Series G: General Guidelines



G1

BEST PRACTICE GUIDELINE

Storm Water Management

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

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This document is the first in a series of the following general aspects Best Practice Guideline documents:

BPG G1: Storm Water Management

BPG G2: Water and Salt Balances

BPG G3: Water Monitoring Systems

BPG G4: Impact Prediction

ACKOWLEDGE-MENTS

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

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APPROVALS

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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 below.

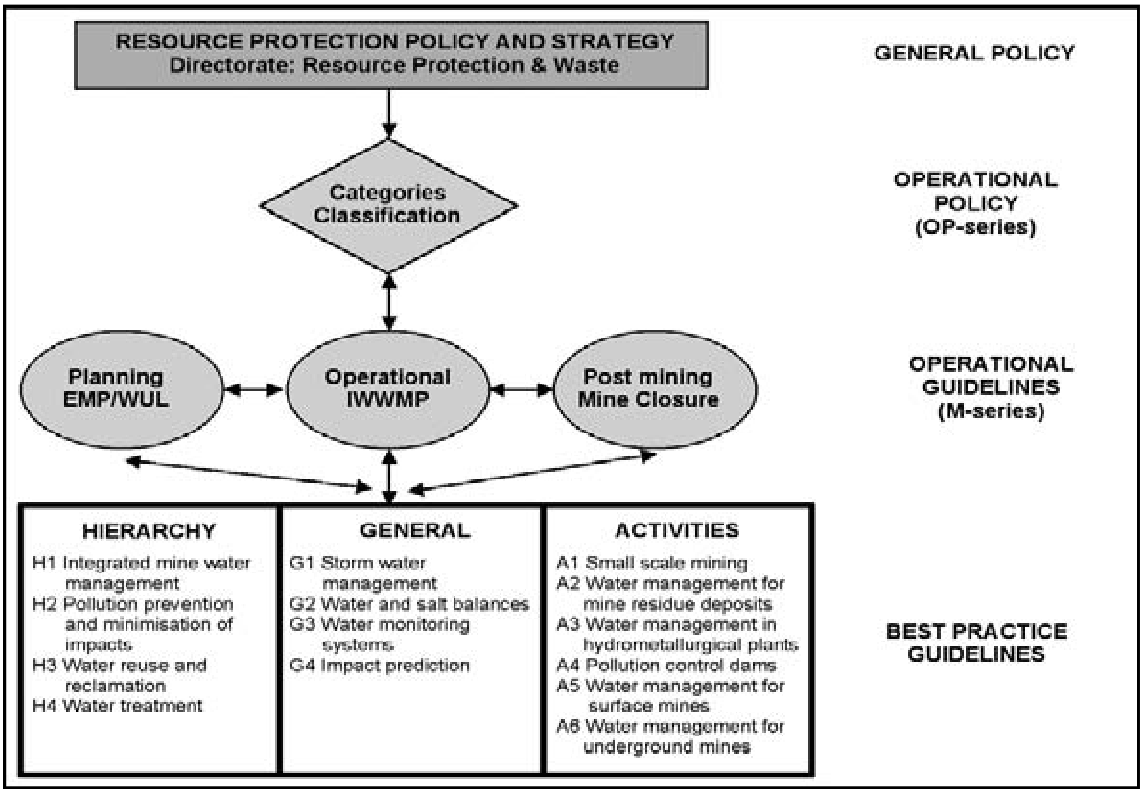
The overall Resource Protection and Waste Management Policy sets out the interpretation of policy and legal principles as well as functional and organisational arrangements for resource protection and waste management in South Africa.

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

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

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

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



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

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

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

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

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

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

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

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

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

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

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

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

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1 INTRODUCTION AND OBJECTIVES OF THIS BEST PRACTICE GUIDELINE

Storm water management and drainage planning are critical components of integrated water and waste management (IWWM) at mining sites. While storm water management is an integral part of IWWM and is documented as part of the Integrated Water and Waste Management Plan (IWWMP), for the purpose of this document, the component of the IWWMP that refers to storm water management is referred to separately as the storm water management plan (SWMP). A SWMP must address the impact of:

- Mining operations on the water flow and water quality processes of the hydrological cycle, and the associated upstream and downstream environmental impacts.
- The hydrological cycle on mining operations, including effects such as loss of production, costs, and impacts of both floods and droughts on the mining operations.

The objectives of a SWMP are site-specific but some general objectives include:

- Protection of life (prevent loss of life) and property (reduce damage to infrastructure) from flood hazards;
- Planning for drought periods in a mining operation;
- Prevention of land and watercourse erosion (especially during storm events);
- Protection of water resources from pollution;
- Ensuring continuous operation and production through different hydrological cycles;
- Maintaining the downstream water quantity and quality requirements;
- Minimising the impact of mining operations on downstream users;
- Preservation of the natural environment (water courses and their ecosystems).

The complexity of the SWMP depends largely on the size and nature of the mining operation, the characteristics of the hydrological cycle at the site, and the sensitivity of the area in which the mine is located to environmental impacts.

