystem services reliant on the same water supply;
- Competing social and industry demands on the same resource;
- Competing industry demand for the same resource;
- Economic value to allow production and processing to take place; and
- Loss of income, jobs or market share if there are production cut-backs and interruptions as a result of water excess or shortage.

Apply general "good" housekeeping and operating practices: (Chapter 7)

- Avoid cross-contamination of materials and chemicals by keeping the work area clean and organized;
- Segregate waste streams (consider piping and storage facilities) based on their level of contamination.
- Install proper safeguards (bunded areas, diversion berms, concrete paving) and implement better cleanup practices (washing, sweeping etc);
- Consider general layout of the site and process plant as well as placement of facility;
- Know and have a good understanding of the plant and water circuits.

Optimize pollution prevention and reduction at source: (Chapter 7)

- Bund, contain and recycle certain high risk areas;
- Roof areas to prevent water infiltration;
- Concrete areas to prevent seepage into underlying groundwater;
- Slope areas to minimize erosion and maximize runoff.
- Divert storm water around major pollution sources.

Optimize water management systems: (Chapter 7)

- Design and operate for the separation of water circuits based on the level of contamination and possible uses. In particular, ensure a separation between process water circuits and the storm water system and ensure that process spillages cannot find their way into storm water systems;
- Develop and maintain an accurate water and contaminant balance for all water circuits – not only for potable water;
- Based on knowledge of which are the primary contaminants of concern (COC) for that particular process plant, develop contaminant balances for each COC and identify potential options for reduction of contaminant load;
- Define the water quality requirements of the different water users within a process plant. Define the worst possible water quality that each user can use without experiencing process or water quality related problems (e.g. corrosion and scaling);
- For storm water management, make provision for future sealing of areas and construction of roofs that cause increase in volume of runoff;
- Keep clean water clean – (refer to *BPG G1: Storm Water Management*) by rerouting groundwater springs and surface water streams to prevent contact with contamination/pollution sources;
- Construct diversion berms and channels to carry clean runoff away from solvent exchange, leach and tailings disposal areas or other possible pollution sources;

- Control erosion through measures such as retention ponds to intercept runoff and protection of stream banks;
- Manage process water. Contain dirty water (refer to *BPG G1: Storm Water Management*) in bunded areas for recycling in the bunded area or channel contaminated runoff and spills in drains to artificial basins and surge ponds (Pollution Control Dams) for containment and possible reuse and/or reclamation (refer to *BPG H3: Water Reuse and Reclamation*).
- Separate circuits to prevent cross-contamination of circuits;
- Setup water management systems in the different phases of development to ensure sustainability. Water management systems incorporated during the design and construction phases of an operation can be tailor-made to the application. With an existing operation, the water management system has to consider the existing system infrastructure.

Undertake inspection/monitoring/ auditing and maintenance: (Chapter 8)

- Ensure that equipment/machinery inspection and maintenance schedules are followed and that equipment/machinery is in peak working order to prevent wastage of raw materials and/or loss of production/processing time thereby ensuring product is not compromised;
- Ensure data availability on plant pollutants (refer to *BPG G3: Water Monitoring Systems*);
- Ensure sufficient water flow meters are installed, maintained and monitored.

Review resource intake/input/raw materials: (Chapter 8)

- Minimize or reduce raw material use;
- Use lowest possible chemical concentrations at which process can operate effectively through tight process control measures to prevent overdosing;
- Control purchasing, handling and storing of materials;
- Substitute raw and auxiliary materials with less harmful ones that can be more efficiently recycled thus feedstocks with fewer inherent by-products;
- Consider products and/or catalysts with longer lives and reuse possibilities;
- Minimize raw water intake into process (water conservation principle);
- Consider novel energy sources and efficient energy use;
- Avoid extraneous water streams being introduced to the process such as off-site runoff finding its way onto the site.

Optimize reuse and reclamation (recycling and recovery): (Chapter 9)

- Minimize waste by retrieving/recovering usable process materials and resources from waste streams;
- Convert in-plant waste and wastewater streams to clean feed, thus allowing for reclamation of chemicals and water for reuse in the plant (refer to *BPG H3: Water Reuse and Reclamation*);
- Recycle process spillages as close as possible to their source and do not allow to mix into one mixed contaminated waste;
- Evaluate waste streams for properties that make them useful rather than for properties that render them wastewater streams;
- Introduce waste into external recycling networks: industrial ecology. One industry's waste may become another industry's raw material;
- Consider new uses for otherwise valueless byproducts. Reclaim byproducts to sell;
- Save money through more efficient use of valuable resources (such as water and raw materials) and reduced treatment and disposal cost for waste.

Investigate process or technology modifications: (Chapter 10)

- Modify products and technologies to eliminate unnecessary production steps;
- Modify processes to minimize waste production and resources use;
- Improve process selectivity and/or conversion;
- Operate at lower temperatures and/or pressures to save energy and reduce the number of processes required to create these high temperature/pressure conditions;
- Implement efficient equipment design;
- Consider innovative unit operations and innovative process integration;

- Avoid heat degradation of reaction products and eliminate leaks and fugitive emissions;
- Perform product life cycle assessment (LCA) including process/activity, extraction, processing, manufacturing, recycling and disposal.

Consider options for application of cleaner technology: (Chapter 10)

- Evaluate the need and significance of cleaner technology to achieve higher production rates, improve product quality, increase operating efficiency, reduce environmental impact, reduce cost, ensure higher percentage on-line time and safe operating conditions;
- Assess the characteristics of cleaner technology;
- Implement cleaner technology in different areas of business such as policy development and institutional relations, environmental and social impact assessment, technological development, company strategy and education, research and training. Steps to implement;
- Applications (examples);
- Review barriers such as economic, technologic and legislative barriers that prevent the implementation of cleaner technology;
- Overcome barriers and implement cleaner technology through governmental intervention, education and training and improved planning.

Water and waste management programme: (Chapter 11)

- Ensure the programme is organized, comprehensive and represents a continuous effort to systematically reduce waste generation;
- Include pre-audit phase (adequate resources, commitment, objectives, scope, employee involvement), audit phase (data and information collection, cost accounting) and feasibility analysis (technology transfer, continuous review);
- Improve environmental auditing and implement environmental policies to achieve improved environmental goals;
- Shift emphasis of training programmes (from treatment to prevent, minimize and control);
- Redesign plants to better accommodate wastes;
- Setup baseline and continual monitoring (refer to *BPG G3: Water Monitoring Systems*) of ground, surface and process water as well as equipment and the subsequent implementation of action plans based on the results.

3

LEGAL FRAMEWORK

3.1 Focus and role of DWAF

The Department of Water Affairs and Forestry (DWAF) is the custodian of all water resources in South Africa and therefore responsible for the protection of these water resources. The protection of these resources includes preventing deterioration of water quality in these resources. From this perspective, DWAF generally focuses on the impact a hydrometallurgical processing plant has on the water resources and surrounding environment, thus outside the plant area. DWAF is therefore generally not too interested in the details pertaining to the site/plant and hydrometallurgical process. It is only once it has been established that the hydrometallurgical processing plant does in fact negatively impact on the surrounding environment and water resources that DWAF becomes concerned with the operation and water management within the boundaries of the plant. At this stage DWAF may investigate water management on the hydrometallurgical processing plant to establish the origin of the impact noted on surrounding water resources.

In terms of any mine hydrometallurgical processing plant and its water and waste management, the following legislation should be considered as a minimum and these can be obtained from internet sites (http://www.acts.co.za or http://www.info.gov.za/gazette/acts):

- Environment Conservation Act, 1989 (Act 73 of 1989) with GN R1182 and GN R1183.
- National Environmental Management Act, 1998 (Act 107 of 1998).
- Minerals and Petroleum Resources Development Act, 2002 (Act of 28 of 2002).
- National Water Act, 1998 (Act 36 of 1998).
- Water Act, 1956 (Act 54 of 1956) (repealed) with GN R1560 re dams with a safety risk.
- Water Services Act, 1997 (Act 108 of 1997).

3.2 National Water Act

The National Water Act of 1998, Act 36 of 1998 (NWA) is the principal legal instrument relating to water resource management in South Africa and it is obtainable from the DWAF internet site (http://dwaf.gov.za/documents). The following is of particular importance:

- Chapter 3, Part 4 states that anyone who owns, occupies, controls or uses land is deemed responsible for taking measures to prevent pollution of water resources.
- Chapter 4 deals with water use regulation;
- Chapter 12 deals with water management in terms of dam safety;
- Section 19 deals with water management at mines in terms of pollution prevention and control;
- Section 21 states the water uses requiring authorization;
- Section 26 (1) provides for the development of regulations requiring monitoring, measurement and recording as well as the effects to be achieved through management practices prior to discharge/disposal.

Regulations on use of water for mining and related activities aimed at the protection of water resources

Government Gazette 20118 (volume 408) notice 704 (GN 704), published on 4 June 1999, stipulates regulations on the use of water for mining and related activities aimed at the protection of water resources. The following conditions are worth noting here:

- Condition 4 regarding restrictions on the location of mining activities.
- Condition 5 regarding the restrictions on use of material.
- Condition 6 regarding the capacity requirements of clean and dirty water systems as well as the containment to prevent spillage between the systems more than once in 50 years.
- Condition 7 regarding the protection of water resources through pollution prevention measures that deals with the collection, containment and reuse/evaporate/treat/dispose of water containing waste; water and waste management; minimizing water contact with mining activities or infrastructure; dam stability; erosion control; recycling of process water and the prevention of process spillages; maintenance of water systems; disposal of waste and wastewater.
- Condition 8 regarding security and additional measures.
- Condition 9 regarding temporary or permanent cessation of activities.

3.3 DWAF Waste Management Series - Minimum Requirements

The Waste Management Series produced by DWAF (second edition published in 1998 and subsequently being revised) indicate DWAF's requirements in terms of the management of waste and consists of a series of documents, namely:

- Minimum Requirements for the Handling, Classification and Disposal of Hazardous Waste.
- Minimum Requirements for Waste Disposal by Landfill (revised in 2005).
- Minimum Requirements for Monitoring at Waste Management Facilities (revised in 2005).
- Minimum Requirements for Waste Management Training (envisaged).
- Minimum Requirements for Upgrading Waste Disposal Operations (envisaged).
- Minimum Requirements for Waste Management Facility Auditing (envisaged).

3.4 Best Practice Guideline series

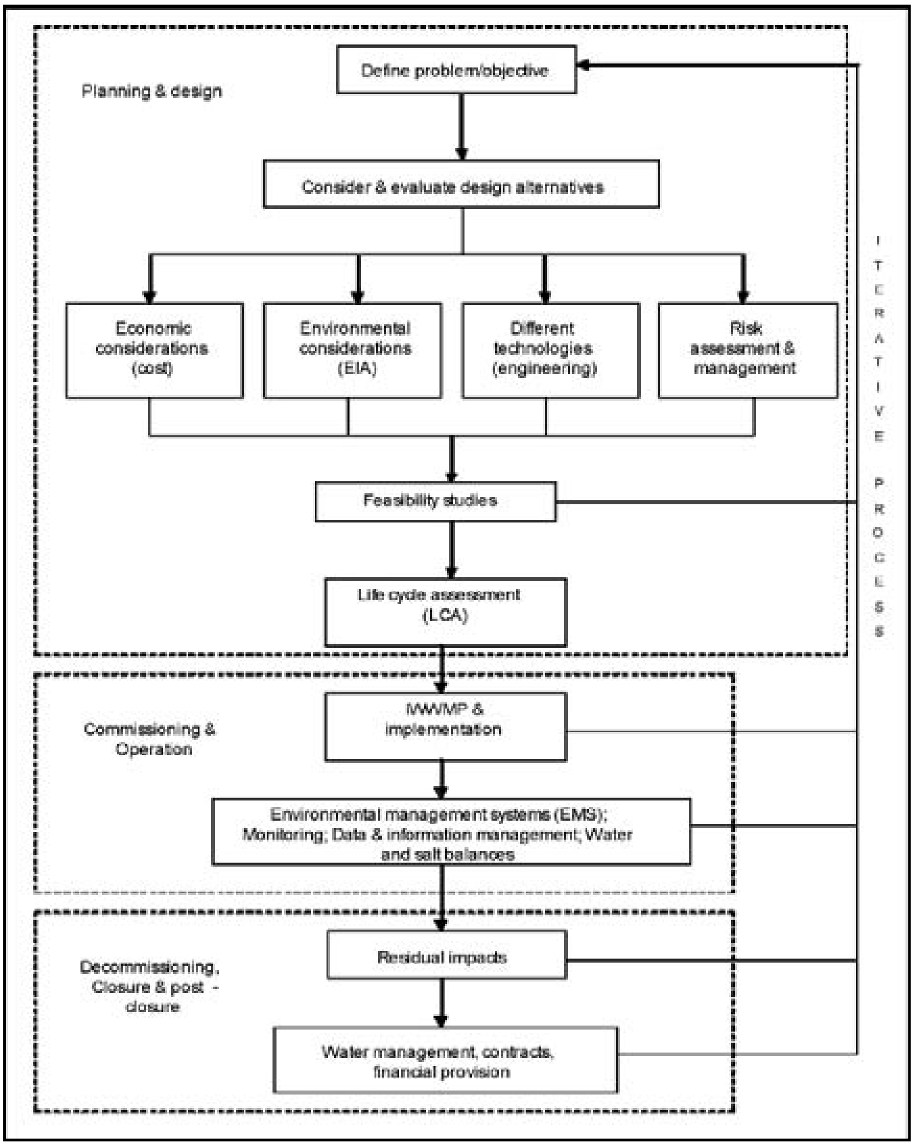
A mine and therefore a hydrometallurgical processing plant associated with a mine are required to implement the principles of IWWM throughout its life cycle. There is no legal or regulatory obligation for a mine or hydrometallurgical processing plant to use the procedures and guidelines provided in this BPG document as currently the only legally required documents associated with IWWM is the Environmental Management Plan (EMP) and Water Use Licences/authorisations Applications (WULA). The procedures and guidelines presented in this BPG need to be incorporated into the EMP and will assist in implementing IWWM. The documentation of the IWWM principles into an IWWM plan can be used as motivation during the WULA. Practical motivation for such a plan is clear as access to such a documented IWWM plan will greatly assist the mine and hydrometallurgical processing plant in meeting its obligations in terms of the various environmental laws and regulations that affect water and waste management over the full life-cycle of the mine.

Further, if a mine and hydrometallurgical processing plant adhere to this BPG and others in this series as well as the principles of IWWM they will be considered to have met the DWAF requirements in terms of source directed regulatory measures.

4 CONSIDERATIONS WITHIN THE MINE LIFE-CYCLE

Water management is aimed at ensuring the effective use of South Africa's scarce water resources and therefore assists with water conservation and the protection of the water resources in general. The stepwise process depicted in Figure 2.1 allows for review at each stage/step. In addition, fully defining the problem and gathering the required data in the initial stages ensures that future decisions are based on complete information. Figure 4.1 below sets out the key points to consider during each of the life-cycle phases.

Figure 4.1: Considerations in the mine life-cycle



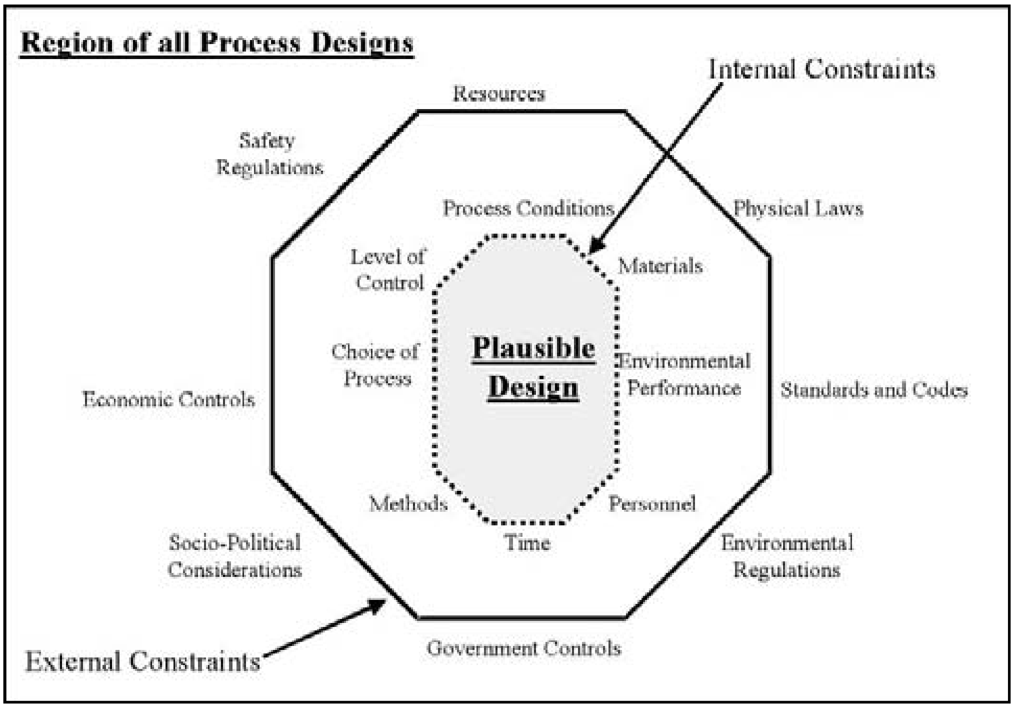
4.1 Exploration, prospecting, planning, feasibility and design phase

Cano-Ruiz and Mc Rae (1999) indicated that including environmental considerations in the problem framing exercise increases the number of constraints on the design process. Generating process design alternatives may include the application of existing design concepts or the generation of new ones from first principles. Time available during design, limits the number of alternatives that can be generated and considered as well as the level of detail to which these alternatives can be analysed (trade-off between comprehensiveness and economy). Engineering analysis usually begins with evaluation of mass and energy balances for each of the candidate process flow sheets and these are then used to determine flow rates, compositions, pressure, temperature, and physical state of all material streams, as well as the energy consumption rates from various sources. Analysis evaluates the design alternatives against a predetermined set of performance indicators (economic and environmental impacts) or objectives. The design process is an iterative process guided by opportunities for improvement. The authors propose that further incorporation of integration principles will reveal opportunities to decrease raw material consumption, realising increased cost savings. Refer to this and other references (Chapter 12) for further reading on the importance of design.

Figure 4.2 below indicates all the aspects and constraints that need to be considered during design. External constraints to consider during the design include:

- Resources
- Safety regulations
- Economic controls
- Socio-political considerations
- Government controls
- Environmental regulations
- Standards and codes
- Physical laws

Figure 4.2: Process design constraints (Marr, 2003)



Internal constraints to consider during the design include:

- Process conditions
- Level of control
- Choice of process
- Methods
- Time
- Personnel
- Environmental performance
- Materials
- *Cost:* 85% of the life cycle cost, financial and environmental, are determined by decisions made in the planning and design phases (Marr, 2003) and the importance of this phase can therefore not be over-emphasised. The early stages of the design process offer the greatest flexibility in selecting the process routes for a facility and decisions made during this stage are therefore critical and have major impacts on future phases. A further estimated 50% of capital expenditure on new plants is associated with issues pertaining to environmental management (Marr, 2003).
- *Life Cycle Assessment (LCA):* Address all material and energy transformations over "cradle to grave". This means emissions and the consumption of resources at every stage in a product's life cycle, from its cradle (raw material extractions, energy acquisition) to its grave (use and waste disposal) needs to be considered. An inventoried listing of environmental technologies, treatment processes, and toxic chemicals used, should be made up front.
- *Environmental Impact Assessments (EIA):* Generally, at the stage at when the EIA is conducted, it is not easy to incorporate EIA information in the design process in order to reduce the environmental impact of hydrometallurgical processing facilities, but it is essential. It is therefore important to ensure that EIA information is incorporated into the design phase and that environmental and community related impacts are considered. Some impacts to be considered include acid mine drainage, metals in the environment, toxic reagents including cyanide, sedimentation and water use, waste, emissions.
- *Environmental impact considerations:* Review and take account of the environmental impacts of exploration, infrastructure development, mining or processing activities, and conduct the planning, design and development of all facilities in a manner that optimises the economic use of resources while reducing adverse environmental impacts to acceptable levels. It is widely recognised that early consideration of environmental matters during the design is needed to obtain good environmental performance at lowest cost (set environmental concerns as constraints on economic optimisation). The early stages of conceptual process design which are generally rather flexible provide the greatest opportunities for identification of potential environmental impacts and to take remedial action.
- *Risk assessment and management:* Employ risk management strategies in planning and design, operation and decommissioning, including the handling and disposal of hazardous materials and waste. If a preliminary risk assessment indicates unacceptable risks for human health or the environment, the lack of full scientific certainty should not be used as a reason to delay the introduction of cost-effective measures to reduce environmental and human health risks to acceptable levels. An example of a detailed risk assessment process used and implemented during the project design phase is shown in Appendix C.
- *Efficiency and optimisation:* Plan, develop and design facilities and processes taking into consideration the efficient use of energy, water and other natural resources and materials, including their recycling and reuse, the minimization of waste and the responsible management of residual materials.
- *Feasibility studies:* Undertake detailed planning and feasibility studies on the overall water balance, site/ plant layout, infrastructure development and operation in consultation with design and process engineers.
- *Technologies:* Consider and evaluate different hydrometallurgical process technologies and designs in order to optimise the overall water balance, reuse/ reclamation and water management.
- *Inputs:* Identify possible water sources (water service providers, local and surrounding catchments, captured rainwater, or water imported with raw materials) and undertake financial assessment of water cost. Review the intake of other resources (energy etc) and raw materials. Determine water quantity and quality requirements based on process design.
- *Outputs:* Aim to minimise emission of contaminants of concern, mass of waste generated, contribution to specific environmental problems, and overall environmental impact.
- *IWWMP:* Compile and include above into an Integrated Water and Waste Management Plan.

4.2 Commissioning and operational phase

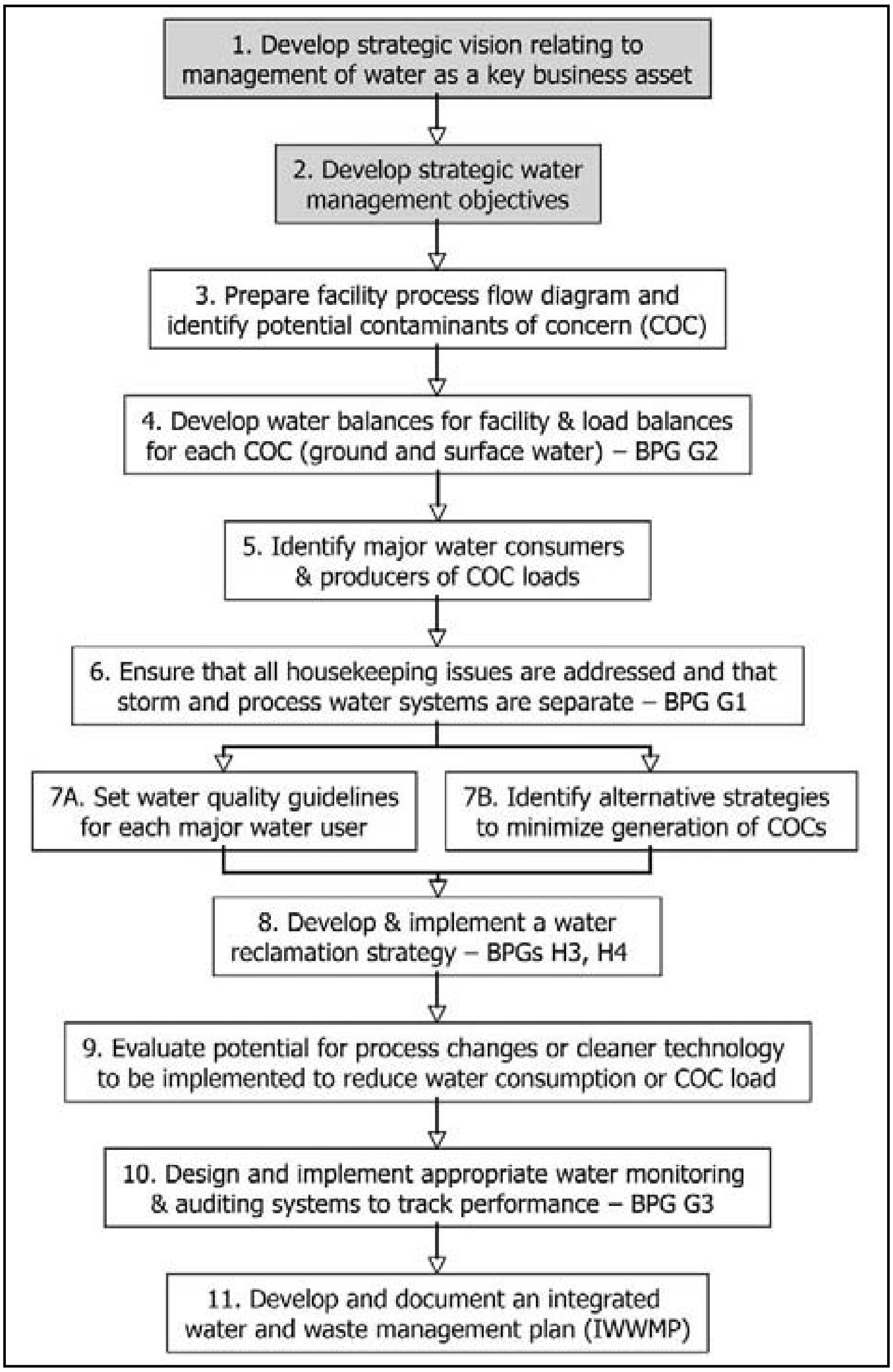
- *Implementation:* Implement designs and processes based on results of planning, design and feasibility phase.
- *Health and safety measures:* Apply control measures to ensure the continued health and safety of all workers on as well as visitors to the site.
- *Pollution prevention:* Optimise pollution prevention and reduction/minimisation at source. Experience has shown that any IWWM plan is more easily and cost effectively applied if pollution prevention strategies were optimally applied first. It is therefore considered advisable to first investigate, develop and implement appropriate pollution prevention strategies wherever possible, e.g. early recognition of the potential for spillages and the adoption of appropriate risk management strategies.
- *General:* Apply general "good" housekeeping and operating practices.
- *Technologies:* Continuously evaluate process technologies and facilities in terms of their water requirements and use. Consider whether modifications, improvements or new technologies can be applied to reduce these water requirements and uses.
- *Environmental Management System (EMS):* Implement an EMS to ensure more effective control and reduce environmental impacts and should include organizational procedures, responsibilities, processes, implementation strategies, measurement and evaluation criteria, efficiency measures, staff training and goals for improvement.
- *Review:* Continuously review and improve water management. Review and revise IWWM plan annually based on performance assessments and changes in the system.
- *Monitoring:* Implement monitoring system to verify performance. Perform regular maintenance, refurbishment, inspections and performance assessments. Environmental audits at regular intervals should also be implemented and include a thorough investigation of every industrial system and process. Refer to *BPG G3: Water Monitoring Systems*.
- *Database:* Store and manage information collected in a database. The database should show baseline conditions as well as allow assessments of data to determine when changes in conditions occur.
- *Water and salt balance:* Refer to *BPG G2: Water and Salt Balances*.

4.3 Decommissioning, closure and post-closure phase

- *Residual impacts:* Verify latent/residual impacts through monitoring systems, performance assessments and predictive modelling.
- *Water management:* Define post-closure water management options and determine best practicable environmental option, e.g. treatment and discharge, irrigation, sustainable development projects, etc.
- *Finances and contracts:* Finalise financial and contractual arrangements/agreements for post-closure water management and maintenance of infrastructure with future landowners and/or responsible parties and/or water users.

5

FINANCIAL CONSIDERATIONS (STEPS 1 AND 2)



5.1 Water, a key business asset (Step 1)

Due to the limited water resources available in South Africa, the competition for this valuable resource is continuously increasing. DWAF as custodian of the natural water resources is responsible for the allocation and management of the demand on the water resources as well as the protection of these water resources against unacceptable quality deterioration. Globally and nationally, the trend has been to prioritise water for human use (domestic use), food production (agricultural use) and aquatic ecosystems (ecological functioning) ahead of industry such as mining. This trend is evident in South Africa and reflected in our legislation and regulations (NWA, reserve determinations).

With attitudes changing, water is increasingly seen as a valuable resource. Increasing water demands have resulted in a higher proportion of water being recycled internally in industries as well as the use of relatively impure make-up water such as treated effluents rather than potable water supplies. The impact of process water quality has therefore also become an important consideration.

It has therefore become important for the mining and hydrometallurgical processing industry to:

- not take water for granted as it is a limited, scarce and valuable commodity in South Africa that needs to be conserved;
- follow a pro-active approach in terms of water management whereby measures are implemented to prevent impacts rather than mitigating impacts after occurrence;
- incorporate water issues into strategic business decision-making to ensure sustainable use and development of the industry;
- ensure all current and future water users are not adversely affected by the metallurgical activities as water is a shared community resource and other users' interest and rights need to be respected;
- reduce operating cost over the long term due to efficient water use through water conservation; and
- optimise reuse and reclamation (refer to *BPG H3: Water Reuse and Reclamation*); and
- realise water is a key business asset with social, cultural, environmental and economic value.

Mines and hydrometallurgical processing plants should therefore identify opportunities and minimise risk in terms of their water management plan. Responsible water management will improve the public's view of the industry, the holding company and the specific operation. Water management is now more often scrutinised by external parties in applications for funding and legal authorisations. It has therefore also become important to incorporate water risk into key business decisions.

5.2 True value and cost of water (Step 2)

In South Africa, water remains relatively cheap and is therefore seldom brought into the production cost equation. The marginal economic advantage of effective water management therefore requires it to be influenced by other factors such as social pressures, coercion from authorities, compliance with legislation or intent to operate in an environmentally responsible manner. Water management can account for up to 15% of the cost of hydrometallurgical processing (Wates and Van Niekerk, 1991) and it depends on water use efficiencies (wastage and losses) and the relative density of process pulps. As the relative density of the process pulp decreases, the water volume in circulation increases, which requires an increase in transport and storage capacity, causing increases in costs. Product lost in the water used for transport should also be considered as a cost factor.

Water costs money and in order to save money an operation needs to reduce water usage (water conservation), recycle more water (refer to *BPG H3: Water Reuse and Reclamation*) and keep used water as clean as possible (pollution prevention) for reuse and ultimate disposal.

The true cost of water includes all direct and indirect costs associated with water and includes:

- *Exploration, prospecting and planning cost* – including:
  - groundwater extraction in exploration area;
  - water used by exploration/prospecting operations and workforce;
  - conceptual and detailed designs;
  - environmental impact assessments;
  - feasibility studies;
  - risk assessments;
  - construction;
  - engineering works;
  - capital outlay etc.
- *Water supply cost* – including:
  - obtaining water from a water service provider (raw water charges);
  - establishing connections to the main water supply line;
  - abstracting water from boreholes or surface water bodies;

- competing industries' demand for same resource;
- trading of water use entitlements in a water scarce catchment;
- excess or shortage of supply etc.

• *Social and cultural cost* – including:
- perception by society and surrounding water users;
- responsible water management to improve public view;
- responsible care;
- ensuring water availability to other users as required;
- water used by industry and therefore lost to surrounding communities and downstream users;
- responsibility to community etc.

• *Environmental and ecological cost* – including:
- water used and discharged thereby affecting the natural surrounding environment including aquatic ecosystems;
- limited resources and regional water shortages;
- environmental responsibilities;
- move the focus from site boundary conditions to catchment level impacts (broader focus);
- consequences of releasing materials to surrounding ecosystems etc.

• *Economic feasibility cost* – feasibility of the operation considering all expenses and incomes.

• *Waste management cost* – including:
- the handling, transport, treatment and disposal of all solid waste residues as well as wastewater;
- waste discharge charges (refer to waste discharge charge system);
- discharge/disposal cost based on volumes/ quantities;
- contaminants load and receiving environment etc.

• *Operational cost* – including:
- water supply;
- equipment;
- reticulation/pumping;
- maintenance and refurbishment;
- labour/personnel;
- power consumption;
- waste management;
- engineering and infrastructure;
- clean and dirty water separation etc.

• *Water reticulation costs* – including:
- pumps;
- pipelines;
- energy/power consumption;
- pumping for transport;
- storage facilities with required capacity;
- water losses and wastage etc.

• *Water treatment cost* – including:
- the treatment of water to improve quality for use or to allow for reuse in the process;
- treatment for use by another industry;
- treatment for discharge purposes etc.

• *Maintenance cost* – including:
- maintaining water infrastructure such as storage facilities, pipelines and pumps as well as monitoring equipment such as flow meters;
- maintenance of water infrastructure due to corrosion/scaling etc.

• *Labour/personnel cost* – including:
- personnel responsible for monitoring water use, sampling water, managing water, information capturing, doing assessments and reporting, maintenance;
- training and skills development;
- jobs;
- interaction and relationships with stakeholders;
- allocation of dedicated human resources;
- support functions etc.

• *Remediation cost* – including:
- mitigation and remediation of spillages during operation;
- remediation and rehabilitation of site after decommissioning and closure etc.

• *Legal cost* – including:
- acquisition of necessary licenses and authorizations;
- fines for breaches of regulations;
- regulatory demands etc.

• *Risk cost* – including:
- technical risk (risk of using a "poorer" water quality versus the saving in water purchasing cost);
- environmental risk that may lead to liabilities;
- market price changes etc.

The true value of water incorporates perceptions of water by external parties and the value for the continued operation of the business, for example:

- Cultural or spiritual associations with water or the land on which water infrastructure is planned;
- The value of ecosystem services reliant on the same water supply;
- Competing social demands on the same resource (e.g. domestic water supply or recreational use);
- Social, cultural, environmental or economic impact on downstream water users if water quality is affected by operations or not available to other water users;
- Impact on reputation for perceived poor water management performance;
- Cost to the operation if water excess or wastewater cannot be discharged;
- Economic value to allow production and processing to take place; and
- Loss of income, jobs or market share if there are production cut-backs as a result of water excess or shortage.

A strategic water management approach should thus ensure that water is more efficiently managed and valued as a vital business and community asset.

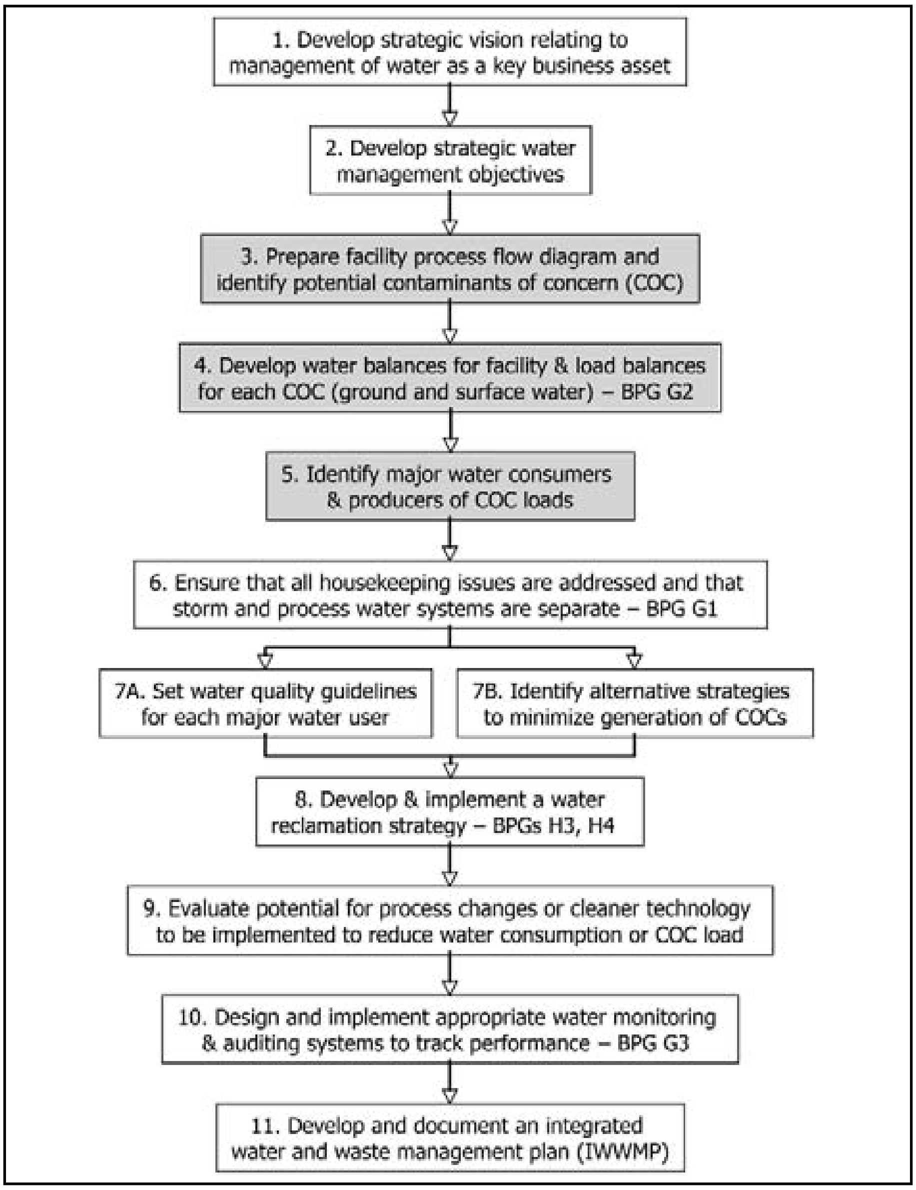
The reuse of process water in hydrometallurgical processing plants is often desirable not only for environmental protection reasons but also for the cost saving associated with it. Cost savings are seen in terms of reducing the quantity of external water to be purchased and consumed, simplifying operations, saving in infrastructure cost by reducing the transportation infrastructure requirements (piping) etc.

In terms of financial considerations, it is also important to realize the benefits industry often brings to an area or community which may include:

- The establishment of water supply infrastructure and water supply to communities in the area;
- Social benefit in terms of job creation, infrastructure and services establishment, improvement of quality of life; and
- Economic benefit in terms of financial investments made in the region and country.

6

INFORMATION GATHERING (STEPS 3, 4 AND 5)



6.1 Site and process knowledge (Step 3)

Only issues known and understood can be managed. To apply “good” housekeeping practices and operating procedures (Step 6), it is therefore essential to have a good knowledge and understanding of the plant. Knowledge and understanding about the following items are required:

- *Site:* General site and plant layout; site locality in proximity to power/electricity supply, water supply, roads, rail and other support infrastructure has obvious benefits; site location in relation to water resources is important in terms of impacts on water resources; underlying geology of the site in terms of possible groundwater impacts; site limitations such as boundary, possible expansions, topographical gradients, soil conditions; site water management plans; site location in terms of locality of ore body (mine) will affect transport cost etc.

- *Environment/catchment:* Geology of the area; groundwater/aquifer characteristics; boreholes and springs; geohydrology; topography of the area; climate (precipitation, evaporation etc); biogeochemical cycles; dams and water courses; hydrology; wetlands; water users; surrounding land uses; sensitivity of receiving and surrounding environment; water quantity and quality (groundwater and surface water); contaminants of concern in terms of the environment; variability of environmental conditions (drought, seasonality etc); reserve determination (obtain from DWAF) and water quality objectives; catchment management agency etc.
- *Process:* Process flow diagram; piping and instrumentation diagrams; process features (pH, oxidation-reduction conditions); process methodologies; process flexibility (expansion); equipment and infrastructure; power/electricity requirements for the process; inputs and outputs; contaminants of concern in terms of the process technology used; process sensitivity to variability and changes; technology design and operation; type and scale of operations; steps including ore preparation, concentration of metal minerals, solubilising metals, purifying solutions through removal of impurities, recovery of metals from solution (oxide ores are for example not well known for their floatation characteristics and are thus treated as whole ores in hydrometallurgical facilities by heap, vat or high-pressure acid leach, or reductive pyrometallurgical processes whereas sulphide ores can be treated in concentrators to separate a concentrate, from the tailings material, which could be further processed in a roaster or smelter followed by a hydrometallurgical facility, or directly by a hydrometallurgical facility).
- *Raw material/ore:* Type of rock/ore being mined and processed (sulphide/oxide); characteristics of the mined material (geochemistry); mineral ore grade; variability and non-homogeneity of ores in terms of metal content; mineralogy; impurities present in the ore body; complexity and variability (quantity and quality) of the feed.
- *Other inputs:* Characteristics of other materials/ chemicals used in the process; concentrations of elements; form of elements (speciation).
- *Water resources:* Be pro-active in investigating potential water supply sources; consider ground- and surface water resources; excess or scarcity of water; sustainability of resources; sensitivity of receiving water resources; water quantity and quality as well as its variability (seasonality); contaminants of concern; assess impacts of water supply sources on process/ plant performance.
- *Other resources:* Allocation of dedicated resources; personnel and teams; training and skills development; infrastructure (equipment); finances (funding); accountabilities; responsibilities; time investment; management commitment and support.
- *Mine/plant water users:* Process water quantity and quality requirements (sulphide ore flotation has strict requirements in terms of the water phase's chemical composition due to wet oxidation); laboratory/pilot studies to investigate impact of water supply on mine/ plant water users; process sensitivity to quantity and quality as well as variability; contaminants of concern; possibility of water reuse and reclamation in or between processes (refer to *BPG H3: Water Reuse and Reclamation*); water treatment required to make water fit for use (refer to *BPG H4: Water Treatment*). Also see Section 6.3 below.
- *Waste:* Solid, liquid and gaseous waste generated on site; handling and management of waste; waste transport; waste treatment to reduce volume, hazardousness or impact; disposal/discharge of waste.
- *Water reticulation:* Reticulation systems; limitations; different and separate circuits; closed circuits; storm water management and incorporation of contaminated storm water into water circuits (refer to *BPG G1: Storm Water Management*); management of process water and spillages; prevention of losses from system (maintenance and inspection); inputs to the system (precipitation, supply water, ground- and surface water abstraction, recycled water); outputs from the system (evaporation, runoff, seepage, regulated and unregulated discharges, losses); storage in the system.
- *Monitoring:* Water measuring and monitoring; monitor all inputs and outputs; assessment of impacts on ground- and surface water resources due to operation; pollution plumes; water and salt balances (refer to *BPG G2: Water and Salt Balances*).
- *Future:* Future plans; changes in technology (cleaner technology – Step 9); expansions; research and development.

6.2 Water and salt/load balances (BPG G2: Water and salt balances) (Step 4)

BPG G2: Water and Salt Balances deals with the design, compilation, implementation and management of water and salt balances in detail and the details will therefore not be repeated here. The following are however, worth noting in this document:

- *Objectives:* Clear objectives should be stated for the water and salt balance; the objectives should consider the current as well as possible future scenarios in the plant (plant life-cycle).
- *Divisions:* The water and salt balance for a large complex operation should be divided into smaller management units; the same formats and procedures should be employed for each management unit to allow the exchange of information over management units; establish boundaries for individual balances; differentiate between different water circuits.
- *Updates:* The water and salt balance should be updated regularly to include process changes, new information, expansions, new data linked with monitoring (refer to *BPG G3: Water Monitoring Systems Systems*), management measures implemented etc; updates should be an iterative process in order to obtain higher levels of accuracy and for refinement; the water and salt balance should be flexible to allow for and accommodate changes.
- *Loads:* Conservative salts should be used to construct overall water and salt balances; pollutants or contaminants of concern can be used to determine pollution loads;
- *Calculation of unknowns:* Unknowns can be calculated through the simultaneous solution of equations; develop such equations; address imbalances.
- *Hydrological cycle:* Consider seasonal changes; wet and dry seasons; precipitation; evaporation; run-off; percolation/infiltration to groundwater aquifer; seepage etc.
- *Output:* Level of detail is based on objective; validation of results/output; manual calculations; spreadsheet based balance; PC-based software; high-end engineering software; computerized system.

Water and salt balances are important water management tools to be used to provide guidance in terms of management actions required, areas to focus on in terms of pollution load, major water consumers, etc.