The SWMP must cover the life cycle of the mine from exploration, through construction, operation, decommissioning, and up to post-closure.

Potential adverse effects of inadequate storm water management include:

- Downstream contamination of natural watercourses due to runoff or spillage of contaminated storm water.
- Flooding, with the resultant damage to property, land and potentially loss of life.
- Loss of catchment yield and addition of large volumes of water to the mine water balance when optimal runoff of clean storm water is not achieved.
- Erosion of beds and banks of waterways.
- Increased recharge through spoils or fracture zones, unnecessarily increasing the water volume that comes into contact with contaminants.

This document aims to give guidance on the development and implementation of a SWMP by meeting the following objectives:

- To provide a practical procedure to develop a SWMP.
- To define the contents of a management system that will ensure compliance with the targets and objectives of the SWMP.
- To define where the expertise of suitably qualified persons is required at the various stages of plan development, implementation, operation and review/audit.
- To reference relevant legislative and policy issues that need to be considered in a SWMP.

The development of a SWMP can, however, not be done in isolation and requires objectives and information that are defined for other water management actions and strategies on the mine. The main water management aspects that need to be integrated with the development of a SWMP are:

- Water reuse and reclamation (see BPG H3)
- Impact prediction (see BPG G4)
- Water and salt balances (see BPG G2)
- Water monitoring systems (see BPG G3)

The application of this guideline is limited by the following factors:

- The focus of this Best Practice Guideline (BPG) is on all areas at mines where impacts may occur due to storm water runoff.
- General surface water management relating to process water circuits and catchment management is not addressed in this guideline.
- Both water quality and quantity are addressed with the focus on the impact on the environment.
- Considerations relevant to storm water management for the purpose of safety, like mine flooding and loss of life, are not specifically covered in this guideline, the primary focus being environmental management. Although this guideline does not address safety aspects, it is important that the relevant safety aspects should be considered and addressed when a SWMP is developed.

It should also be noted that the storm water management plans, as described in this guideline, are applicable to new and operational mines, as well as mines that are in the process of closure.

The layout and content of the document from Chapter 2 on is as follows: -

Chapter 2 - The principles and objectives to be incorporated in the storm water management plan.

Chapter 3 - The hydrological processes that need to be considered in a storm water management plan.

Chapter 4 - Practical steps and considerations; a step-by-step process for setting up the SWMP.

From Chapter 5 on, the document is mainly of a reference nature and provides information on legislative aspects, references and useful reading, a glossary and a list of abbreviations used. Design aids are provided in the Appendices.

As the level of detail addressed in this guideline is not sufficient to guide detailed design of significant or major civil engineering structures, this BPG should be used with due care, taking cognisance of the risks associated with failure, and the level of knowledge of the designer. The reference list provided in this guideline can be used for guidance on detailed design.

2 GENERAL PRINCIPLES OF STORM WATER MANAGEMENT

Good storm water management is based on separating clean and dirty water and therefore incorporates the fundamental principle of pollution prevention. The difference between "dirty" and "clean" water is, however, determined on a site-specific basis and depends on a negotiated standard for each site based on the receiving catchment and downstream users. It is thus not feasible to prescribe in this guideline, standards that clean water must comply with (refer to waste discharge standards and general authorisations). The requirement for the separation of water into "dirty" and "clean" is also influenced by the water quality requirements of the water uses on the mine and downstream users. The requirement of the water uses on the mine is addressed in more detail in *Best Practice Guideline H3: Water Reuse and Reclamation*.

While many of the principles involved in a SWMP are common sense, storm water management often fails to meet its objectives because the designer does not take account of the wider issues. These relate to management and implementation issues, Interested and Affected Parties (IAPs), variations in mine plans, as well as the specific technical requirements of storm water management.

There are four primary principles that need to be applied in the development and implementation of a SWMP.

1 Clean water must be kept clean and be routed to a natural watercourse by a system separate from the dirty water system while preventing or minimising the risk of spillage of clean water into dirty water systems. This will limit the reduction in water flow to the receiving water environment/catchment (loss of water to the catchment) and thus increase the water available in the water resource to other users.

2 Dirty water must be collected and contained in a system separate from the clean water system and the risk of spillage or seepage into clean water systems must be minimised. The containment of dirty or polluted water will minimize the impact on the surrounding water environment.

3 The SWMP must be sustainable over the life cycle of the mine and over different hydrological cycles and must incorporate principles of risk management. Portions of the SWMP, such as those associated with waste management facilities, may have to remain after mine closure since management is required till such time that the impact is considered negligible and the risk no longer exists.

4 The statutory requirements of various regulatory agencies and the interests of stakeholders must be considered and incorporated.

To assist in the application of these primary principles, a number of requirements have been defined to satisfy each principle as presented below.