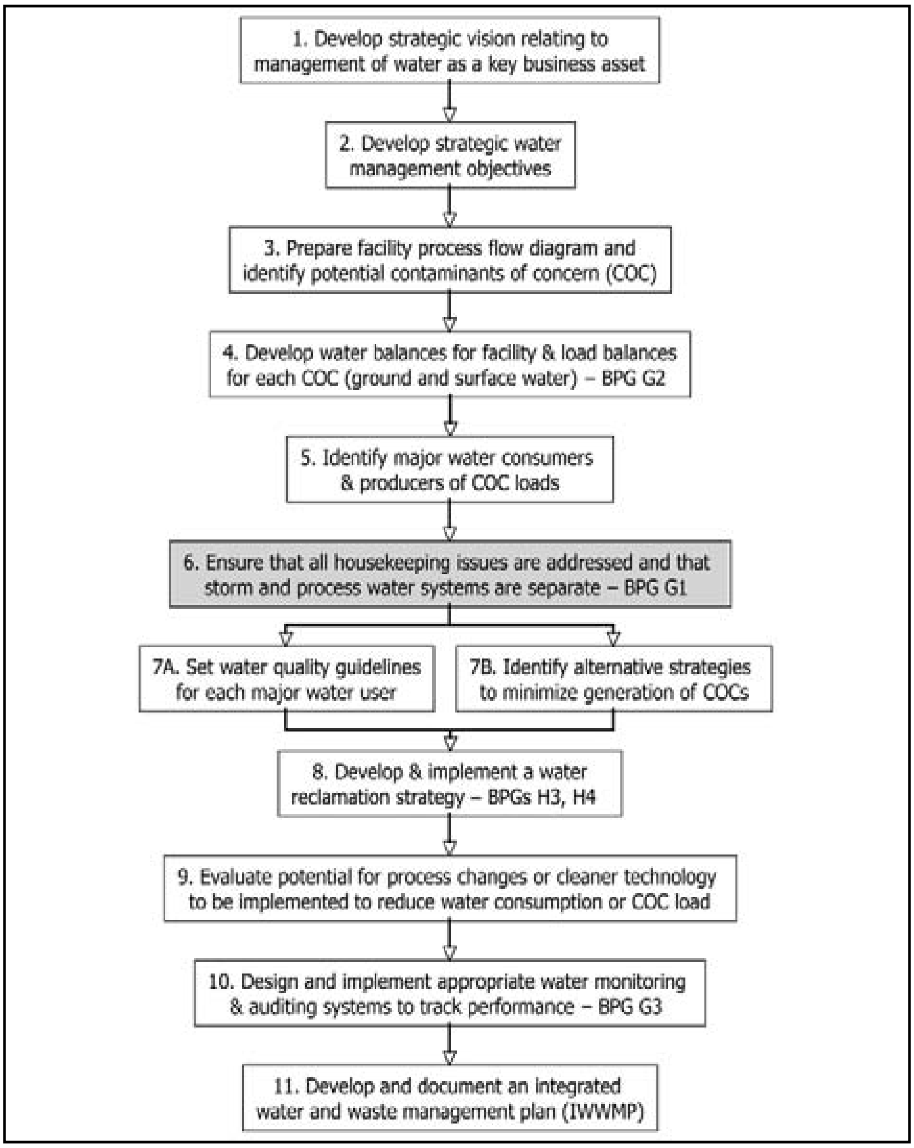
6.3 Mine/plant water users (Step 5)

As part of the site and process information gathering, knowledge should have been obtained in terms of the water sources available. It is equally important to obtain information on the mine or process plant water users in terms of:

- *Water quantity requirements* - Major water consumers.
- *Water quality requirements* – Is potable quality water required or can effluent from another user/process possibly be used? Consider that some mine/plant water users may be sensitive to certain constituents in the water and these constituents may in certain instances have a negative effect on the specific mine/plant water user or its process performance (see contaminants of concern).
- *Sensitivity to quantity and quality changes as well as variability* – Supply water may change in quality over time, for example if water is continuously recycled, some constituents (such as TDS or salinity) may increase in concentration (accumulation) with each cycle (due to evaporation and subsequent concentration of dissolved salts) and may therefore alter the chemistry of the system. Equalization or stabilization ponds (tanks/dams) may be required to ensure less variability to the user sensitive to changes.
- *Contaminants of concern* – These are contaminants or constituents in the water that may affect/impact process performance.
- *Pollution loads* – Constituents found in water at higher concentration than expected. The source of the additional concentration of the constituent/contaminants is a direct result of an activity such as processing. Contaminants are also added to water as it is used and recycled.
- *Water reuse and reclamation* – Examine the possibility of water reuse and reclamation in or between processes. Refer to *BPG H3: Water Reuse and Reclamation*. Consider the time-lag between water being required and water being available during different phases of the mine (for example, processing which requires large quantities of water starts much later than dewatering for bulk sampling and access to the ore body which generates large quantities of water).
- *Water treatment* – Establish water treatment requirements (softening, etc to reduce corrosion/scaling potential). Refer to *BPG H4: Water Treatment*.

7

HOUSEKEEPING AND WATER MANAGEMENT SYSTEMS (STEP 6)



Water is known as the universal solvent since it has the ability to dissolve, to some degree, every substance in the earth's crust and atmosphere. Water is therefore also the main medium for transportation of pollutants/contaminants within the confines of a mining or hydrometallurgical processing operation and from these operations to the outside environment. Water dissolves gasses from the air (SO_2 gas dissolves in rain water to yield acid rain); minerals from the earth's crust (sulphide in pyrite dissolves in water under aerobic conditions to yield sulphuric acid solutions); and it picks up suspended matter from the earth and air (soil particles are carried in runoff during erosion and when water is applied for dust control). Thus, the more water there is to manage, the more difficult the control of pollutant/contaminant migration becomes.

7.1 Minimize water use/water conservation

It is important to minimize the amount of water used in a hydrometallurgical processing operation. The areas of high water consumption should be targeted first in terms of water minimization strategies. Water and wastewater minimization has been driven by the rising cost of raw/potable water from service providers and effluent treatment or discharge charges as well as more stringent environmental legislation. Also refer to water pinch techniques and analyses as described in references (Section 12) and *BPG H3: Water Reuse and Reclamation*. Generally, hydrometallurgical processing involves the use of water for the initial processing of the mined ore and includes amongst others the following functions/applications:

- *Dust control:* Control of wind-borne particles and prevention of pollution. Required on roads because of vehicle movement; required on waste dumps due to drying of material; required in wet scrubbers to prevent dust release into atmosphere.
- *Water-based hydraulic mechanical equipment:* Water affects the hydraulic fluid characteristics in terms of emulsion stability, lubricity, corrosivity and erosive tendencies.
- *Reticulation/transport:* Transport of tailings material to a thickener/clarifier or residue disposal facility for wet deposition; water is often seen as an inert transport medium; transport of wet ore after washing and wet separation processes.
- *Cooling and heating:* Chilled water circuit; condenser cooling system; evaporative cooling especially during exothermic reactions; steam generation; boilers.
- *Processing and reaction medium:* Ore preparation such as washing of mined material and milling and grinding processes. Concentration processes such as separation circuits; magnetic separation; flotation; hydrocyclones; screens; filters; classifiers; thickeners; precipitation. Solubilisation processes such as leaching. Purifying processes to remove impurities such as electro-winning, precipitation, flotation and solvent extraction.
- *Plant cleaning:* Spraying of water for cleaning of spillages

In terms of the above uses, it is important to keep water reticulation circuits separate from each other and closed in certain instances to prevent cross-contamination. For example, the water transporting the milled ore might be considered uncontaminated in terms of chemical composition if the water was uncontaminated to start off with and not mixed with water from another area in the process (thus a closed circuit) since no chemicals are generally added neither do any major chemical reactions take place during the initial milling process of mined material. The suspended material in the water (physical composition of water) is easily removed in a thickener or clarifier through precipitation or via some filter or screen. Wet processes should also be replaced with dry process technologies where possible to reduce water consumption.

7.2 Water segregation

Water containing waste (contaminated water) should be classified and separated based on the level of contamination and possible uses. Very often at hydrometallurgical processing plants, storm water that is not highly contaminated is combined with process spillages within water storage or management facilities (refer to *BPG G1: Storm Water Management*). This limits the reuse possibility of a large volume of water that was only moderately contaminated (contaminated storm water) as it has become more contaminated due to the addition of process spillages. Implementing segregation of wastewater and multiple storage or management facilities will ensure the more efficient reuse of water on the site. Less contaminated water recovered will have numerous reuse possibilities when not mixed with highly contaminated process spillages (refer to *BPG H3: Water Reuse and Reclamation*). The separation of water based on level of contamination will also reduce the quantities of highly contaminated water eventually requiring treatment before reuse or discharge.

7.3 Storage of materials

Avoid cross-contamination by storing all materials, chemicals, products etc separately.

- *Site layout and positioning:* Storage areas should also be organized and planned in such a manner within the general site layout to allow easy access from the area requiring the particular material and avoiding the crossing or bypassing of other different storage areas in an attempt to reach the required material.
- *Reactive chemicals:* Reactive chemicals (chemicals such as lime that readily dissolve in water or chemicals that can react with water) should be stored in closed areas to prevent water (rain or runoff) from contacting them. This storage may include silos (powder chemicals), closed tanks (solutions), sealed drums (oils), closed hoppers (to allow direct addition to process) or sealed bags on pellets within a building with a roof and concrete floor (granular chemicals). Where a process spillage risk exists, appropriate bunding structures should be constructed.

- *Unreactive materials:* Unreactive materials (materials that will not readily dissolve in water or react with water) such as mined ore or dried milled ore might be stored in much simpler structures. These structures' main objective would be to prevent material from washing away and losses (runoff control). This storage may include anything from an open stockpile to a stockpile area with concrete boundaries and a roof.

7.4 High contamination risk areas

Some areas may present a high contamination risk and therefore require special measures to be put in place to prevent any of the contents from reaching any area outside the location. This may include acid storage areas and specific plant areas. To prevent contaminants/ chemicals from such areas reaching the outside environment, it is recommended that the area of location be bunded and sealed with a concrete base (acid bricks or other approved products may also be used for this purpose). The *concrete base* will prevent any spillage from infiltrating and contaminating the underlying soil and groundwater aquifer. The *bunding* will prevent any spillage from reaching surface areas located outside the bund and contaminating surface runoff. The bunding should be designed according to approved guidelines to contain 110% of the capacity of the tank or reactor it contains. To ensure proper spillage clean-up and control, the following is required:

- Bunded area's base should be sloped to allow *drainage to a low point* within the bund. A sump will be located at this point.
- The *sump* will be equipped with a suitable pump which will be level activated. This means that as soon as the liquid in the sump reaches a certain level the pump will automatically be switched on and start pumping.
- The *pump* (suitable to pump the particular liquid) will pump all liquid out of the sump at a set rate into the tank or reactor from which the spillage occurred.
- This system ensures the management of a spillage within the area where it occurs and therefore *recirculates spillages* back to their origin, keeping the system closed.
- In *emergency or extreme events* (such as the rupturing of a tank/reactor during a 1:50 year storm event), where the bund with sump-and-pump system cannot handle the spillage, a second pumping system may be required.
- The second pumping system will only be activated under such emergency or extreme conditions and pump the excess liquid to an *emergency spillage control dam/tank*.

7.5 Storm water management (BPG G1: Storm water management)

Storm water management is dealt with in *BPG G1: Storm Water Management* and the details will therefore not be repeated here. The following points are however worth noting in this document:

- *Hydrological cycle:* Impacts of the hydrological cycle (seasonal variation) on an operation/process and vice versa; dealing with floods (emergency or extreme events); dealing with surface water runoff in a plant; sustainability of a storm water management plan over different hydrological cycles and different phases of the plant (the plant life cycle: design, operation, closure, decommissioning and post-closure).
- *Clean and dirty catchments:* Division of an area into dirty and clean areas or catchments and keeping water from one separate from water from the other; no link between clean and dirty circuits/areas to prevent cross-contamination.
- *Clean areas and clean water:* Keep clean areas clean; keep clean storm water clean by diverting this runoff around possible pollution sources to prevent contact with these pollution sources thereby preventing contamination of clean storm water (construct diversion berms); maximize extent of clean areas and the amount of clean runoff (roofs on buildings with possible contamination sources will prevent rain infiltration to the area and therefore contact with pollution sources, resulting in clean runoff from the roofed area); direct/route clean storm water towards water resources for replenishment (groundwater aquifer and surface water bodies); clean storm water only requires containment when the volume poses a risk (attenuate in retention ponds and control release to prevent soil erosion, damage of stream banks and buildings or life loss); incorporate very small clean area into larger dirty area considering site layout limitations.

- *Dirty areas and contaminated water:* Minimize dirty or contaminated areas; capture and contain contaminated storm water from dirty areas for reuse; consider any runoff that has been in contact with pollution sources as contaminated and unfit for discharge into the receiving environment; prevent seepage of contaminated; prevent overflows of contaminated water from storage facilities; manage captured and contained contaminated water according to the DWAF hierarchy for water quality management (see preface); moderately polluted water (such as contaminated storm water) should not be further polluted by mixing it with process spillages (see Section 7.4).

7.6 Cleaning

Clean-up practices are important and the following should be considered:

- *Clean immediately:* All spillages should be cleaned as soon as they occur and before these spread and contaminate other areas or materials.
- *Report spillages:* All spillages should be reported to the appropriate cleaning team immediately for action.
- *Water for cleaning:* The cleaning of spillages with water (floor washing) should be prevented where possible. Cleaning of spillages with water should be limited to spillages of water solutions or water-soluble liquids. Preferably use process water or dirty storm water for cleaning purposes (also see reincorporation of spillages below). Spillages of solids (powders, granulates etc) should be physically/mechanically picked up (sweeping, dry sucking, scooping etc) and not merely be washed with water (hosing) into storm water drains.
- *Reduce cleaning water quantity:* Reduce water used for cleaning by pipe restrictions in hoses (smaller diameter pipes), using spray jets (cover larger surface area), using mops rather than hoses.
- *Reincorporation of spillages:* Where possible, spillages should be re-incorporated into the circuit from which the spillage occurred to prevent unnecessary losses. This is obviously provided that the spilled material has not been contaminated by another source since this may impact product quality at the end.
- *A waste:* Spillages that cannot be reused or be re-incorporated should be considered to be waste.
- *Hydrocarbon spillages:* Hydrocarbon spillages should be handled in a separate system (oil/grease traps) by an expert in this field.

7.7 Equipment and maintenance

The following is important:

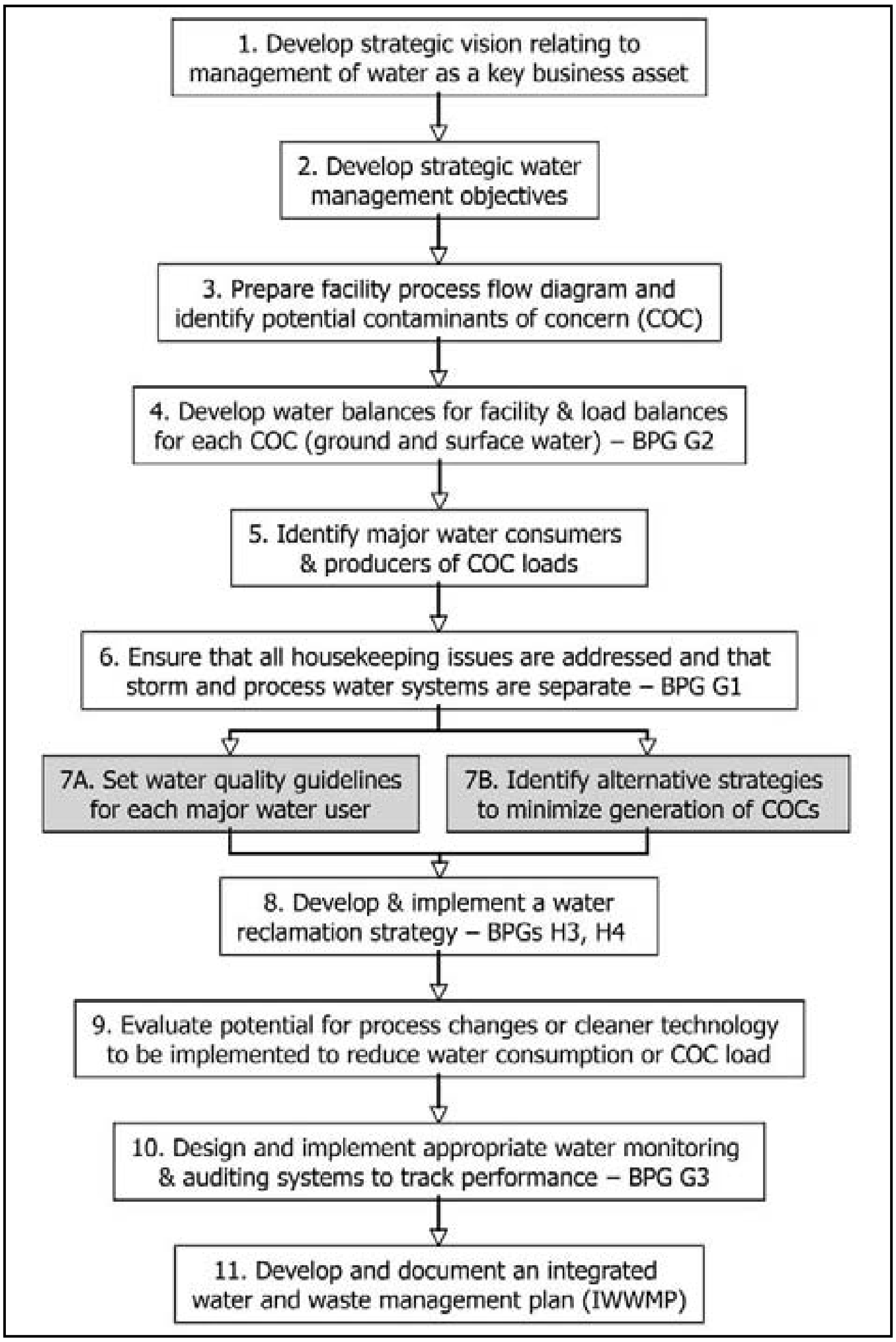
- *Alternative equipment:* Equipment such as liquid ring pumps can be replaced with mechanical sealed pumps; once-through cooling systems can be replaced with recirculating ones etc.
- *Check for leakages:* Check pipes, flanges and fittings regularly to make sure these are in good condition and not leaking.
- *Inspect condition:* Check piping, tanks and valves for repair, refurbishment and corrosion.
- *Pro-active maintenance:* Implement a pro-active maintenance programme in which equipment is regularly checked/inspected, replaced/repaired before water losses are experienced.

7.8 Sustainability

Water management systems incorporated during the design and construction phases of an operation can be tailor-made to the application. These water management systems can then be designed at the start to last throughout the different phases of the mine and processing plant life cycle to ensure sustainability. With an existing operation, the water management system has to consider the existing system infrastructure and layout, future expansions etc.

8

WATER QUALITY AND CONSTITUENTS OF CONCERN (STEP 7)



8.1 Minimize generation of contaminants

8.1.1 Review intake/input/raw materials

Contaminants are substances or constituents found in a medium such as water at a concentration higher than expected from other considerations such as the natural environment, and where the source of the additional concentration of the substance/constituent is as a direct result of human activity (such as mining or processing).

To be a constituent of concern and pose an environmental risk, the constituent must have an inherent capacity or potential to cause harm or impact on another user; the constituent must be present in environmentally significant quantities; the constituent must be available for uptake or absorption within the environment. Refer to Appendix A.

- *Input optimization:* Raw materials and reagents used as input to a hydrometallurgical plant's processing are costly and many include/contain hazardous substances. It is therefore necessary to review the use of these raw materials and consider the following:
  - *Reduce raw/potable water intake:* Water obtained from a water service provider (such as a municipality) or outside source is costly and may constitute a significant portion of the monthly operational cost on a hydrometallurgical plant. Minimizing raw/potable water intake helps towards water conservation. It is not always essential to use water of a potable quality for all applications/processes. Investigate using water of a lesser quality without affecting process performance or product yield. It is important to know process water quality requirements as well as the composition of the input water. (Example: use water stored underground, refer to *BPG H3: Water Reuse and Reclamation* and *BPG: A6: Water Management for Underground Mines*)
  - *Eliminate/reduce auxiliary inputs:* Consider eliminating or reducing input materials such as chemicals/flocculants added to the process. Establish the minimum quantity of the chemicals required or the minimum concentration of the active ingredient required to yield the same product quality and quantity without reducing process performance. Overdosing is costly. By reducing the quantity of the chemical added, the quantity of any hazardous/harmful substances contained in it and added to the process is also reduced and fewer inherent by-products result. Furthermore, establish how critical the chemical is for process performance and product requirements.
  - *Locality of input:* It is possible that by adding the chemical at a different point in the process, its quantity required can be reduced as its use would be more efficient/effective.
  - *Alternative inputs:* Consider replacing/substituting some input materials with less hazardous/harmful materials. Determine which other materials available on the market also contain the active ingredient required for the process. Alternatives may be more cost-effective and less hazardous without compromising process performance or product quality.
- *Logistics:* Improve control of the resources in terms of:
  - *Purchasing:* Compare prices and suppliers of resources; logistics of placing orders and ordering resources from reliable suppliers; tracking of resources' supply; timeous delivery of resources on site by a reliable transport company; payment of suppliers; monitor resources available to ensure timeous ordering; plan for periods of short supply.
  - *Handling and storage:* Deliver; proper storage of materials to prevent losses (secure, prevent wash-away); on-site transport (conveyor belts); maintenance of storage or transport facilities to prevent losses (roofs of buildings). Also see Section 7 on housekeeping.
  - *Addition/control during processing:* Prevent overdosing during addition; mixing to improve effectiveness and reduce quantities required; moving the point of addition in the process to increase efficiency and reduce quantities required.
- *Reuse and reclamation:* Refer to *BPG H3: Water Reuse and Reclamation* and Section 9. Use input materials that can be regenerated or reused; materials with longer lives and reuse possibilities; recycling of used oil/grease; reuse of contaminated water; regeneration of filters used in the process; cleaning and maintenance to ensure continued process performance and operation without requiring replacement of equipment.
- *Energy optimization:* Reduce energy requirements as it is also a large monthly expense in any hydrometallurgical plant; alternative process technologies that require less energy; investigate novel energy sources; ensure efficient energy use.
- *External material/streams:* Avoid contact with non-process chemical and extraneous water streams (such as off-site runoff finding its way onto the site, also refer to storm water management in Section 7

and *BPG G1: Storm Water Management*); prevent external material/streams from entering the circuit.

8.1.2 Optimize pollution prevention and reduction at source

Mine-related/derived pollution is one of the major causes of water quality degradation in many parts of the world and potential sources of pollution from a mine or hydrometallurgical processing plant include effluent discharges, leachate or runoff from residue disposal facilities, storm water and the intentional or accidental release of process streams to surrounding areas.

Each mineral has a set of unique physical and chemical properties, and therefore requires the use of specific extraction and refining techniques. Environmental complications therefore vary between sites principally because of the mineral targeted for extraction, the geological setting in which the mineral occurs and the use of different chemical reagents (see Section 8.1.1) and processing techniques (see Section 10).

The underlying theory behind pollution prevention is that it is economically more sensible to prevent wastes rather than implement expensive treatment and control technologies to ensure that waste generated does not threaten human health and the environment. Pollution prevention, which lessens or eliminates waste generation, is classified as source reduction. Source reduction is one of the least expensive methods of waste minimization and is often achievable with minor process changes or simple improvements to housekeeping techniques.

Source control is defined as any activity that reduces or eliminates pollution/contamination or the generation of waste at the sources through either practice or process changes and may include:

- Product changes;
- Material or resource input changes (see Section 8.1.1);
- Technology changes (see Section 10 on cleaner technology); and
- Implementation of good operating practices (see Section 7 on housekeeping).

Pollution minimization is mainly addressed in Section 7 in terms of housekeeping and the following points are reiterated here but not discussed in detail again:

- Segregation of clean and dirty water including the separation of process water and storm water as well as the separation of clean storm water from contaminated storm water.
- The capturing, containment, and reuse of process water and contaminated storm water on the site.
- Bunding, containment and recycling of water and spillages in certain high risk areas to recirculate/reuse as close to source/origin as possible.
- Construct roofs over storage and process areas to prevent water infiltration and maximize clean runoff.
- Place concrete in storage and process areas to prevent seepage into underlying groundwater.
- Slope areas to minimize erosion and maximize runoff volume and rate in order to minimize contact with possible pollution sources.
- Diversion of storm water around major pollution sources to minimize contact with pollution sources thereby increasing clean storm water available to replenish water resources.

8.2 Water quality requirements for mine/plant water users

Certain water quality related problems such as scaling (see *Appendix A*) may be experienced by certain mine/plant water users depending on the quality of the water supplied. Water quality related problems are directly linked to the constituents of concern and it is therefore possible to determine the constituents responsible for water quality problems being experienced. Different mine/plant water users may experience different problems relating to the same water quality and therefore each mine/plant water user has its own unique water quality requirements. Since water quality requirements are determined by site-specific factors including locality, mining and processing methods, and commodity mined, only general principles and considerations are noted here.

For water to be reused within the mine or hydrometallurgical processing plant, a clear definition of the water quality requirements of the mine/plant water users must be prepared. This will consider constituents that may interfere with the performance of processes or with product quality or yield.

It is important that the constituents of concern be determined based on a reliable data record over an extended period (refer to *BPG G3: Water Monitoring Systems*) and with the appropriate statistical calculations (minimum, maximum, 95th percentile etc) as well as through consideration of the water quality related problems experienced by the users (see *Appendix A*). The water quality objectives for the mine/plant water users will represent the worst possible water quality that can be tolerated but that still eliminates/reduces any process or other problems experienced to an acceptable level.

The concentration or quantities of product in wastewater or process water depends on the efficiency of the process technology used. Product losses also increase with increasing water consumption and poor water management therefore leads to poorer extraction efficiency. Consequences of poor management can also include poor process water quality and the associated corrosion and scaling, which ultimately again reduce process efficiency. Recovery efficiency and product quality may suffer due to the presence of contaminants in process water.

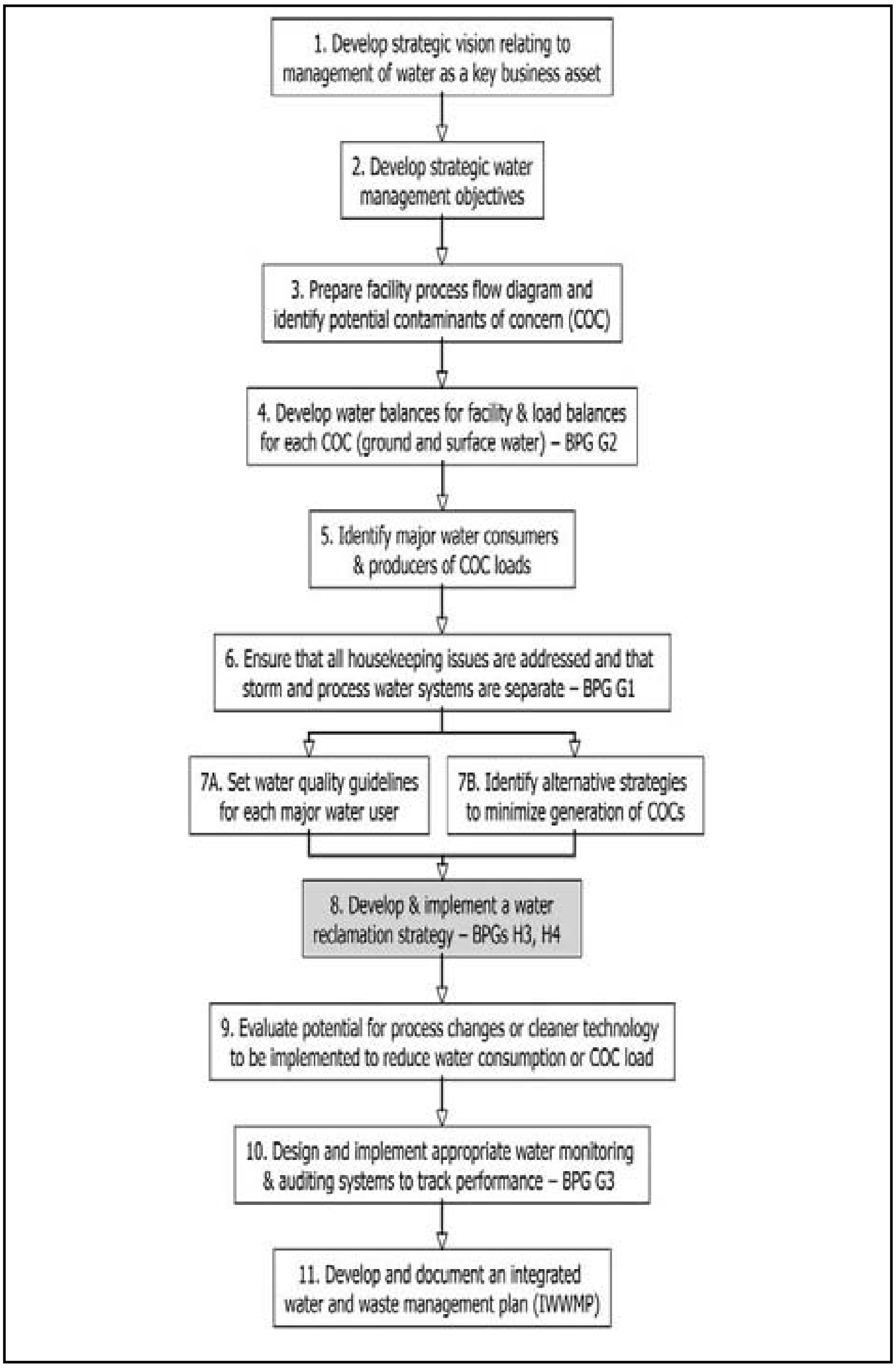
8.3 Monitoring, maintenance, inspections and audits

Monitoring: Reference is made to *BPG G3: Water Monitoring Systems* which provides clear guidance on why (objectives), how (procedures), what (parameters), when (frequency) and where (location) to monitor. It further provides details from the design phase of a monitoring programme through the implementation and data collection phases, through to reporting (data management, manipulation, presentation and reporting format) and auditing (internal/external review) phases.

Maintenance: All equipment and machinery associated with the hydrometallurgical plant should be maintained (e.g. cleaning of pipes to prevent scale build-up) on a regular basis to prevent process failure or reduced process performance due to malfunction. If regular maintenance is not conducted, raw materials may be wasted, processing time may be lost or products may be compromised. A maintenance schedule will ensure that all equipment and machinery are in peak working condition.

Inspections and audits: It is important to conduct inspections (internally) to ensure monitoring and maintenance is conducted as planned and to ensure appropriate action is taken based on the monitoring and inspection outcomes. Internal and external audits will also highlight problem areas that require management actions.

9 WATER REUSE AND RECLAMATION (STEP 8)



In order to maximize water reuse and reclamation, it is important to minimize water quality deterioration by preventing pollution. See previous sections (Sections 7 and 8).

The scarcity of water resources available to the mining and hydrometallurgical processing industry (due to the demand of other users) and the desire to reduce effluent discharges from mining and hydrometallurgical processing operations are the main reasons for the reuse and reclamation of process water in the mining and hydrometallurgical processing industry.

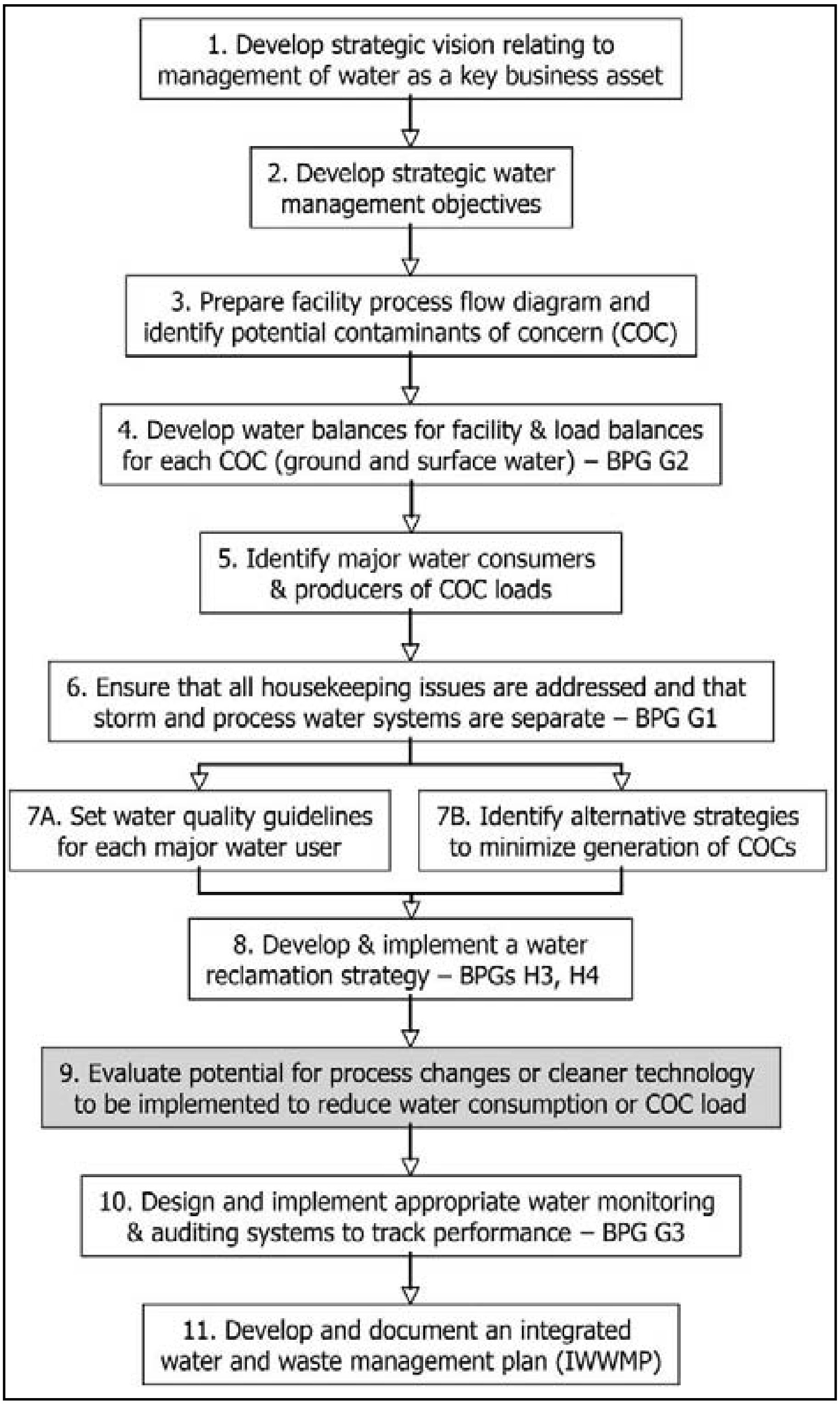
A separate BPG document was prepared on water reuse and reclamation (refer to *BPG H3: Water Reuse and Reclamation*) and the details are therefore not repeated here. The following points are however worth noting in this document:

- *Opportunities* for water reuse and reclamation:
  - Areas where large volumes of water are used or disposed;
  - Areas where good quality water is imported and poor quality water is lost;
  - Areas where good quality water is purchased/ abstracted while water of a poorer quality is acceptable for use; and
  - Areas where the implementation of pollution prevention measures/strategies do not result in the elimination of pollution.
- *Benefits* of water reuse and reclamation:
  - Cost saving due to reduced raw water intake from outside (abstraction from water resources or purchasing from water service provider), more efficient use of valuable resources as well as reduced disposal and treatment cost for wastewater;
  - Legal compliance as waste minimization and water conservation goals are met;
  - Limit liabilities by reducing and minimizing release to and impacts on the surrounding receiving environment;
  - Protect public health by preventing pollution of the environment and water resources;
  - Protect the environment through pollution prevention, especially the water resources (minimize water quality deterioration);
  - Water conservation through reduced intake and consumption;
  - Reclamation of materials that have a high reclamation value and/or a severe impact on the environment; and
  - Improve public image due to concern shown for the environment.
- *Water sources:* Identify and consider all possible or alternative water sources including boreholes from which groundwater can be abstracted, streams/dams from which water can be abstracted in the local or neighbouring catchment, captured rainwater, water imported with the raw materials, other surrounding industries with excess water and having to discharge water, mine/plant process units discharging water (water/effluent generating processes), water service providers (municipality etc). Implement all possible measures to prevent/minimize the pollution of these water sources. Characterise the water sources with respect to flow rate (quantity), quality and variability through a monitoring system (refer to *BPG G3: Water Monitoring Systems Systems*). Aim to use water sources with minimum amount of treatment due to the cost associated with water treatment (refer to *BPG H4: Water Treatment*). Ionic strength of water source is important as it may influence solubility of other constituents present in process materials.
- *Minimize water intake:* Only purchase water (potable) from water service providers for processes requiring such good water quality or additional water requirements that cannot be supplied in the system. Only obtain water from outside sources (environment or other industries) that cannot be supplied within the system.
- *Mine/plant water users:* Establish clear and accurate water quantity and quality requirements/criteria (fit-for-purpose) for all mine and process related water users. Establish water quality constituents affecting/ impacting on product quality or yield and/or process performance and determine minimum acceptable standard required from water supply. Mine/plant water users should be provided with the poorest possible water quality but which does not cause significant user, product quality or process related problems (scaling etc). Compile water use inventory - list of existing and potential mine/plant water users (indirect or direct). Group mine/plant water users with similar water quality requirements (in terms of key constituents) together to provide a number of different water quality groups/ categories. Water sources, depending on the origin and contaminants, may have a deleterious effect on certain hydro-metallurgical processes and it is therefore essential to establish the contaminants within the sources that may impact on or adversely affect the process.
- *Minimize consumptive water use and losses:* Minimize evaporation from evaporative cooling systems and clean water storage facilities. Limit evaporative cooling systems (investigate air cooling). Minimize seepage (through appropriate lining) and overflow (through sufficient capacity, GN 704) losses from all water systems.

- *Process technology:* Investigate alternative process technologies or modification/changes to existing process technologies that could be applied and that use less water (see Section 10).
- *Water reticulation systems:* Optimally match mine/plant water users with the identified water sources, taking cognizance of economic and practical restraints with regard to having different water reticulation systems. Therefore, identify opportunities for reusing effluent water from one process as influent water to another process. Establish where water reticulation networks and storage facilities may need to be installed or extended/enlarged or modified. Align and allocate recycled water quality and quantity to various mine/plant water users. Achieve the minimum use of raw water or optimal flow configuration in the particular system of operations.
- *Unused internal water sources:* Categorize all unused internal water sources (inside the mine or hydrometallurgical processing operations) that have not been allocated for reuse to a specific mine/plant water user based on one of the following factors: poor quality; surplus water in the system; very small quantity; or isolated location. If water quality is acceptable, consider an authorized discharge in consultation with DWAF.
- *Discharge/dispose:* All potential discharges considered should be discussed with DWAF in terms of discharge points and quality limits. All discharges or disposals require an authorization (NWA, Section 21). Specialist investigations and risk assessments may be required.
- *Treatment:* Decide on a potential water treatment technology (active or passive, chemical or biological) based on contaminants of concern. Refer to *BPG H4: Water Treatment* and also consider the following:
  - Water user requirements – mine/plant water users, surrounding industries, downstream users, aquatic ecosystem and environment;
  - Technology reliability and technical feasibility;
  - Treatment technology requirements - flow rate/volume; quality; quantity and quality variation, surface land area required and available;
  - Residue/waste streams - characteristics, disposal, reduction of quantity, sludge stabilization and stability, byproduct recovery;
  - Financial requirements and responsibilities - capital cost and operating expenditure;
  - Technology performance risk assessment - performance reduction or failure and its impacts;
  - Sustainability - different phases, life-cycle; variations; and
  - Laboratory/pilot plant studies - address uncertainties.
- *Alternative uses:* Reassess possible use of water after treatment either on the mine/plant, at surrounding industries or for downstream users. Industrial ecology - introduce wastewater or effluent into external recycling networks; one industry's waste may become another industry's raw material.
- *Monitoring:* Institute monitoring and auditing to ensure that adverse effects of unacceptable reclaimed water quality are not manifested, i.e. corrosion, scaling, reduced process performance. Evaluate performance and implement corrective actions if necessary.
- *Sustainability:* Ensure water reuse and reclamation strategy is sustainable over the plant's life cycle and different hydrological cycles.
- *Materials or byproduct recovery:* Evaluate waste streams for properties that make them useful rather than for properties that render them waste. Minimize waste by retrieving/recovering usable process materials and resources from waste streams. Thus, not only water reclamation but also reclamation of chemicals for reuse in process, new uses or sale.
- *Future:* Develop water and salt balance projections (refer to *BPG G2: Water and Salt Balances*) for future scenarios, including closure and post-closure. Long-term planning and sustainability should be considered and therefore predictions on water quality and quantity into the future should also be incorporated (predictive modeling) to ensure that reuse and reclamation strategies are not affected by future processes/plans.

10

PROCESS CHANGES OR CLEANER TECHNOLOGY (STEP 9)



10.1 Need and significance

Cleaner production technology and process changes/ modifications are pro-active and preventative measures, which aim for process- and/or product–integrated solutions that are ecologically and economically efficient (eco-efficiency). The objective is to tackle possible pollution problems before they develop rather than remediate them after they have occurred, thus reducing levels of pollutants in waste streams (contaminants of concern) prior to release or reducing water requirements. In this regard, cleaner production also ties in with pollution prevention and reduction. Cleaner production is very much in line with the DWAF water management decision-making hierarchy and international waste management hierarchies, which also follow preventative approaches. Market and regulatory pressures lead most companies to invest in the development or acquisition of new technologies and management practices to achieve cleaner production.

Cleaner production and process modifications can achieve the following:

- Higher production rates as unnecessary production steps are eliminated through innovative process integration;
- Minimize waste production and disposal by avoiding heat degradation of products, recycling, eliminating spillages and fugitive emissions;
- Improved product quality and yield by considering product life cycle assessment (how products are produced, processing, extraction, manufacturing, etc., as an integrated approach);
- Increased operating or production efficiency through improved process selectivity and/or conversion and more efficient equipment;
- Higher percentage on-line time and long campaign life between rebuilds (shut-downs) through more efficient equipment design;
- Safe operating conditions considering for example how waste is handled, transported and disposed of;
- Significant reductions in environmental impact, in terms of reduced liquid/water, solid and gas/air emission generation;
- Conservation of resources such as materials, energy and water due to their reduced use (for example operating at lower temperatures and/or pressures);
- Reduced operating and/or production costs (compare with conventional "end-of-pipe" clean-up technology); and
- Decreased liabilities due to reduced environmental impacts and waste production (minimization/reduction, reuse, recovery and disposal).

Cleaner production therefore combines gains in productivity with improvements in environmental management. The mining industry has already made some progress by employing cleaner production practices such as reduction in noxious air emissions, decrease in levels of toxic contaminants in effluent discharges, major upgrading in land management etc. These improvements have led to a reduction of conventional end-of-pipe treatment in favour of pollution prevention practices at source. Integration of cleaner technologies and strategies can be achieved by including highly efficient equipment and control systems, state-of-the-art environmental management measures and comprehensive environmental management plans.

Due to the large quantities of material, energy and water used in the mining and hydrometallurgical industry, significant opportunities are available for waste reduction/minimization and cleaner production. Pollution prevention by "cleaner technologies" is important not only because of the environmental protection advantage but also because of the cost savings associated with these. Waste reduction/minimization as used in this context refers to in-plant modifications that reduce the volume or degree of hazardousness of waste and wastewater generated.

10.2 Implementation

Cleaner production should address five major areas of business:

- Policy development and institutional relations – working towards setting performance standards; establishing financial arrangements and corporate buy-in; implementing efficient environmental management systems.
- Environmental and social impact assessment – using social indicators to monitor societal effects over time; promoting stakeholder participation; monitoring environmental impacts.
- Technological development – promoting research and development; introducing life-cycle assessment to operations; developing technological solutions.

- Company strategy – continuously improving management systems; monitoring predicted impacts and unexpected events; designing incentives for employees to engage in environmental practices.
- Education and training – enhancing environmental awareness within the workforce; training for innovative community relationships; collaborating with independent agencies.

Implementation steps:

- Identify existing and proven cleaner technologies available on the market.
- Assess existing cleaner technologies in terms of applicability and practicality.
- Conduct feasibility study - analyze investment; research options or adaptations required, etc. May include laboratory or pilot plant studies.
- Monitor to ensure cleaner technologies play their appropriate role over the long-term.

10.3 Barriers preventing cleaner production

Often barriers of an economical, technological and legislative nature hinder the implementation or adoption of cleaner technology but these can be overcome through improved planning, employee education and increased government intervention.

10.3.1 Economic barriers/constraints

Conventional end-of-pipe abatement requires less capital investment, less development and less disruption to production processes than cleaner technologies and strategies. Economic barriers are particularly relevant to smaller mining companies who have less funds available and are more economically driven. These companies mostly keep to the minimum standard (discharge etc) required without prosecution realizing that their operation may still impact on the environment.

Commodity market price: The mining industry cannot control the value of the commodity and a downturn in price affects how each mine is managed. A shift to regulatory compliance is noted with price drops since funds are no longer available to invest in proactive technologies. Economic pressures may force a company to abandon “cleaner” methods and adopt less expensive methods instead, which are more prone to environmental degradation.

Lack of resources (funds, time, personnel etc): A limited environmental budget restricts spending on highly efficient, expensive pollution prevention and cleaner production technologies and only a mode of regulatory compliance is maintained. Limited budget means less personnel and time spent on this function as well.

Financial incentives: Incentives are needed to shift to a mode of cleaner production and these are limited within most governments.