PRINCIPLE 1: KEEP CLEAN WATER CLEAN

- Identify and where possible, maximise areas of the mine that will result in clean storm water runoff (for example open veld areas) as well as infrastructure associated with the mine (for example office areas) and ensure that runoff from these areas is routed directly to natural watercourses and not contained or contaminated.
- Ensure that clean storm water is only contained if the volume of the runoff poses a risk, if the water can not be discharged to watercourses by gravitation, for attenuation purposes, or when the clean area is small and located within a large dirty area (refer to Section 4.2). This contained clean water should then be released into natural watercourses under controlled conditions.

PRINCIPLE 2: COLLECT AND CONTAIN DIRTY WATER

- Ensure the minimisation of contaminated areas, reuse of dirty water wherever possible and planning to ensure that clean areas are not lost to the catchment unnecessarily.
- Ensure that seepage losses from storage facilities (such as polluted dams) are minimised and overflows are prevented.
- Ensure that all possible sources of dirty water have been identified and that appropriate collection and containment systems have been implemented and that these do not result in further unnecessary water quality deterioration.
- Ensure that the contained dirty water is managed according to the hierarchy of mine water management steps as indicated in the Preface.
- Ensure that less polluted water or moderately polluted water is not further polluted. Where possible less and more polluted water should be separated. This will assist in the reuse water strategy and improve possibilities for reuse based on different water quality requirements by different mine water uses. Refer to BPG H3: Water Reuse and Reclamation. This will also reduce quantities of water eventually requiring treatment.

PRINCIPLE 3: SUSTAINABILITY OVER MINE LIFE CYCLE

- Ensure a commitment from management and staff, including making available adequate human resources (with appropriate qualifications and experience) and adequate financial resources for both the design and implementation of the SWMP.
- Ensure that the SWMP is formulated concurrently with the mine planning and layout of infrastructure and that it takes account of all life cycle phases of the mine from planning through to post-closure.
- Identify and quantify the risk of failure of components of the SWMP and the consequences of such failure. Risk management is critical to the success of the SWMP, including the consideration of the consequences of extreme events (extreme rainfall and emergency events), as well as potential water shortfalls in areas subject to drought.
- Consider possible changes or upgrades (increased production, additional facilities, expansions, etc.) that might occur during the life cycle of the mine.

PRINCIPLE 4: CONSIDERATION OF REGULATIONS AND STAKE-HOLDERS

- Identify items of legislation relevant to the environment and water resources and ensure compliance with these (refer to Chapter 5).
- Include effective liaison with the Department of Water Affairs and Forestry (DWAF) to ensure that the statutory requirements are met.
- Communicate and liaise with Catchment Management Agencies.
- Incorporate the constitutional rights of the environment and other users of the water resource and consider the expectations of interested and affected parties by ensuring that:
  - During the course of mining, upstream and downstream users are not adversely affected.
  - Sensitive habitats and landscapes are identified and protected.
  - The mine commits to a progressive improvement of water quality where it is being affected by mining. The mine needs to specify details pertaining to and actions to be taken for the continual improvement of water quality in the SWMP.
  - The concerns of IAPs are addressed, and that there is effective communication involving both the identification of issues, and the addressing of these issues.
  - There is transparency and a reasonable flow of information on the SWMP from the mine to IAPs.
  - At the end of mining, the mine has a plan that can be implemented to sustain and protect the reserve, as well as preserve the water quality and quantity upstream and downstream of the mine after mine closure.

ADDITIONAL GENERAL PRINCIPLES

- In the first instance, a catchment-based approach to the SWMP should be followed. This will identify current and potential water management issues in a catchment, and place the mine into context within the catchment. The SWMP should follow a precautionary approach being proactive rather than reactive.

- Appropriate technical studies to adequate standards need to be undertaken in order to understand the storm water system. This includes designing to sound engineering design principles, complying with relevant regulations and procedures, and the use of suitably qualified persons where required by law, or where the consequences of failure of the systems are significant.
- A range of management measures and options should be considered and compared before a final choice is made.
- Performance indicators need to be identified and implemented e.g. the operating level of a dam should be set taking into consideration the additional capacity that must be available to accommodate a storm event as required by the relevant legislation and policies.
- Finalisation of the SWMP should be followed by implementation, operation, monitoring and auditing. This implies that the performance of the SWMP should be reviewed regularly and where necessary modified. For an existing mine, the principle of continually improving the SWMP should be part of the management strategy.
- The effective training of staff and their roles and responsibilities in terms of the SWMP is key to the success or failure of the plan.

SPECIAL CONSIDERATIONS FOR OPEN CAST PITS

- The size of unrehabilitated areas (pit, spoils, unvegetated areas) that produce contaminated runoff should be minimised.
- Development of the pit should be planned to promote maximum diversion of clean water. The diversion works may therefore need to be moved as the mine develops.
- Rehabilitation should be planned to promote free drainage and to minimise or eliminate ponding of storm water. On-going rehabilitation as mining operations progress is required.
- The capacity to rapidly pump water out of the pit into storage dams should be maintained. This will assist in minimising water quality deterioration due to long-term retention of storm water in contact with materials that may cause water quality deterioration.