10.3.2 Technology barriers

Structural barriers: Investments (financial and resources) in current systems used may prevent changes to other technologies since a) employees with skills and knowledge pertaining to the specific current system may then have to be trained in another technology or outside assistance may be required, requiring additional investment; and b) the infrastructure supports the current system and applying a new technology may require additional and/or new infrastructure to be established, requiring further investment.

Lack of time to conduct pilot plant or laboratory studies: The mining industry is pressed for time due to production pressures and there is limited time available to conduct pilot plant and/or laboratory studies to test the application and feasibility of new technologies. Research and development are often not priorities as the focus is on production. Industries therefore often find themselves going with a proven technology which is the safer option in cases where no pilot plant or laboratory studies have been conducted (refer to *BPG H4: Water Treatment*).

Lack of available systems: A significant portion of global mineral production originates from grassroots operations, which lack the appropriate technologies to avoid environmental problems. Also refer to small-scale mining operations (refer to *BPG A1: Small-scale Mining*).

Technology and information gaps: Insufficient knowledge of cleaner production and cleaner technologies available on the international market; uncertainty in impact predictions; inactiveness in the environmental management arena; shortage of necessary expertise; lack of promotion and dissemination of cleaner production and cleaner technologies may prevent its implementation.

10.3.3 Legislative barriers/pressures

Environmental legislation is continually developing and being amended/changed to such an extent that systems that are now recognized as being effective pollution prevention methods could easily become outdated in the years to come. The volatile nature of best practice technologies and the frequently changing regulatory environment makes the selection process for environmental technologies difficult and can discourage implementation of cleaner technologies. Current cleaner technologies may in future be mere environmental compliance machines. Thus changing regulations can turn existing cleaner technologies into future compliance investments. Mines, in general, therefore tend to operate in line with set standards in environmental legislation and only change operations when necessary. Long-term planning to invest in proactive environmental measures is difficult since it is difficult to hit a “moving target”. Though South Africa as a developing country has strict environmental regulations, effective enforcement programmes are often lacking thereby preventing the implementation of cleaner production.

Environmental legislation should include:

- Clear, continuous policies to support waste minimization and cleaner production.
- Regulatory frameworks and enforcement.
- Consideration of characteristics of industrial production processes.
- Clear understanding of the difference between compliance investments and cleaner technology.
- Coordination among different governmental agencies at different levels.

10.4 Overcoming barriers

10.4.1 Governmental intervention

Often financial support and appropriate technology is required to improve production processes. Government should take a leading role in promoting cleaner production and indicate it as a national and provincial goal for economic and environmental policy. Priorities may include:

- *Economic instruments and assistance:* Economic instruments or financial incentives to motivate mines to implement cleaner production may include levies, tax breaks and subsidies. Government currently finances research such as that by the Water Research Commission (WRC) and provides guidelines such as the BPG series. Ensuring that banks, insurance companies and other lending institutions favour cleaner technologies in their investment decisions.
- *Technical incentives and assistance:* Working with educational facilities (universities) and private sector (industry). Government-academic-industrial partnerships. Each partner provides a different area of expertise (technical, training and education). Environmental technology demonstration projects.
- *Provision of information:* Government to obtain and disseminate appropriate information concerning cleaner technologies and strategies, outlining their contribution to economic aims. Provide documented results of successful cases and educational materials in press.
- *Certification:* Developing and implementing a cleaner technology certification system for products, processes and services.

10.4.2 Education and training

Education and training is required for an increased level of awareness and to increase employee and community knowledge. Awareness training should not only aim to acquaint people with environmental problems but also to ensure that ecological effects are fully understood. Education should be included for employees involved in research, material purchasing, environmental equipment design, installations, running and management of final technological setups. Promotion campaigns for cleaner technology will also contribute to creating awareness.

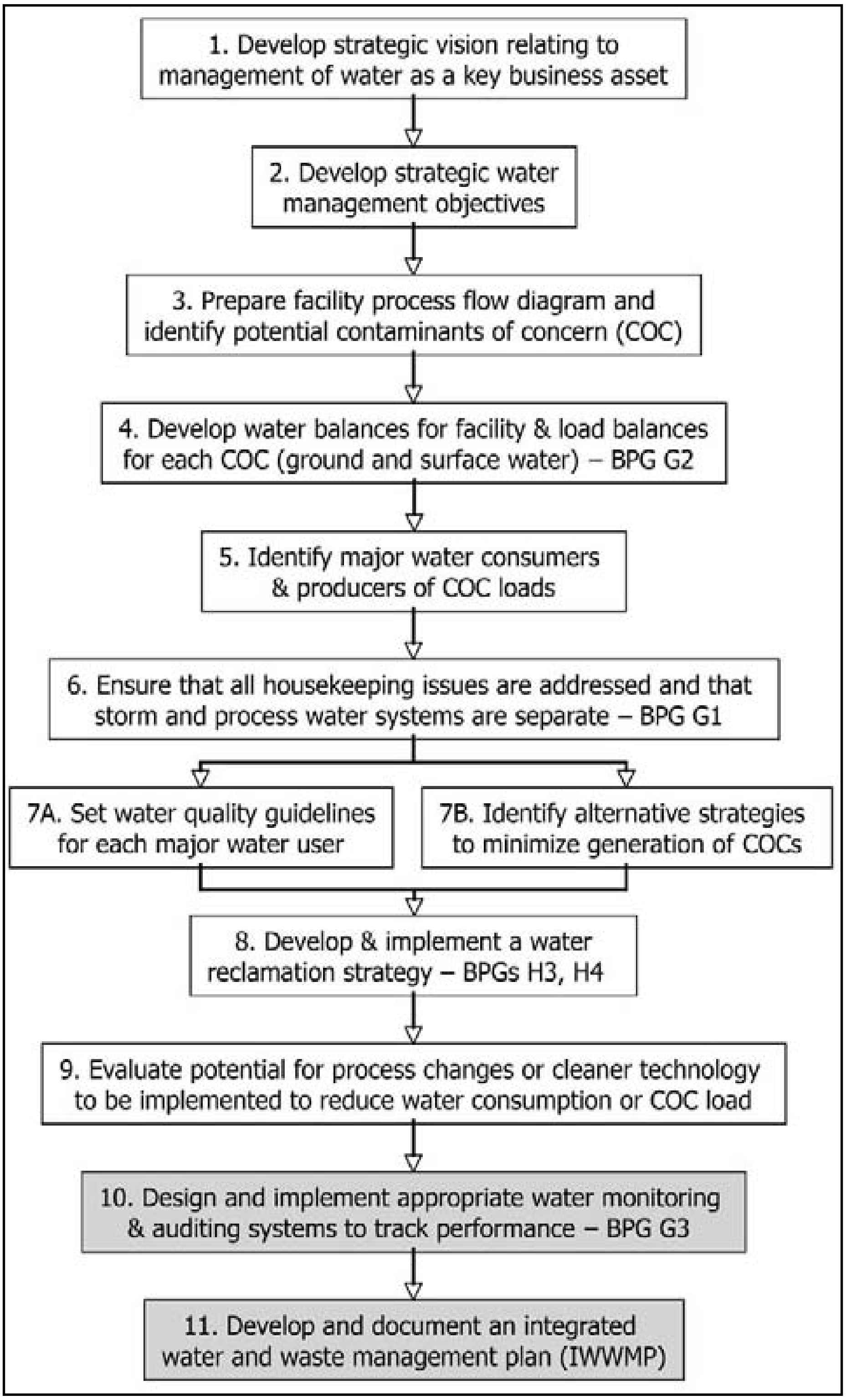
10.4.3 Improved planning

For new mines, environmental issues must be accounted for in the original blueprints. An inventoried listing of environmental technologies, treatment processes, and toxic chemicals used, should be made up front. In the design of the mine, ecological “situations” should be accounted for when determining where to implement specific environmental technologies.

For existing mines, an environmental management system (EMS) would ensure more effective control and reduce environmental impacts and should include organizational procedures, responsibilities, processes, implementation strategies, measurement and evaluation criteria, efficiency measures and goals for improvement. Environmental audits at regular intervals can also be implemented and should include a thorough investigation of every industrial system and process. Environmental monitoring and technological assessments are also important.

11

INTEGRATED WATER AND WASTE MANAGEMENT PLAN (STEPS 10 AND 11)



The integrated water and waste management plan (IWWMP) should aim to continuously and systematically reduce waste generation, prevent pollution and minimize impacts.

To implement a comprehensive IWWMP, the following is required:

- Adequate *resources* in terms of finances, competent personnel, infrastructure and other requirements.
- *Commitment* of the company, management and employees to the objectives of the IWWMP.
- Monitoring which includes data and information collection, cost accounting and feasibility analysis (continuous review).
- Environmental impact monitoring and environmental policies to achieve improved *environmental goals*.
- *Training and awareness programmes* emphasizing pollution prevention, impact minimization and control/management.
- Hydrometallurgical plants *designed* to better accommodate wastes, prevent pollution and minimize impacts.
- Baseline and continual operational monitoring (refer to *BPG G3: Water Monitoring Systems*) of ground, surface and process water as well as equipment and the subsequent implementation of *action plans* based on the results.

The IWWMP should include detailed discussions on the following subjects:

- *General information:* Applicant details, holding company details, plant locality, supporting surface infrastructure (road, rail, power), land ownership and use, plant surface infrastructure, processes (raw materials and chemicals, products and waste).
- *Legislation:* Applicable legislation, existing permits, legal requirements.
- *Current water environment:*
    - Climate – regional; temperature; precipitation; evaporation; wind; extremes.
    - Topography and geology.
    - Surface water catchment - water courses (rivers/streams) and dams; wetlands.
    - Affected groundwater zone – aquifers; boreholes; springs.
    - Water quantity (volumes/flows/yields) and quality - monitoring points, frequency, parameters, baseline and operational; data management.
    - Water authority (regional DWAF office); water uses (plant and downstream); water supply.
- *Water management:*
    - Water sources – availability; supply and available to operation; drought and water restrictions; water service providers; water suppliers; surrounding industries with excess water, boreholes, surface water bodies (streams/dams), process water on the mine/plant.
    - Water rights - legal standing; licence conditions.
    - Water users on mine/plant - consumption patterns; individual processes; water requirements in terms of quantity and quality; sensitivity to variations.
    - Water reuse and reclamation (refer to *BPG H3: Water Reuse and Reclamation*). Refer to Step 8, Chapter 9.
    - Water conservation - minimisation of water use; long term reduction of consumption; set objectives.
    - Process water management - water and salt balance; possible pollution sources; pollution prevention measures; minimisation of waste loads in water; high contamination risk areas; safety factors; system failures; accident and emergency plans; monitoring and auditing. See Chapter 7.
    - Storm water management - separation of clean and contaminated storm water; release of clean storm water; containment of contaminated storm water; maintenance; erosion and sediment control. See Chapter 7.
    - Groundwater management – possible pollution sources; pollution prevention measures; pollution plumes; impacts; management measures; monitoring.
    - Water treatment (refer to *BPG H4: Water Treatment*).
    - Disposal/discharge – alternatives/options considered; socio-economic impacts; impact assessment; monitoring; management; financial provision; consultation with DWAF.
- *Waste management:* Site selection; classification of waste; hazardous substances in waste; handling; transport; leach potential; lining systems; leachate interception; disposal practices etc.

- *Commitments:*
  - Monitoring – water and waste quality and quantity; monitoring points; frequency; parameters; baseline; operational; data management; record-keeping; impact and risk assessments; performance reviews; inspections and audits; indicate action/target levels and water quality objectives.
  - Management – maintenance; minimizing impacts; pollution prevention; minimize discharges/seepage; set targets; health of water dependent ecosystems; reporting to management; reporting to authorities; training; responsibilities; accountability; emergency and contingency measures; review processes in place and implement action plans as required; performance indicators to evaluate success of management strategies and plans.
- *Consultation process:* Stakeholder communication; regulatory authorities; interested and affected parties; community expectations; forums/process for information sharing; meetings; database; public participation; advertisements and notifications in media; complaints register; water as a shared community resource; respect water rights of other users; consider downstream water quality problems (DWAF water quality guidelines for specific uses).

For each water use it is therefore important to ensure the following points are addressed:

- problem statement and/or impact;
- management plan or operational procedures;
- maintenance and inspections procedures;
- performance indicators and compliance monitoring; and
- emergency contingency procedures.

Water and waste management system designs should be based on the following considerations:

- Pilot scale testing is not considered completely reliable.
- The treatment of supply water is seldom a viable option due to the complexity of water treatment processes and sludges produced as well as the cost associated with treatment and sludge management. However, intake water or raw water quality deteriorates and the industry may find itself required to pre-treat water for usage in certain unit processes (refer to *BPG H4: Water Treatment*). Look at new water treatment technology.
- Flexibility should be incorporated into the reticulation, storage and distribution systems and networks to ensure efficiency. Systems must be able to absorb variations/surges and supply a variable demand from unit processes. Design based on average process flows is thus inappropriate. Centralized water storage facilities should be considered (refer to *BPG G1: Storm Water Management*).
- Consider water demand and effluent generation patterns of different unit processes. For example water available from shaft dewatering peaks over the weekend whereas consumption of water by the plant tails off during this period. Process or contaminated storm water must be consumed in preference to raw water (refer to *BPG H3: Water Reuse and Reclamation*). Also consider mineral and product recovery from effluent streams in future.
- Numerous unit processes exist, each with their own demands patterns and water quality objectives. Unit processes must manage their own water systems through a water and salt balance (refer to *BPG G2: Water and Salt Balances*). An effluent generator remains responsible for the water until it is absorbed in an alternative unit process or disposed of in accordance with water quality objectives for the catchment.
- Contamination of water used to transport material leads to progressive deterioration of water returned and available as process water. Consider closed circuits or separate circuits in certain instances.
- Increasing volumes of water to be managed increases requirements for pump, piping and storage facilities thereby increasing cost.
- Minimize contaminants discharge/emission; inefficiency and wastage; contribution to specific environmental problems; overall environmental impact.
- Improve automation and communication systems.

There is also the temptation to follow a principle of "minimum compliance" where costs are not considered to be significant. This type of water and waste management (reactive or ad-hoc) is less efficient and environmentally friendly than a pro-active system with full commitment to effective management of the water cycle. An effective water and waste management system establishes objectives and ensures these are integrated into the day-to-day management of the mine/plant. A water management system must therefore satisfy the quality and quantity demands by all unit processes but also the objectives of the environment on which it impacts.

The proposed structure and contents of an IWWMP is as follows:

I EXECUTIVE SUMMARY

Briefly covering:

- Background
- Process description
- Environmental description
- Water system characterization
- Management Programmes
  - Waste Minimization and Recycling
  - Water Use Efficiency
  - Water Containing Waste
  - Storm Water Management
  - Groundwater Management
  - Remediation and Rehabilitation
  - Water Monitoring
  - Emergency and Contingency Discharge Management

II MAIN DOCUMENT

1 Introduction

1.1 Background

1.2 Contact Details

1.3 Location of project

1.4 Property description

1.5 Legal Assessment

1.5.1 Existing Lawful Uses

1.5.2 Summary of Water Uses

1.5.3 Summary of Relevant Exemptions

1.5.4 Summary of General Authorizations

1.6 Section 27 Motivation

2 Project Description

2.1 Purpose of the Document

2.2 Objectives of the project

2.3 Physical project description

2.3.1 Extent of operation

2.3.2 Mining method

2.3.3 Project life description

2.3.4 Infrastructure requirements

2.4 Residue and Emissions

2.4.1 Waste Stream Identification

2.4.2 Waste Stream Characterisation

2.4.3 Waste Management

2.4.4 Waste Recovery and Reduction

3 Environmental Status quo

3.1 Climate

3.1.1 Regional Climate

3.1.1.1 Mean rainfall

3.1.1.2 Evaporation

3.1.1.3 Maximum Rainfall

3.1.1.4 Temperatures

3.1.1.5 Meteorological climate

3.2 Soil and Land capability

3.3 Surface Water

3.3.1 Water Management Area

3.3.2 Surface Water Hydrology

3.3.3 Surface Water Quality

3.3.4 Mean Annual Runoff (MAR)

3.3.5 Resource Class and River Health (Applicant)

3.3.6 Set Resource Class Objectives (DWAF/Reserve)

3.3.7 Surface Water User Survey

3.3.8 Sensitive Areas Survey

3.4 Groundwater

3.4.1 Aquifer Characterisation

3.4.2 Groundwater Quality

3.4.3 Hydro-census

3.4.4 Potential Pollution Source Identification

3.4.5 Groundwater Model

3.5 Socio-economic Environment

4 Quantitative Risk Assessment

4.1 Safety, Health, Environment and Quality Policy

4.2 Objectives and Strategies

4.3 Key Performance Area and Indicators

4.4 Methodology Followed

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APPENDIX A
WATER QUALITY
ISSUES

A.1 Water management in hydrometallurgical processing

Water management system designs should be based on the following considerations, in terms of water quality, in addition to those mentioned in the BPG:

- Cyanide, usually in return water should not be permitted in milling circuits.
- Organics should be isolated from carbon circuits. Oil and grease are nutrient sources for microbiological organisms causing fouling.
- Sodium and potassium in process water should be limited in the production of ammonium diurinate.
- Manganese levels should be minimized and should be reduced to insoluble forms before disposal.
- Soft water and/or demineralized water should be provided for boiler feed.
- Suspended solids should not be present in gland service water.
- Water with scaling characteristics should not be used in refrigeration systems.

Table A.1 below summarizes water consumption in the hydrometallurgical processing industry in terms of what water is used for, water quality requirements, reuse capability and environmental impact.

Table A.1: Water use in hydrometallurgical plants (Marr, 2003)

Water Use	Reaction medium Transport Utilities Pollution abatement
Inventory	Large
Re-use capability	Moderate to High
Water quality	Potable to Demineralized
Losses	Inventory Evaporation Spills/Releases Products
Environmental Impact	Consumption Ecotoxicity Eutrophication Acidification Chemical Oxygen Demand (COD) Suspended Solids (SS)

Some relevant references dealing with water management issues at hydrometallurgical plants are listed below.

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A.2 Generic constituents of concern in hydrometallurgical processing

Broadhurst (2007) summarized the generic grouping of the constituents of concern to tie up with potential water management objectives as follows:

Dissolved solids - expressed as total dissolved solids (TDS), electrical conductivity (EC) or ionic strength: The presence of salts can generally be linked to both feed ores and processing operations (e.g. as leachants etc). Salts can be divided into two further sub-groups:

- Major soluble salts: These include the sulphates, chlorides and carbonates of Ca, Mg, Na and K. These salts are relatively abundant and common in natural environments and uncontaminated water due to their abundance in the earth's crust and their relative high solubility. They are all essential elements and only exhibit toxic effects at relatively high concentrations. Guidelines are based on aesthetic and physical properties rather than toxicity. They are the major causes of corrosion and scaling of plant equipments and, as a combined group, can result in salinization of soil and water resources.
- Minor soluble salts: These include F, Br, I, phosphate, nitrate and nitrite salts. These salts are also essential elements, but are generally present at lower concentration levels in natural environments and have a greater toxicity than the major soluble salts.

Trace metals and semi-metals: These generally arise from the feed ore. These elements can vary quite considerably in terms of both their biological effect and environmental concentrations. These, though present in the earth's crust, do not occur in a natural uncontaminated environment in soluble or bioavailable form.

Anthropogenic processing reagents: These include plant input reagents or chemicals produced as side-products during processing which do not generally occur in natural environments. These include cyanide, organic extractants, and surfactants (oil, grease, tars etc). These elements are generally non-essential and harmful to the eco-system and mammals at low concentrations. There are however, generally more opportunities to reduce these at source than those elements arising from the feed ore.

Physical characteristics: These comprise mainly of pH and suspended solids and have a greater effect on plant performance (corrosion, scaling etc). The main effect of pH is indirect, as pH has an influence on solubility. pH is therefore considered to be one of the main variables controlling the leachability of constituents from materials (also redox potential).

A.3 Physical water-related problems experienced in the hydro-metallurgical industry

In hydrometallurgical processing, the need for higher mineral recoveries has led to more elaborate recovery methods, most of which involve the extensive use and recycling of water. These operations necessitate stricter control over the condition of the circuit/process water in order to maintain efficiencies and to avoid water-related operational problems such as scaling, corrosion and fouling which are discussed in Table A.2 below.

The soluble inorganic compounds most commonly encountered in these waters are a source of potential trouble through deposition in water pipes, equipment and boiler tubes. Contingency action plans to handle reduced process performance or process failure should also consider these in that deposits might have formed and once process conditions have been corrected, these deposits may still exist and need to be dealt with.

In the operation of every cooling, heating and steam generating system, the water changes temperature. Higher temperatures and substance build-up increase both corrosion rates and scale forming tendencies. Evaporation in open cooling systems and boilers increases the dissolved solids content of the remaining water and these increased concentrations can become the cause of either scale formation or intensified corrosion unless corrective treatment is applied. Suspended solids or microbial organisms, in the make-up water or scrubbed from the air, can result in considerable physical and microbial fouling problems.

Table A.2: Water-related problems experienced

	Scaling	Corrosion	Fouling
Definition	Precipitation of substances, whose solubility in water has been exceeded, in a very dense and adherent form, onto the surrounding surfaces.	Metal reverts to a compound similar to those found in nature. Electrochemical process in water.	Deposits form from material suspended in water or from growth of microbiological organisms. Often associated with scaling and/or corrosion.
Origin/formation/ cause	Change in water temperature or increase/decrease in dissolved solids content or concentration, specifically calcium and magnesium. Pipe velocity (speed at which water is conveyed)		Suspended solids or microbial organisms in make-up water or scrubbed from the air.
Physical recognition	A chemical deposit (material) building up on the surface thereby clogging the pipes.	Thinning of metal; metal is eaten away.	Build-up of material onto the surface thereby clogging the pipes.
Effects	Affect heat transfer rates. Impede flow of liquids. Process throughput may be decreased due to reduced flow. Plug distribution systems.	Waste of useful metal. High maintenance cost.	Affect heat transfer rates. Impede flow of liquids. Create differential concentration cell corrosion. Harbour anaerobic corrosive bacteria. Plug distribution systems.
Factors required for formation	Supersaturation. Nucleation. Adequate contact time for adherence.	Usually under cathodic control (cathode reaction is rate determining). Uneconomical to eliminate - control rate by controlling pH, EC and alkalinity.	Material suspended in water. Microbiological organisms (bacteria, algae, fungi).
Factors promoting formation	Increased pH. Increase temperature. Reduced flow velocity. Long lengths of piping.	Dissolved gasses (O_2, CO_2, H_2S, NH_3). Dissolved solids concentration (increased EC, SO_4 and Cl interfere with protective film). Increased temperature - increase chemical reaction rate. Differential concentration cells (galvanic current under deposits). Large volume pumps.	Conditions for growth of microbiological organisms. Reduced flow velocity. Ammonia, carbon compounds, hydrocarbons (oil), phosphates as nutrients for microbial organisms.
Examples of types	Calcium carbonate Calcium sulphate Magnesium silicate Iron oxides	General surface corrosion. Pitting (crater-like), including galvanic.	Physical. Microbiological.

	Scaling	Corrosion	Fouling
Monitoring	Deposit monitors, chemical analysis, deposit analysis.	Corrosion coupons, electrical devices, deposit monitors, chemical analyzers, test heat exchangers, equipment inspections.	Deposit monitors, chemical analysis, deposit analysis, biological monitoring (bacterial counts).
Inhibition or control	Limit critical specie concentration (controlled bleeding or pretreatment). Reduce alkalinity (acid dosing). Alter system design or operation (increase flow, reduce temperature, limit passes in heat exchanger, reduce heat fluxes by decreasing heat load or increasing size) Inhibitors (threshold inhibition, crystal modification, chelation, dispersion, conditioning for sludge formation). Maintain surfaces deposit free. Increase pipe velocity (> 2m/s).	Inhibitors interfere with anodic or cathodic reactions: Anodic – chromate, orthophosphate, nitrite, silicate, ferrocyanide; Cathodic – calcium carbonate, polyphosphate, zinc, magnesium; Anodic and cathodic – organic filming amines. Metallic coatings. Control water chemistry. Oxidizers (chromate). Film formers (soluble oil, phosphates). Reactive metal (Mg/Zn blocks as sacrificial anodes). Increase pipe velocity (> 2m/s).	Water clarification (inorganic and polyelectrolyte polymer flocculants). System design (ensure turbulent flow). Limit concentrations (decrease by increasing blowdown rate). Slipstream filters (reduce suspended solids). Air rumbling and back flushing (pressurized air stream to increase flow velocity, dislodge matter settled in low flow areas). Limit nutrients for organisms. Dispersants (bio or chemical). Biocides (penetrants or dispersants)

APPENDIX B: VARIOUS HYDRO-METALLURGICAL PROCESSES

Below are a number of process flow sheets taken from the WRC report 1550/1/07 (Broadhurst, Hansen and Petrie: 2007) representing some of the different sub-sectors in the mining and mineral processing industry. A process flow sheet is a representation or schematic diagram showing the steps of a process in sequential order. These are for example purposes only and therefore not discussed in detail but merely explained in terms of the terminology. Further discussion and information is contained in the WRC report and reference should be made to this for further detail.

Figure B.1: Coal hydrometallurgical processing flow sheet (WRC 1550/1/07)

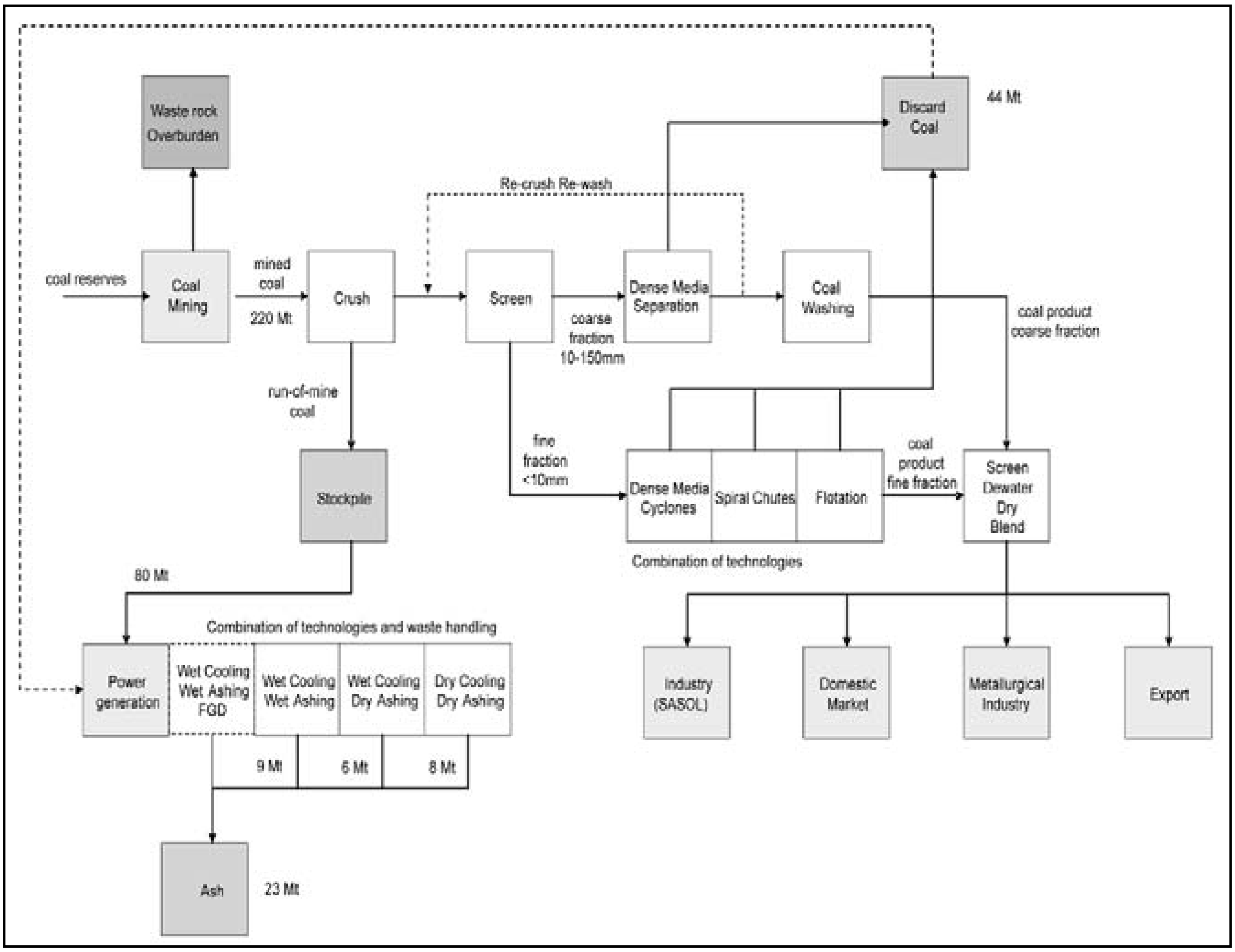


Figure B.2: Gold hydrometallurgical processing flow sheet (WRC 1550/1/07)

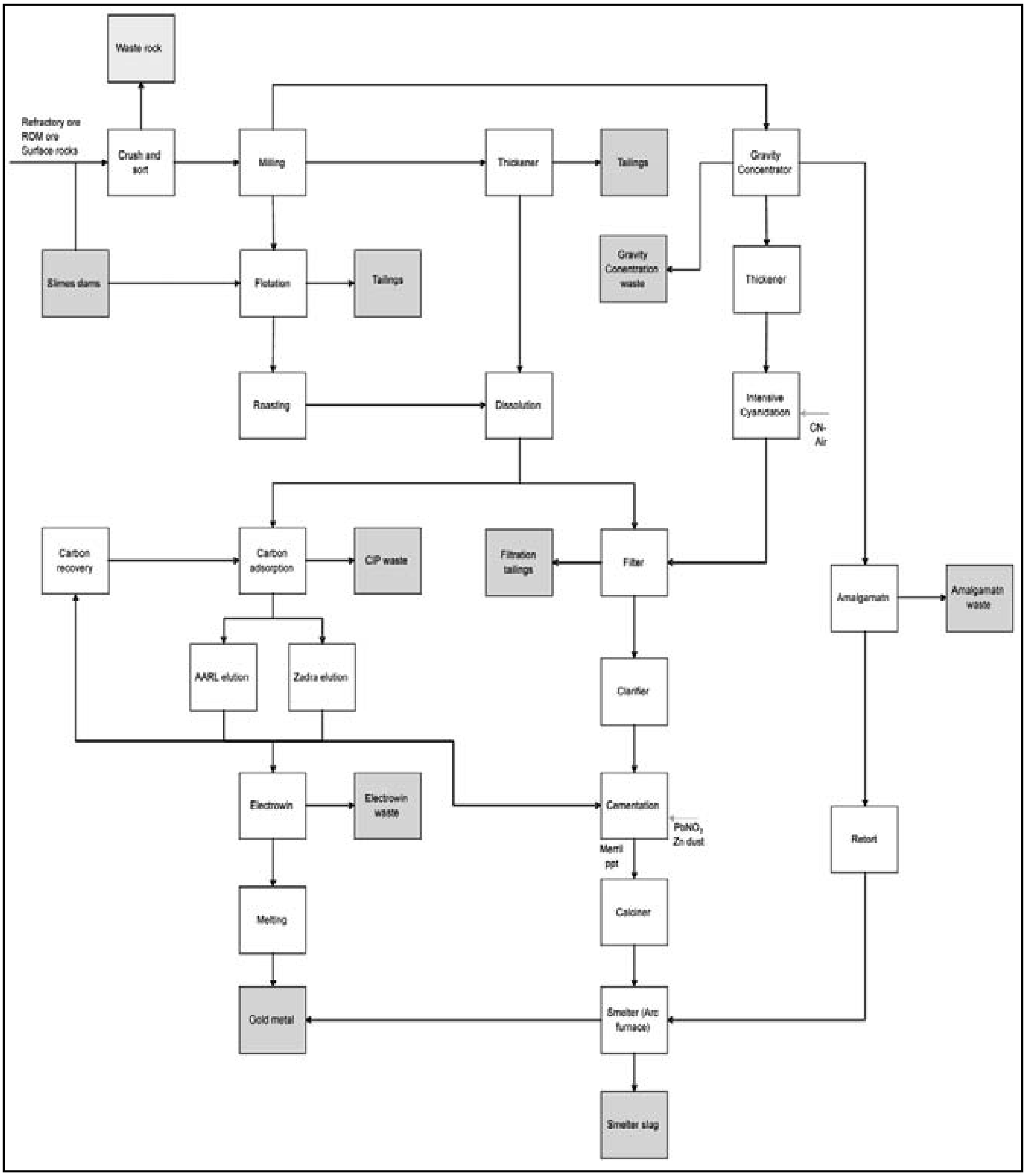


Figure B.3: PGM hydrometallurgical processing initial beneficiation flow sheet (WRC 1550/1/07)

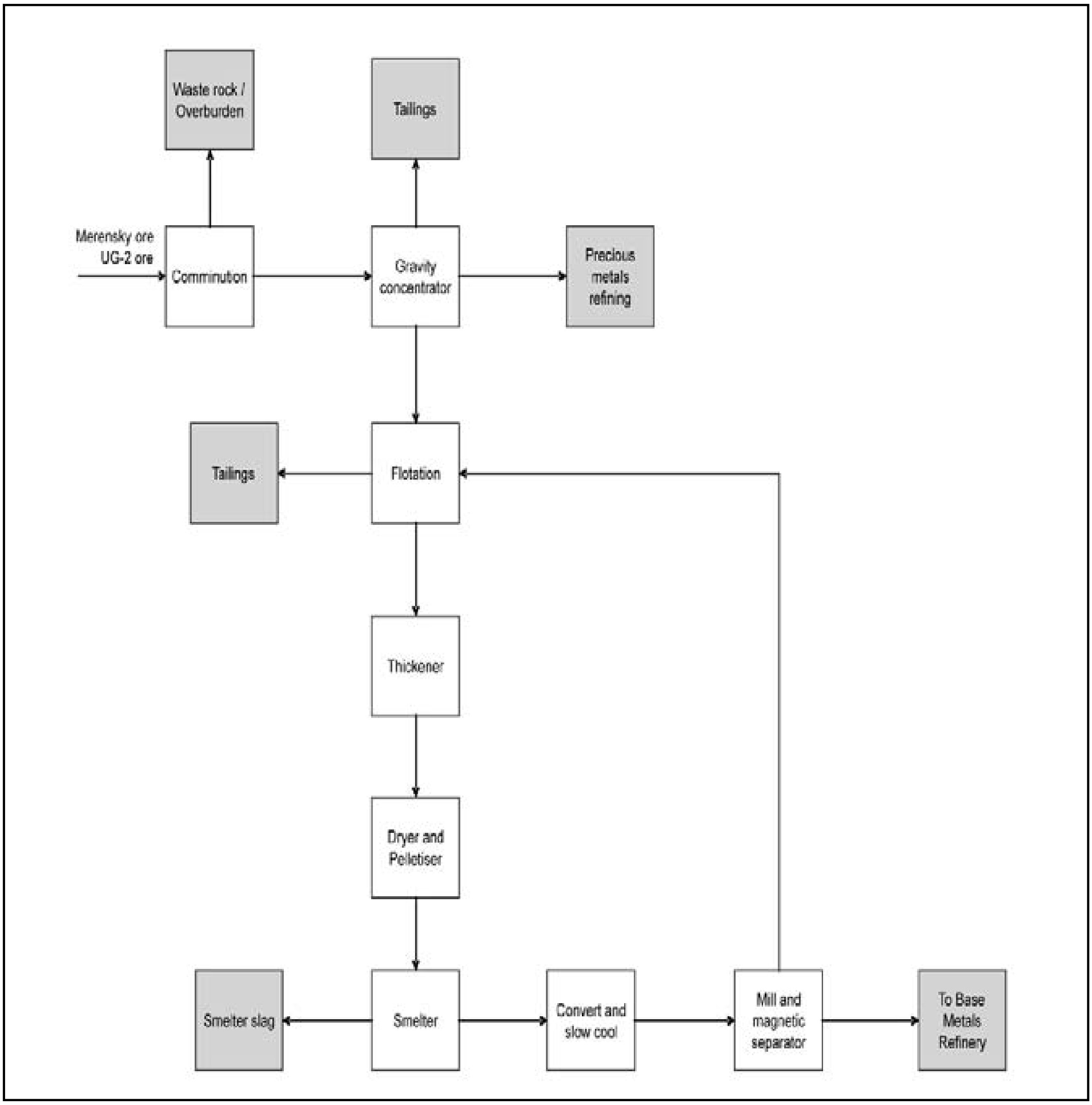


Figure B.4: PGM base metals refining flow sheet (WRC 1550/1/07)

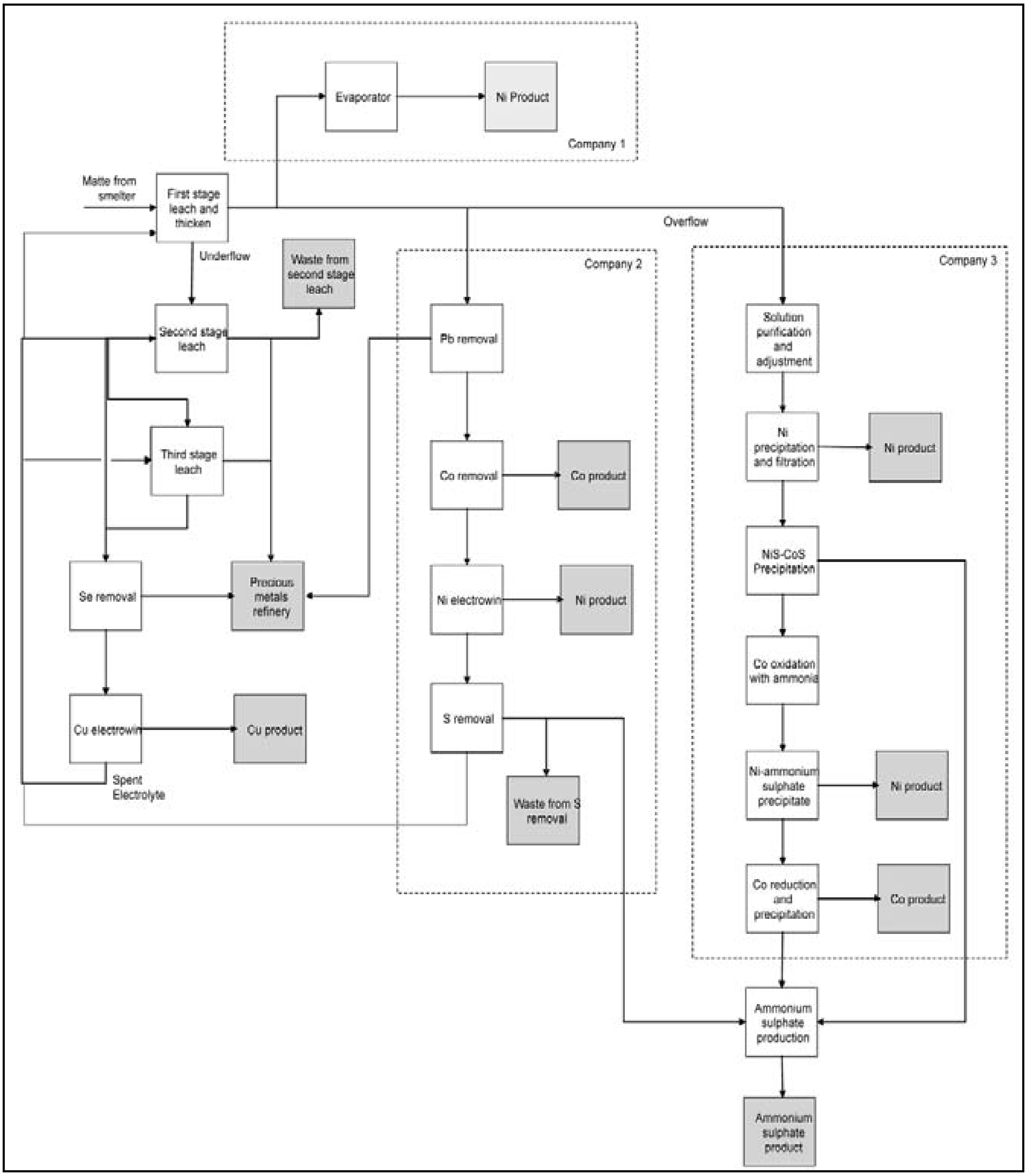


Figure B.5: General ferro-alloy ore processing flow sheet (WRC 1550/1/07)

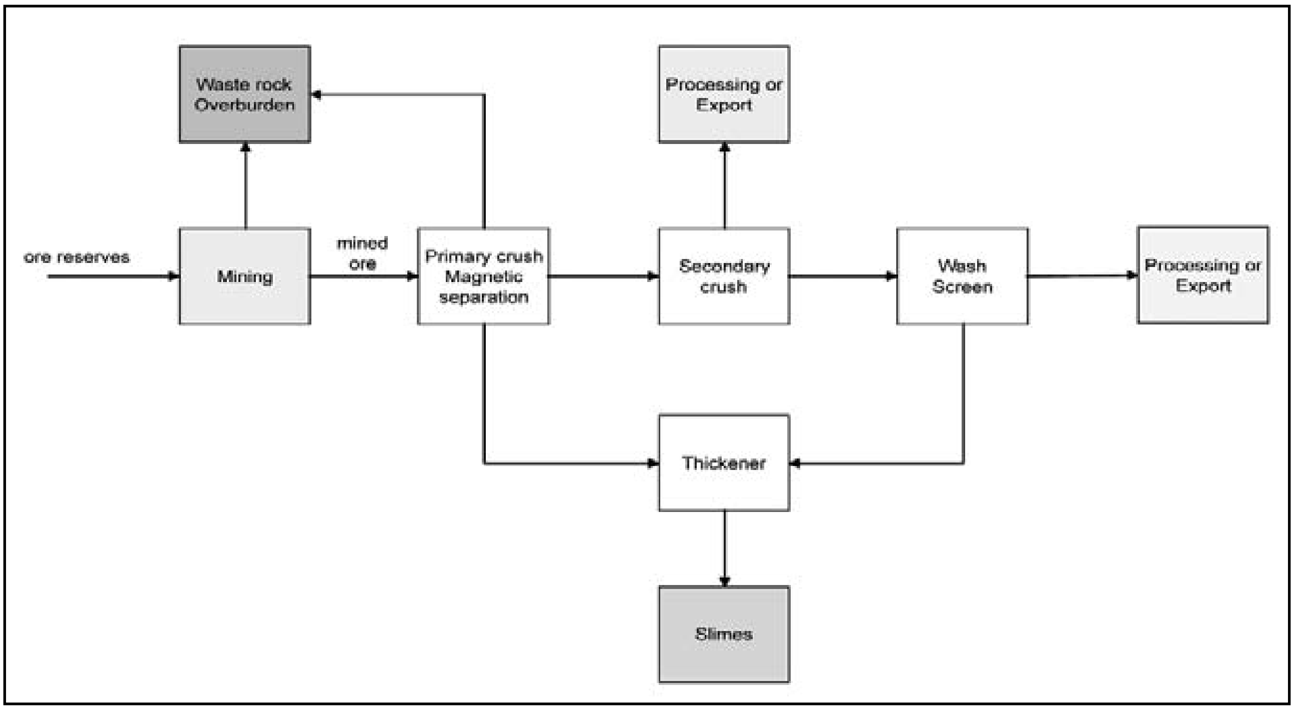


Figure B.6: Stainless steel flow sheet (WRC 1550/1/07)

See WRC 1550/1/07 for further flow sheets on Fe-Si, Si-Mn, Fe-Cr, Fe-Mn, Fe-V.