3

OVERVIEW OF THE HYDROLOGICAL CYCLE AND PROCESSES

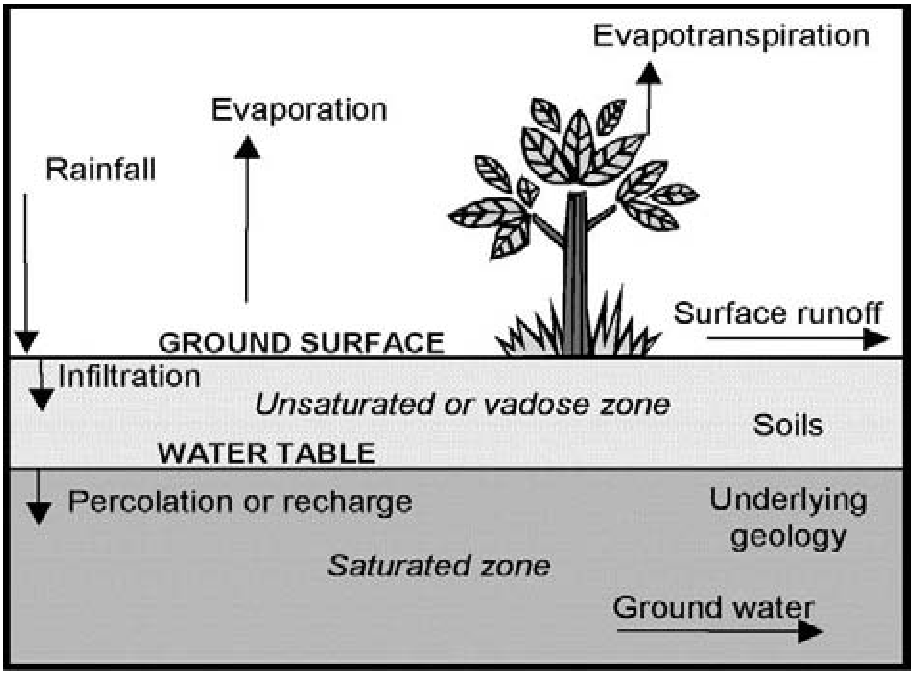
This section provides a brief overview of the hydrological cycle and its constituent processes – see Figure 3.1. Its purpose is to introduce personnel without a hydrological background to the relevance of components of the process. The reader is also referred to the references and useful information in Chapter 6 for more detail.

Comprehensive storm water management should give due consideration to the orderly discharge of storm water (rainfall and runoff) from storms of both low and high severity/intensity within the hydrological cycle since it should control and manage various hydrological cycles that fluctuate randomly. The incorporation of systems to handle storm events of different frequency and intensity will ensure that risk to life and property is minimised over many hydrological cycles. Insight into the hydrological cycle provides information on flooding probabilities and a full range of flood events should be considered to manage risk. Thus a risk management approach that considers the full range of hydrological event severities is needed to define appropriate measures and responses.

The relevant hydrological processes on a mine site include the following: -

- Precipitation
- Surface run-off
- Evaporation
- Stream flow
- Infiltration
- Evapotranspiration
- Percolation or recharge
- Ground water flow

Figure 3.1: Schematic of hydrological processes



3.1 Precipitation

In South Africa, precipitation is primarily rainfall. Hail, snow, and sleet are considered to be insignificant factors since they do not significantly contribute to the overall precipitation figures.

Hydrologists characterise rainfall in terms of the duration, intensity, and variation of intensity of the rainfall event. These characteristics depend on the meteorological mechanisms causing a storm, and vary significantly across the country. On the Highveld, thunderstorms typically generate intense rainfalls of short duration (several hours or less); while in Kwa-Zulu Natal, cyclonic related events can produce relatively intense rainfalls for several days.

While the more extreme intense rainfall intensities are important for the sizing of conveyance structures designed to manage peak flows, the seasonal variation of rainfall including wetter years is often of greater significance in terms of managing the overall water balance on the mine. In terms of the SWMP, this is important in the sizing of containment structures for both clean and dirty water. Mean Annual Precipitation (MAP) varies from about 100mm on the West Coast to about 1 000mm on the East Coast.

The concept of probable maximum precipitation (PMP) should be mentioned here. It is meant to represent an upper bound for rainfall, i.e., the most intense rainfall physically possible for a given storm duration. PMP is generally only used for extreme recurrence events, and should be used with caution by inexperienced practitioners. The Regional Maximum Flood (RMF) technique has proven to be a more reliable prediction of extreme events in South Africa.

Rainfall data is given in the publication Surface Water Resources of South Africa (1990), from the SA Weather Services, while daily data can be obtained directly from the Weather Services for their respective monitoring stations.