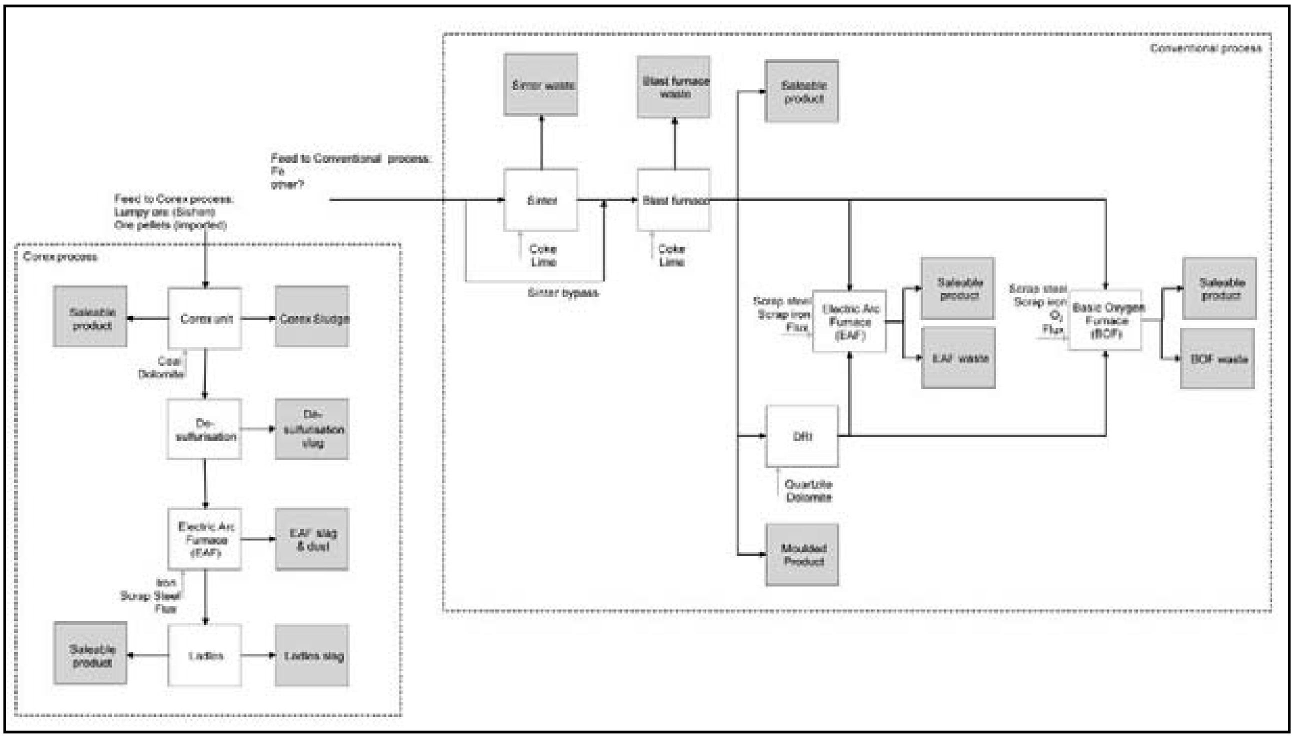


Figure B.7: Non-ferrous metals initial concentration flow sheet (WRC 1550/1/07)

See WRC 1550/1/07 for further flow sheets on aluminium (Al), zinc (Zn), copper (Cu) and phosphate.

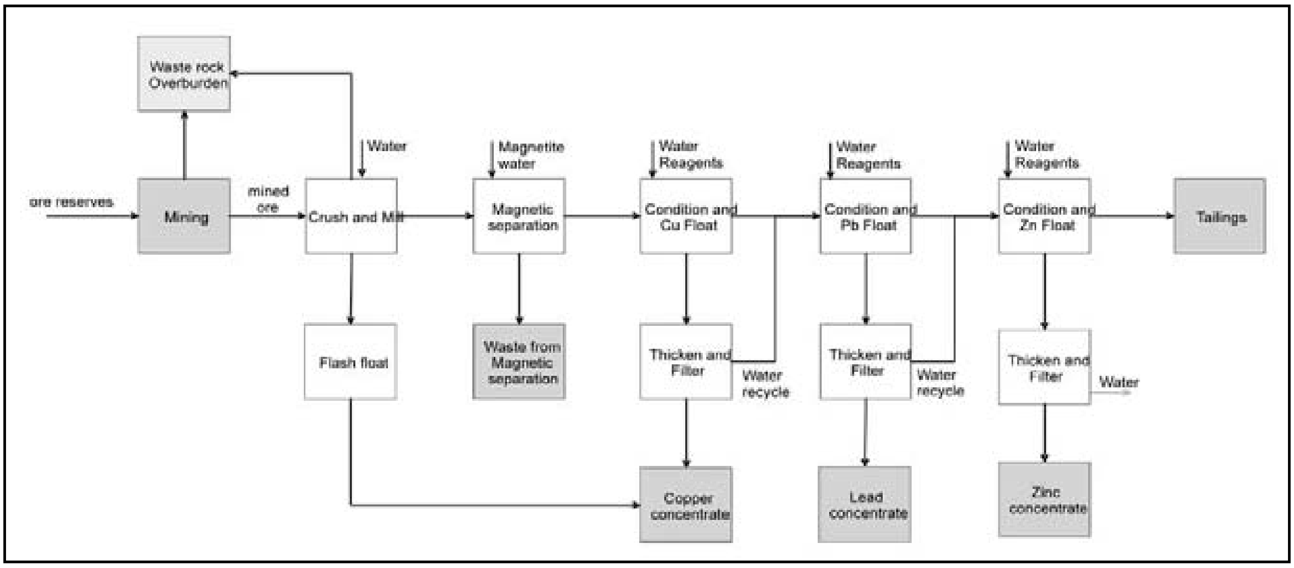


Figure B.8: Mineral sands processing flow sheet (WRC 1550/1/07)

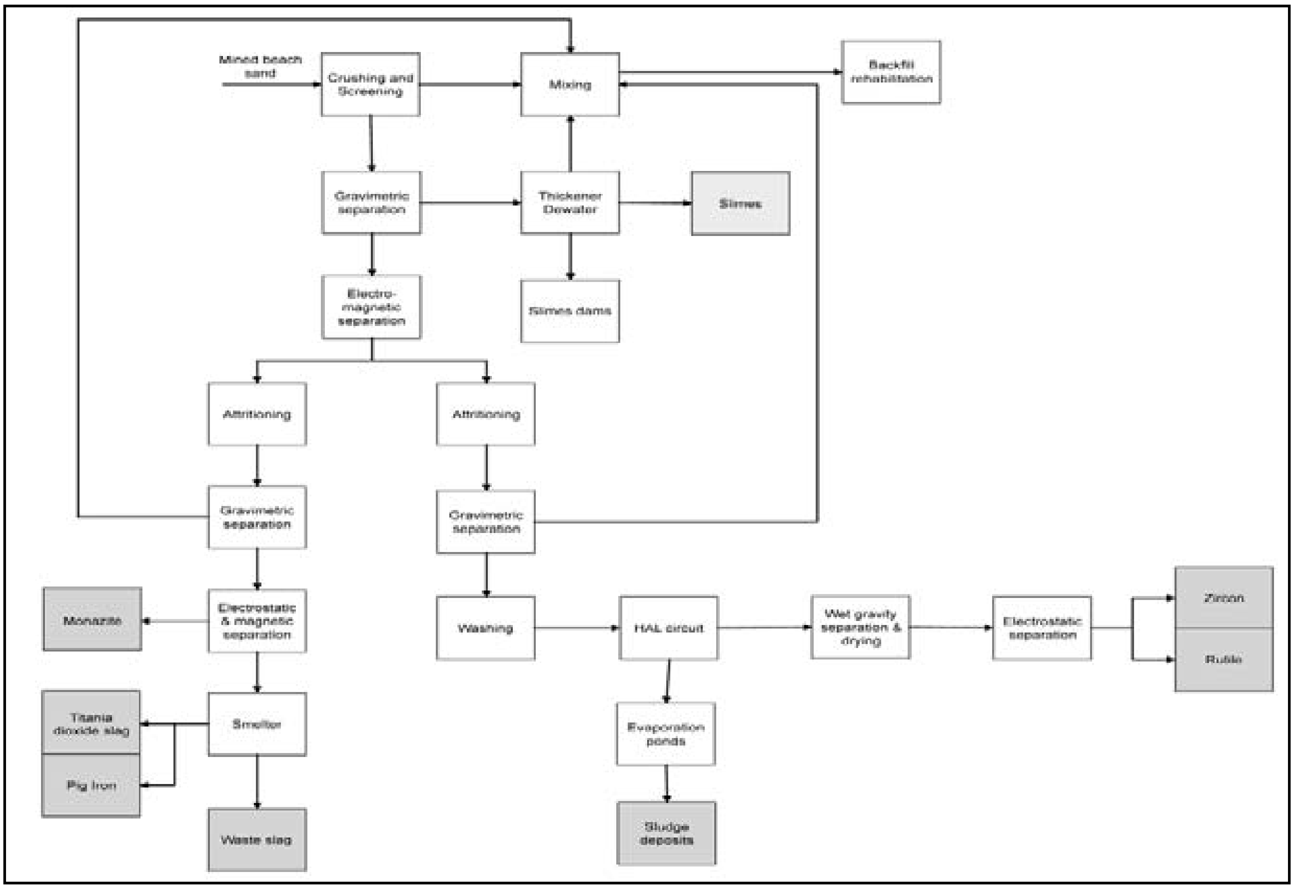


Figure B.9: Uranium and gold processing flow sheet (Valliant and Bergen, 2006)

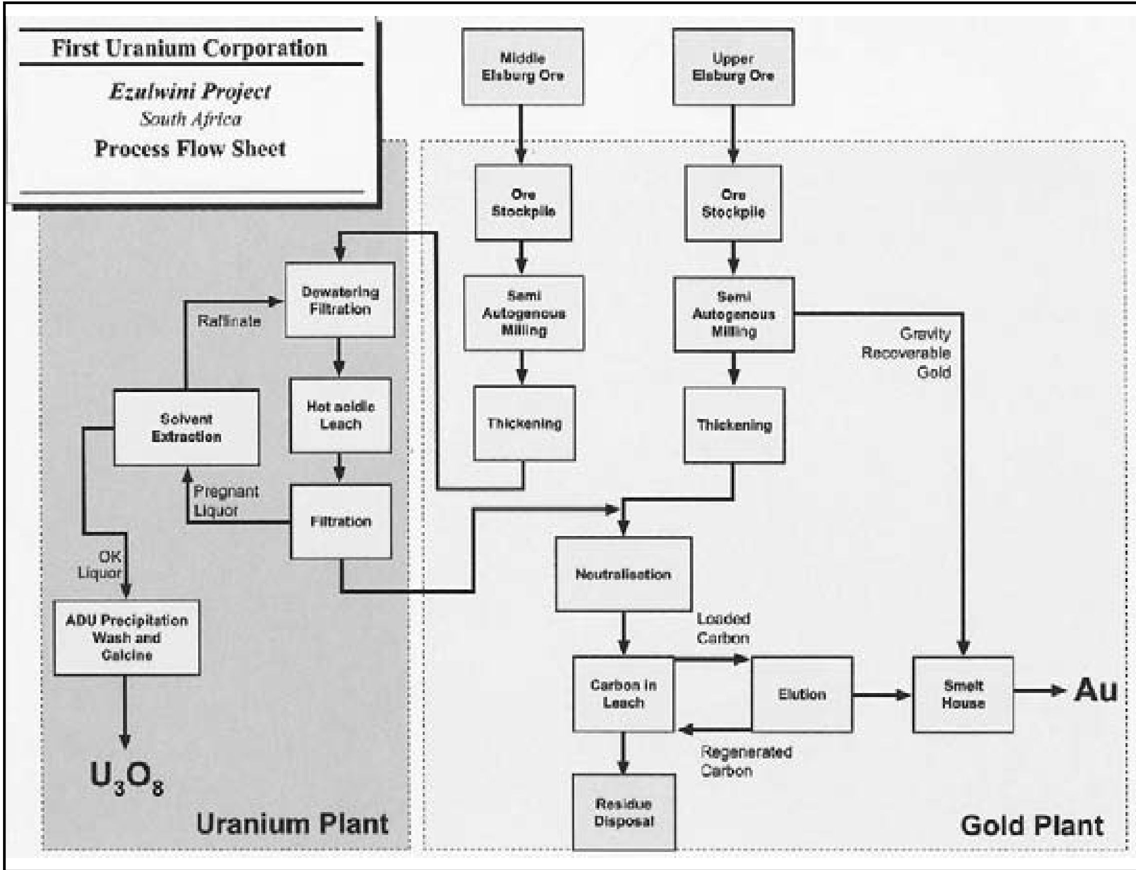


Table B.1: Explanation of terminology and abbreviations used in diagrams

TERM	ABBREVIATION	DEFINITION
Anglo American Research Laboratories Elution[1]	AARL elution	Gold is generally desorbed or recovered from activated carbon by means of one of two elution systems, the AARL or the Zadra elution systems. Both systems use hot caustic cyanide solutions as eluates.
Attritioning[2]		Frictional removal, using mechanical means, of surface layers (generally passivating layers) covering an ore or mineral particle.
Base Metals[2]		A metal that oxidizes or corrodes relatively easily, and react variably with dilute hydrochloric acid (HCl) to form hydrogen. Metals falling into this category normally include nickel, cobalt, lead and zinc. Copper is considered a base metal as it oxidizes relatively easily, although it does not react with HCl. It is commonly used in opposition to noble metal.

1 www.pfwa.com.ca
2 www.answers.com
3 www.steel.org

TERM	ABBREVIATION	DEFINITION
Basic Oxygen Furnace[3]	BOF	A towering cylinder lined with heat-resistant (refractory) bricks, used by integrated steel mills to smelt iron from iron ore. Its name comes from the "blast" of hot air and gases forced up through the iron ore, coke, and limestone that load the furnace.
Calciner/Calcining Furnace[2]		A heating device, such as a vertical-shaft kiln, that raises the temperature (but not to the melting point) of a substance such as limestone to make lime.
Calcine[2]		To heat (a substance) to a high temperature but below the melting or fusing point, causing loss of moisture, reduction or oxidation, and the decomposition of carbonates and other compounds.
Cementation[2]		A metallurgical coating process in which iron or steel is immersed in a powder of another metal, such as zinc, chromium, or aluminium, and heated to a temperature below the melting point of either. Cementation is the process by which one substance is caused to penetrate and change the character of another by the action of heat below the melting points of the substances.
Carbon in Leach[2]	CIL	Activated carbon is added to a gold ore slurry contained in leach tanks. The carbon adsorbs the gold from the solution as cyanidation of the ore proceeds.
Carbon in Pulp[2]	CIP	Milled gold bearing ore is mixed with a cyanide solution, which causes the gold to complex with the cyanide, and activated carbon particles. The activated carbon is pumped up through tanks counter-current to the cyanide slurry solution. As activated carbon and loaded cyanide solution meet, the soluble gold-cyanide complex adsorbs to the activated carbon. These particles are removed from the slurry and gold is recovered.
Clarifier[2]		A piece of equipment used to filter a liquid.
Conditioning		A process in which reagents and ore are allowed to come to steady state before further processing of the ore continues.
Convert[2]		To change (something) into another form, substance, state, or product.
Corex[3]		COREX® is a patented coal-based smelting process that yields hot metal or pig iron. The output can be used by integrated mills or EAF mills.
Dense Media Separation[4]	DMS	Separation of relatively light (floats) and heavy (sinks) particles, by immersion in a bath of intermediate density. This is the dense or heavy media, a finely ground slurry of appropriate heavy material in water. Barite, magnetite ferrosilicon, and galena are in principal use.
Direct Reduced Iron[3]	DRI	DRI is processed iron ore that is iron-rich enough to be used as a scrap substitute in electric furnace steelmaking.

TERM	ABBREVIATION	DEFINITION
Electric Arc Furnace[3]	EAF	Steel-making furnace where scrap is generally 100% of the charge. Heat is supplied from electricity that arcs from the graphite electrodes to the metal bath. Furnaces may be either an alternating current (AC) or direct current (DC).
Electrostatic Separation[2]		Process of separating non-conductive particles from conducting particles. Electrostatic separation of finely pulverized materials is carried out in electrostatic separators.
Electrowin[5]	EW	Most metals occur in nature in oxidized form in their ores and thus must be reduced to their metallic forms. The ore is dissolved following some pre-processing in an aqueous electrolyte or in a molten salt and the resulting solution is electrolyzed. The metal is deposited on the cathode (either in solid or in liquid form), while the anodic reaction is usually oxygen evolution. Several metals are naturally present as metal sulphides; these include copper, lead, molybdenum, cadmium, nickel, silver, cobalt and zinc. In addition, gold and platinum group metals are associated with sulphidic base metal ores. Most metal sulphides or their salts are electrically conductive and this allows electrochemical redox reactions to efficiently occur in the molten state or in aqueous solutions.
Ferro Alloy[5]		Any alloy of iron and another metal, especially one of silicon, manganese, chromium and vanadium, used in the production of specialist steels as they have a lower melting point than the pure metal.
Flotation[2]		The process of separating different materials, especially minerals, by agitating a pulverized mixture of the materials with water, oil, and chemicals. Differential wetting of the suspended particles causes unwetted particles to be carried by air bubbles to the surface for collection.
Gravity Concentration[2]		Any of various methods for separating a mixture of particles, such as minerals, based on the differences in density of the various species and on the resistance to relative motion exerted upon the particles by the fluid or semi fluid medium in which separation takes place. The separation of liquid-liquid dispersions based on settling out of the dense phase by gravity.
Gravity Separation[6]		If there is a certain difference in density between two minerals or rock fractions they can be separated by using this difference. Separation by gravity covers two different methods. Separation in water (Gravity concentration) Separation in a heavy medium (Dense Media Separation, DMS)
Hot Acid Leach	HAL	A hot sulphuric acid leach (HAL) circuit to remove iron coatings from the non-magnetic heavy minerals during mineral sands beneficiation

[4] http: www.maden.hacettepe.edu.tr/dmmrt/dmmrt320.html

TERM	ABBREVIATION	DEFINITION
Leach[3]		In the chemical processing industry, leaching is known as extraction. Leaching has a variety of commercial applications, including separation of metal from ore using acid. In a typical leaching operation, the solid mixture to be separated consists of particles, inert insoluble carrier A and solute B. The solvent, C, is added to the mixture to selectively dissolve B. The overflow from the stage is free of solids and consists of only solvent C and dissolved B. The underflow consists of slurry of liquid of similar composition in the liquid overflow and solid carrier A. In an ideal leaching equilibrium stage, all the solute is dissolved by the solvent; none of the carrier is dissolved. The mass ratio of the solid to liquid in the underflow is dependent on the type of equipment used and properties of the two phases. Leaching is widely used in extractive metallurgy since many metals can form soluble salts in aqueous media. Compared to pyrometallurgical operations, leaching is easier to perform and much less harmful, because no gaseous pollution occurs. The only drawback of leaching is its lower efficiency caused by the low temperatures of the operation, which dramatically affect chemical reaction rates. There are a variety of leaching processes, usually classified by the types of reagents used in the operation. The reagents required depend on the ores or pre-treated material to be processed. A typical feed for leaching is either oxide or sulphide.
Magnetic Separation[4]		By creating an environment comprising a magnetic force (Fm), a gravitational force (Fg) and a drag force (Fd) magnetic particles can be separated from nonmagnetic particles by magnetic separation. Magnetic separation is widely used to remove tramp iron from ores being crushed, to remove contaminating magnetics from food and industrial products, to recover magnetite and ferrosilicon in the float-sink methods of ore concentration, and to upgrade or concentrate ores. Magnetic separators are extensively used to concentrate ores, particularly iron ores, when one of the principal constituents is magnetic.
Matte[2]		A mixture of a metal with its sulphides, produced by smelting the sulphide ores of copper, lead, or nickel.
Mill[2]		To grind, pulverize, or break down into smaller particles in a mill.

[5] *www.wikipaedia.com*

[6] *http://www.metsominerals.com/inetMinerals/mm_home.nsf/FR?ReadFormandATL=/inetMinerals/mm_segments.nsf/WebWID/WTB-041213-2256F-B42B4*

TERM	ABBREVIATION	DEFINITION
Mineral Sands[2]		Heavy mineral sands are a class of ore deposit which is an important source of zirconium, titanium, thorium, tungsten, rare earth elements, the industrial minerals diamond, sapphire, garnet, and occasionally precious metals or gemstones. Heavy mineral sands are placer deposits formed most usually in beach environments by concentration due to the specific gravity of the mineral grains. It is equally likely that some concentrations of heavy minerals (aside from the usual gold placers) exist within streambeds, but most are of a low grade and are relatively small.
Oxidation[2]		The combination of a substance with oxygen.
Pelletising		Formation of aggregates of about ½-inch (13-millimeter) diameter from finely divided ore or coal.
Platinum Group Metal	PGM	Platinum, palladium, rhodium, ruthenium, osmium and iridium.
Precipitation[2]		In chemistry, a process in which a solid is separated from a suspension, sol, or solution. In a suspension such as sand in water the solid spontaneously precipitates (settles out) on standing. In a sol the particles are precipitated by coagulation. A solute (dissolved substance) may be precipitated from a solution by several means. It is often difficult to obtain a pure substance by a single precipitation, and a substance may be further purified by reprecipitation after it has been redissolved. The term *precipitation* is also applied to the separation of particles of a solid or liquid suspended in a gas.
Pyrometallurgy[5]		The branch of extractive metallurgy in which processes employing chemical reactions at elevated temperatures are used to extract metals from raw materials, such as ores and concentrates, and to treat recycled scrap metal. For metal production, the pyrometallurgical operation commences with either a raw material obtained by mining and subsequent mineral and ore processing steps to produce a concentrate, or a recycled material such as separated materials from scrapped automobiles, machinery, or computers. Pyrometallurgical preparation processes convert raw materials to forms suitable for future processing. Reduction processes reduce metallic oxides and compounds to metal. Oxidizing processes oxidize the feed material to an intermediate or a semi finished metal product. Refining processes remove the last of the impurities from a crude metal.
Refine		To reduce to a pure state; purify.

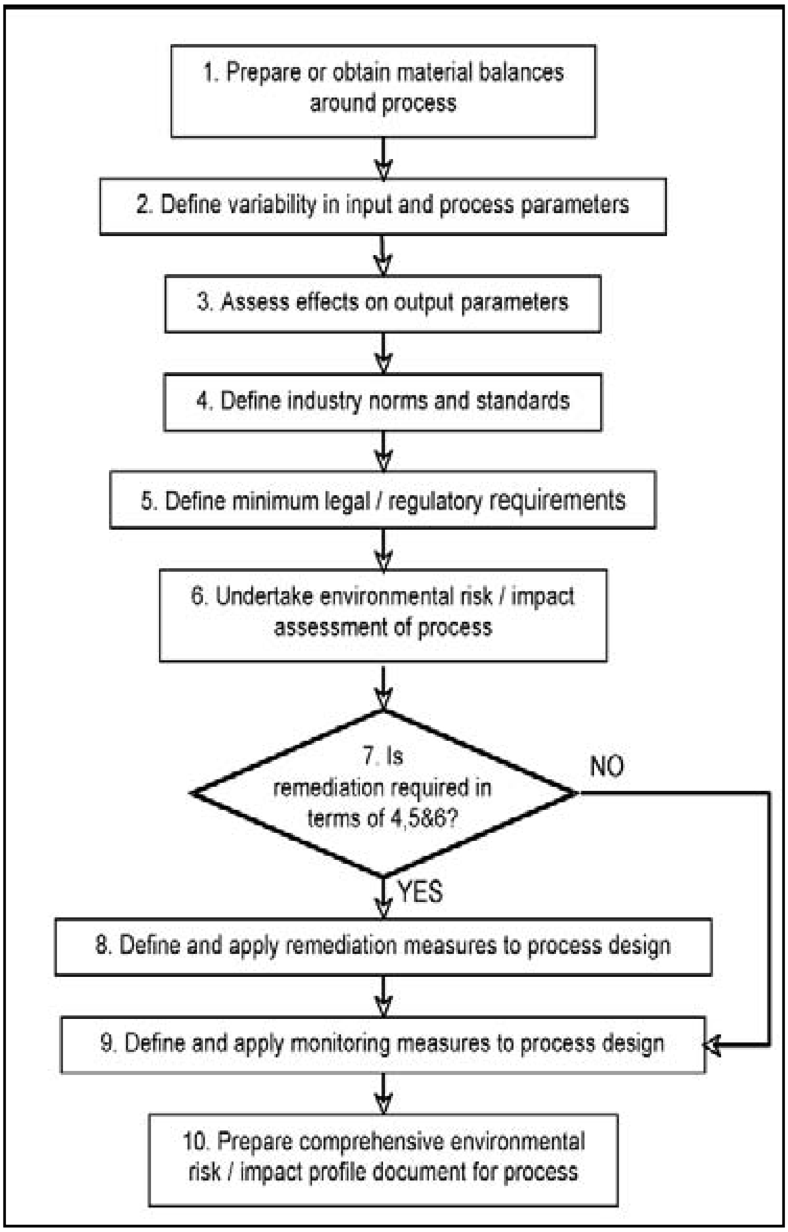
TERM	ABBREVIATION	DEFINITION
Sinter[2]		Process in which a coherent bonded mass (sinter) is formed by heating metal powders without melting; used mostly in powder metallurgy.
Separation[6]		After liberation of all individual minerals in a rock or an ore feed, either by grinding or by natural size reduction (beach sands a.o.) they can be separated individually. Depending on their behaviour, different technologies are applied.
Slag[5]		Slags are the by-product of smelting ore to purify metals. They can be considered to be a mixture of metal oxides; however, they can contain metal sulphides and metal atoms in the elemental form. While slags are generally used as a waste removal mechanism in metal smelting, they can also serve other purposes, such as assisting in smelt temperature control and minimizing re-oxidation of the final bullion product before casting. In nature, the ores of metals such as iron, copper, lead, aluminium, and other metals are found in impure states, often oxidized and mixed in with silicates of other metals. During smelting, when the ore is exposed to high temperatures, these impurities are separated from the molten metal and can be removed. The collection of compounds that is removed is the slag. Different smelting processes produce different slags. In general they can be classified as ferrous or non-ferrous. The smelting of copper and lead in non-ferrous smelting, for instance, is designed to remove the iron and silica that often occurs with those ores and separates it as an iron silicate based slag. Slag from steel mills in ferrous smelting, on the other hand, is designed to minimise iron loss and so mainly contains calcium, magnesium, and aluminium. Slag has many commercial uses, and is rarely thrown away. It is often reprocessed to separate any other metals that it may contain. The remnants of this recovery can be used in railroad track ballast, and as fertilizer. It has been used as a road metal and as a cheap and durable means of roughening sloping faces of seawalls in order to progressively arrest the movement of waves. Ground granulated slag is often used in concrete in combination with Portland cement as part of a blended cement. Ground granulated slag has latent hydraulic properties, which means that it reacts with water to produce cementitious properties. Concrete containing ground granulated slag develops strength over a longer period, leading to reduced permeability and better durability properties. Since the unit volume of Portland cement will also be reduced, concrete is less vulnerable to alkali-silica and sulphate attack.
Slimes		Ore that has been milled to such a fine grind that, when mixed with water, it forms a slime material.

TERM	ABBREVIATION	DEFINITION
Slow Cool		Matte from a smelter is poured into a mould and allowed to cool extremely slowly (over a period of days) in order to produce various crystalline products allowing further separation of material downstream.
Smelter[2, 5]		A smelter is a specialised metallurgical furnace that allows smelting to occur. Smelting is a method of separating gold, silver, and other metals from their ores with fire and heat intense enough to melt the ores.
Solvent Extraction[2]	SX	A technique, also called liquid extraction, for separating the components of a liquid solution. This technique depends upon the selective dissolving of one or more constituents of the solution into a suitable immiscible liquid solvent. It is particularly useful industrially for separation of the constituents of a mixture according to chemical type, especially when methods that depend upon different physical properties, such as the separation by distillation of substances of different vapour pressures, either fail entirely or become too expensive. Industrial plants using solvent extraction require equipment for carrying out the extraction itself (extractor) and for essentially complete recovery of the solvent for reuse, usually by distillation. *See also* Distillation.
Tailings		Tailings (also known as tailings pile, slickens[1] or gangue) are the waste materials left over[2] after removing the minerals from ore. Tailings and gangue represent external costs of mining. As mining techniques and the price of minerals improve, it is not unusual for tailings to be reprocessed using new methods, or more thoroughly with old methods, to recover additional minerals. In coal and oil sands mining, the word ‘tailings’ refers specifically to fine waste suspended in water and the word ‘gangue’ is not used.
Thickener[5]		A non-filter device for the removal of liquid from a liquid-solids slurry to give a dewatered (thickened) solids product; can be by gravity settling or centrifugation.
Waste Rock/ Overburden[2]		Material overlying a useful mineral deposit.
ZADRA Elution[1]		A process for the removal or recovery of gold from activated carbon (see AARL elution)

APPENDIX C: EXAMPLE OF DETAILED RISK ASSESSMENT PROCESS AT PLANT DESIGN STAGE

A strategy for the risk-based environmental assessment of a proposed new hydrometallurgical process plant is presented in this document. This is a practical strategy that was actually implemented for a new process that was developed before the first plant was built. The process that was followed is shown in Figure C1 below.

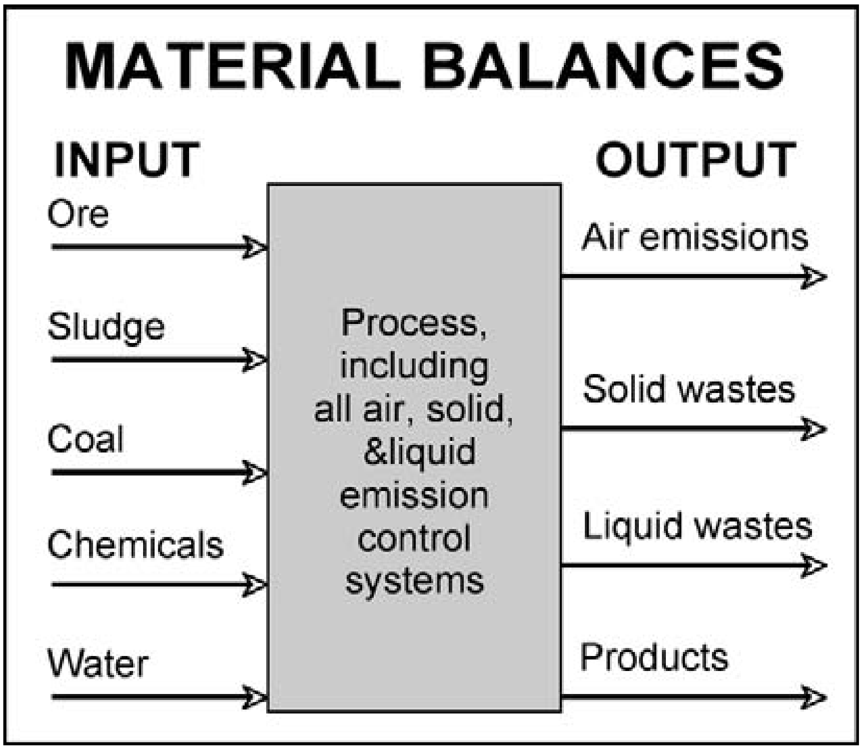
Figure C.1: Environmental Risk Assessment Process



Step 1: Prepare or obtain material balances around the metallurgical process

A detailed material balance must be constructed around the metallurgical process (including all air, solid and liquid control systems). The balance will include all inputs raw materials, ore, chemicals, water) and all outputs (products, air emissions, solid wastes, liquid wastes). In undertaking the balance, it will be important to follow all waste products to their final repository (e.g. a baghouse may be constructed to remove particulate matter from stack gasses, the baghouse dust may then be slurried, possibly contaminating water, the slurry may then be dewatered and the sludge may be disposed of at a solid waste disposal facility where further surface and ground water contamination may occur and, if the sludge is allowed to dry out, fugitive dust may be generated).

Figure C2: Schematic of Material Balance Around Process



It is generally anticipated that much of the information required to prepare these material balances will be available from the project process engineers, although it is possible that additional information will need to be obtained from pilot plant studies. The performance of various emission control systems may need to be defined on the basis of supplier's specifications or knowledge of similar installations elsewhere. The final material balances should be compiled by a joint team comprising plant process engineers and environmental specialists.

Step 2: Define variability in input and process parameters

Depending on where the process plant is to be constructed and the nature of the mineral deposit or deposits that are to be mined to provide feedstock to the plant, it is possible that the inputs to the process may change significantly over the plant lifespan. In this step of the assessment process, the variability that can be expected in the input parameters will be clearly defined. The characteristics of the inputs which are of interest are those which have an effect on the nature of any environmental emissions (e.g. sulphur, volatiles and ash content of coal, radioactivity of ore, trace metal content of ore, characteristics of input chemicals, etc.). Where possible, the distribution of parameter values should be described and defined. In addition to the variability in input parameters, any variability in process and operating conditions which can be expected should also be defined.

Step 3: Assess effects of variability on output parameters

The variability in input and process parameters which has been defined in Step 2 should be assessed in terms of the effects on the material balances for the process. Depending on the nature of the variability and the understanding of the effects thereof, it may be necessary to undertake probabilistic modelling in order to properly define the resultant material balances.

Step 4: Define industry norms and standards (benchmarks)

If there are no other identical process plants in operation and therefore, no norms or standards for environmental emissions, such norms and standards should be available for other similar processes. The emission norms and standards for these applicable processes should be collated into a reference document. The norms and standards will include definition of “Best Available Technology” in terms of emission controls as specified internationally.

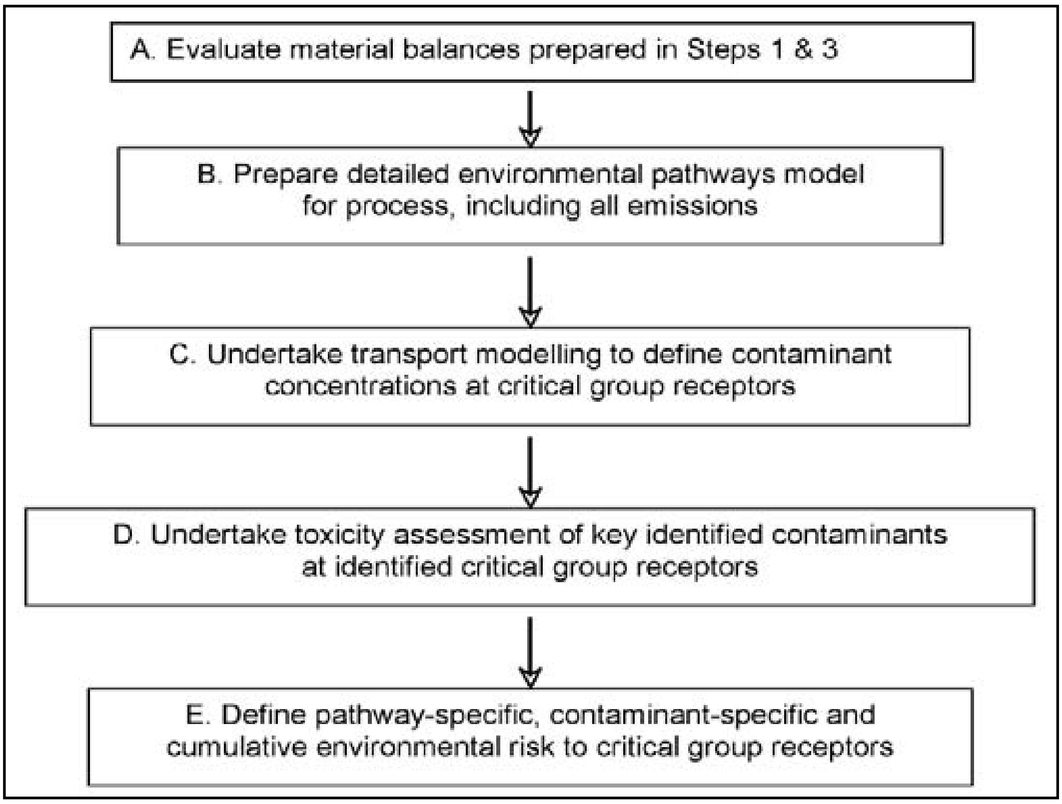
Step 5: Define minimum legal/regulatory requirements

The legal and regulatory requirements which will apply to the planned process plant must be defined for the South African situation. Whereas it will be important to ensure that the proposed process complies with legal and regulatory requirements, these requirements should be viewed as the minimum, and the environmental risk assessment process should evaluate the real environmental problems independently of these requirements. The reason for adopting the risk approach is that the regulatory requirements regularly change and linking the performance of the proposed process to these changing goalposts will make it difficult to define and manage the environmental performance over the whole plant life cycle.

Step 6: Undertake environmental risk/ impact assessment of process

The environmental risk/impact assessment process should be rigorous and designed to withstand any local or international scrutiny. This Step of the overall process has been further divided into 5 separate tasks as shown in Figure C3 and described in the text.

Figure C3: Detailed Environmental Risk/Impact Assessment Process



Task A: Evaluate material balances prepared in Steps 1 and 3

The material balances which were prepared in Steps 1 and 3 should be critically evaluated in order to define those aspects which pose some potential environmental risk. Particular focus should be placed on the various waste streams which are generated, their proposed disposal routes and any environmental risks/impacts which may arise there, both through application of approved management and operation procedures and through failure of these approved procedures. This task should culminate in the definition of all contaminant source terms in terms of location, quantity and quality for best and worst case scenarios.

Task B: Prepare detailed environmental pathways model for process, including all emissions

Task C and the subsequent Tasks D and E apply for the assessment of the site-specific risks of the process at a particular location. The potential critical receptors must be defined for each of the best and worst case scenarios identified in Task A. The critical receptor concept is based on defining a hypothetical, conservative but realistic human or ecological receptor which may be affected by the proposed process and its waste streams through one or more pathways. The critical receptor(s) is/are chosen to represent the most highly impacted-upon receptors such that there is confidence that if the critical receptor is assessed to be exposed to an acceptable risk, then all other potentially exposed receptors are subject to an even lower risk.

Using the identified critical receptors, a comprehensive contaminant and exposure pathway analysis should be undertaken in order to define all the air, water and land pathways through which the various contaminants from the defined source terms may travel. This pathway analysis should be undertaken using an appropriate computer code developed for this purpose and should include all pathway interactions which may reasonably occur.

Task C: Undertake transport modelling to define contaminant concentrations at critical group receptors

Once the pathway analysis has been completed, the transport of contaminants along these pathways will need to be modelled. For example, for the atmospheric pathway, the dispersion of particulate and gaseous emissions will need to be modelled using appropriate computer codes in order to derive the concentration of these contaminants at the critical receptor. Similarly for the surface and ground water routes, taking into account other intermediate receptors such as macro-invertebrates, aquatic species, sediments, livestock and irrigated crops wherever appropriate. The output of this task would be a specified concentration, duration and probability of key contaminants at the critical receptors.

Task D: Undertake toxicity assessment of waste streams

With the information provided in Tasks A, B and C, a toxicity assessment can be undertaken to define the deleterious effects, if any, resulting from the various contaminants in the various waste streams. Such a toxicity assessment must be based on the methodologies proposed by the Department of Water Affairs and will focus on the potential maximum toxicity (the conservative approach) of the waste streams and the mobility of the contaminants into different environmental pathways.

Task E: Define pathway-specific, contaminant-specific and cumulative environmental risk to critical group receptors

Based on the toxicity assessment which were undertaken in Task D and the pathways and transport modeling undertaken in Tasks B and C, it will be possible to define the environmental risks for each contaminant or for each pathway or cumulatively for all contributing risk factors. This will enable later phases of the project to focus remediation or design changes to those components of the process train which directly contribute most significantly to the unacceptable risk which needs to be addressed. In this way, the beneficial effects of any remediation measures can be rapidly assessed in terms of real effect at the particular receptor of interest.

Step 7: Is remediation required in terms of Steps 4, 5 and 6?

The environmental risks/impacts which are assessed in Step 6 need to be evaluated in terms of the industry norms and standards and the minimum legal/regulatory requirements defined in Steps 4 and 5. The risks should also be evaluated in terms of the assessed consequence to the critical receptors as defined in Step 6. If unacceptable risks are identified, then appropriate remediation measures will need to be evaluated in terms of modifying the existing design of the process plant. Should it be found that no remediation is required, then the existing process design will need to be evaluated in terms of monitoring systems to ensure that these are adequate.

Step 8: Define and apply remediation measures to process design

If the assessment in Step 7 indicates that unacceptable environmental or legal risks are associated with the proposed process as it is currently engineered, then appropriate remediation measures should be identified. The correct place to apply the remediation measures will be highlighted by the pathways and transport modelling exercise undertaken as part of Step 6. For example, it may be decided to add a water treatment plant to the process train to ensure that liquid effluent discharges pose no significant risk to the receiving environmental media, or it may be decided to separate certain solid waste streams and dispose of them under tightly controlled conditions or treat them to a less toxic form.

Step 9: Define and apply monitoring measures to process design

In order to ensure that the proposed process can demonstrate to regulators and other interested and affected parties that it poses no undue environmental risk, it will be necessary to design, implement and maintain an appropriate environmental monitoring programme. This monitoring programme will also provide the plant operators with the requisite information for ensuring that appropriate management controls are applied at the earliest possible stage. Even the best designed process can have equipment malfunctions and the monitoring systems should be designed to identify such malfunctions timeously before serious environmental impacts are caused. The monitoring programme which will include both source and receptor monitors will also provide the proof that the environmental risk/impact is acceptable.

Step 10: Prepare comprehensive environmental risk /impact profile document for the process

Detailed documentation should be prepared which clearly describes the rigorous evaluation process which the proposed plant will have been subjected to. The environmental risk to the critical receptors for the different evaluation scenarios should be clearly specified and the required emission control and monitoring equipment to ensure acceptable risk should also be clearly defined. The report should also draw comparisons between the proposed process plant and other similar operations in terms of environmental risk/impact.

APPENDIX D
CHECKLIST

D.1 Purpose of checklist

Reference is again made to Figure 2.1. Below you will find a checklist, the purpose of the checklist is different for different users and as follows:

- *Mining industry use:* Guide hydrometallurgical processing plant engineers/workers as to which aspects need to be considered in terms of water management on their site.
- *Internal DWAF use*: Assist DWAF officials, not familiar with the details of a hydrometallurgical processing, with the evaluation of an IWWMP through checking and ensuring all aspects have been considered and covered in the IWWMP. The DWAF official can then adequately evaluate and review the IWWMP. DWAF officials are generally are not concerned with the details of water management on hydrometallurgical processing plants except in the case where such a plant impacts on the surrounding environment (refer to Section 3.1: *Focus and role of DWAF*).

Answering NO to any of the questions in the checklist below, does not imply that an IWWMP is incomplete. A reason for a NO answer is possible and acceptable and should not be perceived in a negative manner.

ITEM	YES	NO	RECOMMENDED ACTION/ REASON
STEP 1: Is water considered as a *key business asset* and included into strategic business decisions?			
STEP 2: Is the *true cost and value of water* considered and the following included? • Exploration and planning cost • Water supply cost • Social and cultural cost • Environmental and ecological cost • Economic feasibility cost • Waste management cost • Operational cost • Water reticulation cost • Water treatment cost • Maintenance cost • Labour/personnel cost • Remediation cost • Legal cost • Risk cost			
Are the *benefits* of the hydrometallurgical processing plant mentioned? In particular in terms of its contribution to the community, region and country.			

ITEM	YES	NO	RECOMMENDED ACTION/ REASON
STEP 3: Are *details on the site and process* provided? • Layouts, infrastructure and support services • Environmental details in terms of particularly the water environment and its sensitivity • Process details • Inputs including raw material/ore and other chemicals • Water resources - availability, sustainability, variability etc • Other resources – personnel, finances, infrastructure • Waste details • Water reticulation • Monitoring programme • Future plans			
STEP 4: Does a *water and salt balance* exist? The water and salt balance should state clear objectives, be regularly updated and consider the different hydrological cycles. Refer to *BPG G2: Water and Salt Balances.*			
STEP 5: Are details provided in terms of the *mine/plant water users* and their water requirements (quantity and quality), their sensitivity to changes/variability and contaminants of concern (COC)?			
STEP 6: Is water use minimized? (Are *water conservation* strategies therefore implemented?)			
Is *water of different qualities segregated* and are there different water management systems for each of these?			
Are *materials stored* in an appropriate manner on site based on its reactivity with water and the area in which it is used?			
Is there a specific water management system for *areas with a high contamination risk* to prevent it from impacting on other water management systems and other plant areas?			
Is a *storm water management system* in place? Refer to *BPG G1: Storm Water Management*. Does the storm water management system ensure that clean water is kept clean and released to the receiving environment? Does the storm water management system ensure that contaminated storm water is captured and contained?			
Are *spillages cleaned* quickly and handled in an appropriate manner?			
Is *equipment* regularly inspected and maintained?			
Are *housekeeping and water management practices sustainable* over the life-cycle of the mine/plant? See Chapter 4.			
STEP 7: Is the *generation of contaminants minimized* through input optimization, pollution prevention and pollution reduction at source?			
Are the *water quality requirements for the mine/plant water users* established?			

ITEM	YES	NO	RECOMMENDED ACTION/ REASON
Are *monitoring, maintenance, inspections and audits* conducted?			
STEP 8: Is a *water reuse and reclamation* strategy implemented? Refer to *BPG H3: Water Reuse and Reclamation and BPG H4: Water Treatment*. The water reuse and reclamation strategy should: • Identify opportunities for water reuse and reclamation • Indicate the benefits of water reuse and reclamation • Identify and consider all water sources available • Attempt to minimize water intake, consumptive water use and water losses • Maximize water reuse and reclamation by providing mine/plant water users with the poorest water quality possible without affecting the process or product quality • Optimize the water reticulation system • Consider the destiny of unused internal water sources in terms of the water management hierarchy by considering treatment to allow reuse, alternative uses, outside users, discharge/disposal. • Consider the advantages of material or byproduct recovery			
STEP 9: Are *process changes and cleaner technologies* considered for implementation?			
What are the *barriers preventing the implementation of cleaner production* and how are they overcome?			
STEP 10 and 11: Is an *IWWMP*, which considers and documents all the above considerations and principles, in place?			