Floods: To manage flood risk and hazard it is important to consider a range of flood events and to evaluate flood behaviour, peak flood discharges and peak flood levels on the mine site. Elements (infrastructure, etc.) that may be affected by floods should be identified and the hazard to them be evaluated. The hazard may range from a nuisance (delays in crossing a flooded road), to economic (lost production) to threat to safety and lives. The risk management plan for floods should include structural works (diversions and its impact on downstream habitat and users), planning considerations (key buildings in less flood-prone areas), building controls (design of building for floods), and emergency measures (evacuation plan, warnings). Reference should also be made to the restriction on location of mine infrastructure in close proximity to watercourses (flood lines, etc.) in terms of the National Water Act (NWA), Act 36 of 1998. Also refer to Appendix A.

3.2 Infiltration

Infiltration is the process whereby some of the rainfall reaching the earth's surface moves through the soil surface and into the soil profile.

In South Africa, more than 80% of rainfall infiltrates into the soil (on average). Horton's equation is often used as an infiltration model, giving a characteristic parabolic reduction in infiltration rate from some initial value, to a value referred to as an ultimate (equilibrium) rate. The rate of reduction is determined using a decay constant.

On undisturbed land, most of this infiltrated water is then available for evapotranspiration i.e. use by plants, or evaporation. On land disturbed by changes in the geology (for example fractures in underlying rock), the infiltrated water will not be retained in the soils and be available for evaporation or evapotranspiration but will percolate into the underlying aquifers (see Section 3.6 on percolation). On land disturbed by human activity such as mining (open cast spoil heaps), the water retention may be less or more than for undisturbed land since significant volumes of water may percolate through the material (waste rock) or be retained in the material (fine tailings material) depending on the characteristics of the material.

3.3 Surface Run Off

Water is shed as surface run off whenever rainfall reaches the ground faster than it infiltrates the underlying soils. The volume and rate of the surface run off is a factor of many variables, including antecedent rainfall, intensity and duration of rainfall and the nature of the soil and vegetation cover.

The Surface Water Resources of South Africa (1990) details expected run off for South Africa computed as annual run off in mm. On a large catchment, the Mean

Annual Runoff (MAR) is seldom more than 6 to 10% of Mean Annual Precipitation (MAP).

However, run off during single storm events may be considerably higher depending on the catchment characteristics. Values of around 35 to 40% of rainfall are not uncommon, and may increase to as much as 70 to 80% or even a 100% on small catchments during cyclonic rainfall events. Some guidance on the determination of run off is given in the brief discussion of hydrological techniques in the appendices.

Built up areas (office and hostel areas at mines for example) or potential future areas of development can also be expected to significantly increase run off within a catchment.

3.4 Evapotranspiration

Evapotranspiration is the process whereby plants extract water from the soil profile and respire it as water vapour through their leaves to the atmosphere. Evapotranspiration rates are often predicted using empirically based transfer functions similar to those for evaporation. Surface Water Resources of South Africa gives evapotranspiration rates (Crop Factors) from which the seasonal demand for water by vegetation (and various crops) can be determined.

The importance of this in the SWMP is that mining may affect the evapotranspiration characteristics of certain areas (possibly by removal of vegetation to accommodate mining infrastructure). A reduction in evapotranspiration may imply an increase in percolation, together with increased surface runoff.

Grassland evapotranspiration was found to vary between 0.1 mm/day (winter in Secunda) and 3 mm/day (summer in Secunda). Winter evapotranspiration was generally less than 1mm/day and tended towards zero as winter progressed. Summer values ranged between 1 and 3 mm/day.

In contrast, trees used between 0.5 and 3 mm/day throughout winter, with water use being dependent on the degree of canopy development. Water use during summer varied from 1.5 to 12 mm/day and always exceeded grass water use, except in those cases where tree canopies were not fully developed. The difference in water use between the two growth forms (grass and trees) narrowed during the summer months, with grasslands sometimes exhibiting similar rates of water use to trees. Tree water use expressed on the basis of evaporation per unit leaf can be expected to be in the range for commercial forestry tree species. Most trees transpire at rates of less than 1l/m^2/day, with rates of 0.5l/m^2/day in winter months. Distinct differences in rates of water use are evident among trees.

3.5 Evaporation

Evaporation is water passing from the surface of a water body into the atmosphere as vapour. It is normally determined using either a S-pan or an A-pan, and the evaporation from a large water body can be determined (lake evaporation) by applying the correct `pan factor' to the `pan evaporation'. The factors for S or A-pans are considerably different with A-pan being larger than S-pan. The S-pan (based on a large square pan buried below ground surface) is generally being used by hydrologists, and the A-pan (based on a small round pan situated on surface) by agriculturists (for irrigation purposes). Lately, wind speed and wind directions are often also used in calculations to determine evaporation rates.

In South Africa, of all the water entering soil storage, about 40% will leave by evaporation, and, on average, about 25% of all river inflow to storage reservoirs will be lost through evaporation.

Although evaporation is less variable than rainfall, the seasonality of both of these is important because a SWMP based on average rainfall and average evaporation will result in spillages during the wet season. This is despite the fact that most areas of South Africa are water deficit areas, i.e., evaporation exceeds rainfall. Evaporation rates typically vary from more than 2 400mm/yr in the northwest, to less than 1 400mm/yr along the East Coast.

It may also be important to note that the published data on evaporation refers to clean water only, and evaporation from mine water facilities may be affected by the salinity of the water, or the presence of substances such as oil on the surface of the dams. Evaporation of highly saline water can reduce to as little as 70 to 80% of that for clean water. On most mines, the reduction due to salinity may be negligible, or be of the order of 5 to 10%.

Evaporation figures (as monthly or annual evaporation) can be obtained from the same sources as for rainfall data. The installation of an on-site weather station would provide significantly more reliable data specifically for evaporation and evapotranspiration than evaporation pan data.

3.6 Percolation Or Recharge

Percolation or recharge is the vertical movement through a saturated or nearly saturated soil matrix. It represents the surplus water which, having infiltrated into the soil, is not taken up by plants, evaporated or retained in soil, and moves vertically downwards under gravity to recharge ground water aquifers or mined out areas.

In open cast mining, percolation represents a potentially significant recharge of clean water into the dirty water system, and in total extraction underground mines, percolation is drained vertically through the fractures created during collapse.

In the Highveld, the percolation to the deeper aquifer within the undisturbed Karoo rock system is typically believed to be of the order of 3 to 5 % of MAP. Disturbance of the strata by either open cast or total extraction type underground mining can significantly increase this figure, and this is further exacerbated when percolation pathways combine with poor draining areas, or surface water flow paths.

3.7 Streamflow

As surface run off flows down a catchment, at some point it collects into a definable watercourse and becomes streamflow. Stream flow stations should be coordinated with precipitation and water quality monitoring sites. The siting of streamflow stations should facilitate in the calibration of models. An experienced hydrologist should select at least one “key” stream gauging station (a site where a current meter can gauge stream flows to determine a reliable rating curve). It is also important to identify existing or past official stream gauging stations of DWAF in the vicinity of the mine. These stations can be incorporated or re-activated and then be incorporated as part of the stream gauging network with the benefit of more data available. Chapter 4 of this guideline gives some indication of the management of flows within watercourses. However, once mining affects a natural watercourse, this is considered a water use and a license is required. A mine can expect that a specialist in this field will be required to assist them in motivating, designing and constructing a structure such as a river diversion. This is not discussed in detail in this document.

Water quality monitoring is required at mine lease entry and exit points in all major streamflows, this allows definition of change in the quality of any streamflow entering or leaving the mine lease area. Water quality should be monitored in at least one catchment not affected by mining (control catchment) to provide an indication of natural variation in water quality over the life cycle of the mine.

3.8 Ground Water Flow

Once water has infiltrated or percolated into a ground water system, hydraulic head or the water levels of the ground water body largely determine its movement. Understanding of ground water flow is a specialised field since, although ground water moves or flows generally with surface topography and from areas of high to lower hydraulic head, the direction and quantity of flow is affected significantly by the aquifer characteristics, discontinuities and the nature of the ground water regime (e.g. confined, unconfined). The determination of these properties requires specialised investigations and experience.

Impacts on ground water flow almost always require to be assessed by a specialist in this field.

Seasonal variation

Rainfall and evaporation, which largely drives the hydrological cycle, shows seasonal variation across South Africa with most places having distinct “wet” and “dry” seasons. Seasonal variation can significantly affect storm water management at a mine. For example, it might be necessary to store water as the mine goes into the dry season and may experience water shortages whereas water storage facilities (especially “dirty” water containment facilities) should be kept at a lower level during the wet season to prevent spillages during high rainfall events and floods which may pose environmental risk.

4

PRACTICAL STEPS AND CONSIDERATIONS

The stepwise procedure that could be followed in the development of a storm water management plan (SWMP) is shown as a flowchart in Figure 4.1 and is discussed in the following sections. While the mine itself can undertake many of the steps, it is important to ensure that suitably qualified persons are used where necessary.

It should be noted that there is no specific point in the process that requires consultation with DWAF or any other government department. It is, however, recommended to consult with the relevant government department at any stage during the process when it is deemed necessary or when guidance is required. One should be aware that some actions have legal implications and the relevant government department should be consulted well in advance of implementing the planned activity. For example obtaining the required water use registration certificate from DWAF before the action, i.e. the specific water use, commences. The National Water Act (NWA), Act 36 of 1998, Section 21 specifies water uses requiring water use registration and in cases where these uses are not covered by General Authorisations, water use licensing requirements without which such water use would be considered illegal and could result in prosecution. Consultation with DWAF or other government departments usually focuses on a process, e.g. water use license application or EMPR, of which the SWMP is a subsection and separate consultation may therefore not be required for the SWMP. Some of the main legal aspects relevant for storm water management are presented in Chapter 5.

4.1 Exploration Phase

The exploration phase is often overlooked as part of a SWMP. The impacts on water are generally small, the primary issues being relationships with landowners, and the environmental disturbance caused by access roads, mining camps, and drill pads (Refer to standard prospecting environmental management programme.) There is also the issue of drilling fluids, petroleum products, camp wastes and the like. However, during this phase, baseline monitoring of water quality and the collection of weather information can commence. Refer to BPG G3 Water Monitoring Systems.

This exploration is different from prospecting for gold or diamonds, which is considered as mining and not an exploration activity. Similarly, bulk sampling activities (opencast mini pits) must also be handled as a mining activity and not exploration.

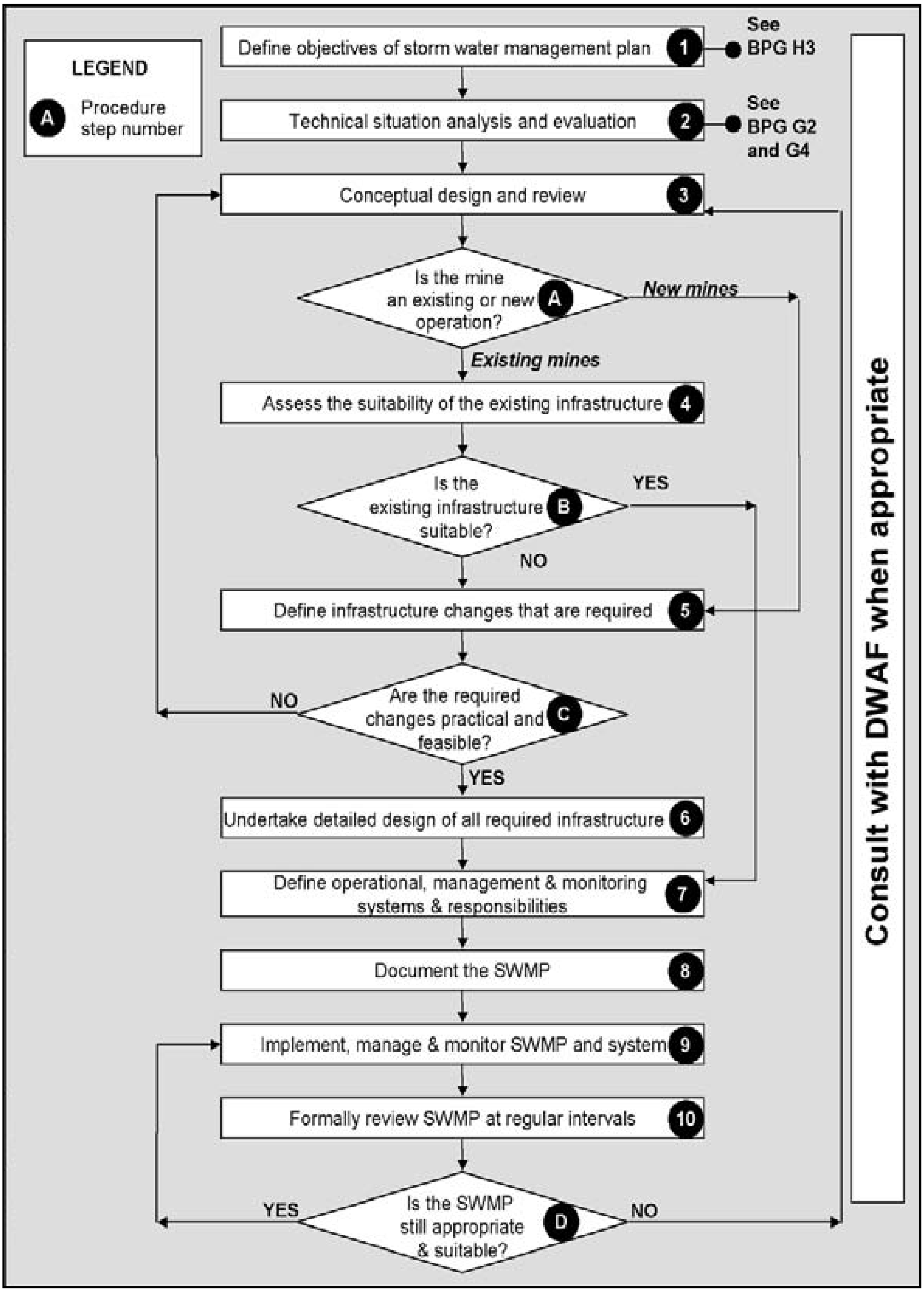
4.2 Design and Construction Phase

While a detailed methodology for the development of a SWMP is presented here, the following general points should be noted: -

- The SWMP should be designed to convey runoff in a controlled manner that will not adversely affect upstream, adjacent or downstream properties and users of a watercourse.
- Formulating a SWMP is a planning process that examines all options, opportunities and constraints before selecting the most appropriate option. Water management and general mine planning should be integrated in order to find the most cost-effective solution for the mining process. Failure to address water management issues during the mine planning stage may restrict future management options and increase the future cost of mining.
- A set of procedures should describe the nature and frequency of performance checks.
- The mine plan will change during the life of mine. The SWMP should, therefore, be robust enough to cope with these changes and the uncertainties associated with the ore body extent, the direction and sequence of mining, and the need to have a sustainable solution at closure.

NOTE: It is important to emphasize that existing mines without a detailed and appropriate storm water management plan will also need to undertake Steps 1 to 8 prior to implementation. Steps 1 to 8 are therefore not only for new mines that are in the design phase of their life cycle.

Figure 4.1: Procedure to Develop Storm Water Management Plan



Step 1: Define objectives of the storm water management plan (SWMP)

As with the development of any management plan, the process of developing a storm water management plan (SWMP) should be preceded by a clear definition of the objectives that are to be achieved with the SWMP. This step is important for both existing mines and new mines that are still in the planning process. Mines need to ensure that their SWMP is in accordance with the requirements for the master plan (SWMP for the catchment or region).

From experience, this aspect of storm water management can be problematic. The tendency is either to set specific objectives that are not practically achievable, or vague generic objectives that can never be monitored or measured. It is recommended, therefore, that each objective be specific, measurable, attainable and feasible. This implies that the mine has to commit itself to specifics, such as the elimination of a particular source of contamination by a specific date, or limiting the catchment affected by mining to a certain area. The intention is not to duplicate all of the objectives set in the EMPR document, and discretion should be used as to which objectives are relevant.

Broad objectives should be set for the overall SWMP that are in compliance with relevant legislation and catchment-based management objectives (master plan objectives). More detailed and site-specific objectives can be set for specific facilities or areas of a mine. Typical aspects that should be considered when setting objectives for the SWMP are:

- Catchment objectives that need to be met or protected.
- Statutory requirements.
- Management of risk, such as separation of dirty and clean water for a defined precipitation event or recurrence interval.
- Water balance management, where this is applicable to storm water. This could involve several objectives related to minimising the impact on the catchment yield and quality. Refer also to BPG G2.
- Interaction with regulators and the community.
- Operational and emergency monitoring and documentation (refer BPG G3).
- Provide for incidents and accidents, and contingencies associated with incidents and other emergencies.
- Water quality.
- Sustainability, e.g. limiting erosion within the storm water management system.
- Performance indicators.
- Training and research.

A few examples of specific primary objectives that could be set are:

- Separate and collect all storm water that has a quality potentially poorer than X (water quality specified and negotiated for the specific catchment) into dirty water storage facilities for reuse within the mining operations.
- Ensure that all storm water structures that are designed to keep dirty and clean water separate can accommodate a defined precipitation event. (The magnitude of the precipitation event used in such an objective statement must, as a minimum, adhere to the relevant legal requirements.)
- Route all clean storm water directly to natural watercourses without increasing the risk of a negative impact on safety and infrastructure, e.g. loss of life or damage to property due to an increase in the peak runoff flow.
- Ensure that the maximum volume of clean water runoff is diverted directly to watercourses and the minimum amount of storm water reports to the pit floor of an open cast mine.

During the SWMP development process, it may be necessary to revisit the objectives to ensure that they are in fact achievable.

Step 2: Technical situation analysis and evaluation

After the objectives of the SWMP have been defined, a situation analysis and evaluation is required consisting of the following actions:

- Divide mine into “clean” and “dirty” areas.
- Identify watercourses, drainage paths and catchments that are in the mining area. Divide the mining area into catchments based on areas where mining will affect surface hydrology and those where it will not.
- Identify the physical location and characteristics of all existing or required water management infrastructure.

Integration and optimisation of the proposed SWMP with the mine plan and master plan (SWMP for catchment or region) is critical at this stage and this is an interactive process, especially for new mines where different options need to be compared and optimised. Common problems that occur at this stage include:

- The positioning of ramps such that run-off from rehabilitated areas cannot drain back to the catchment.
- Total extraction planned to occur in areas with high risk of subsidence.
- Lack of consideration of how water will be managed upstream of final voids at closure.
- Inadequate consideration of watercourses and associated flood management around these.
- Siting of "dirty" facilities close to watercourses with inadequate space to construct suitable management structures.

Action 2.1: Divide mine area into clean and dirty areas

This classification should preferably be undertaken on the basis of data that has been collected for storm water quality; if this data is not available as is the case with new mines, then land use or planned land use should form the basis of the classification. It may also be desirable to sub-divide the "dirty" areas into different classes such as "moderately dirty" and "dirty". The sub-division of dirty areas is not a specific requirement of this guideline, but is recommended in cases where it serves to provide assistance with water management, for example as part of a water reuse strategy where different mine water uses require different water qualities (see also *BPG H3: Water Reuse And Reclamation*). Table 4.1 provides an example of how land uses can be used to classify runoff water quality into three classes. (It should be noted that the list is not a comprehensive list, but illustrates the application of the classification system).

Table 4.1: An example of classification of areas according to land use

Classification	Area	Comment
Clean	Undisturbed land area	Regional geology or agricultural practices may contaminate runoff.
	Formal residential areas with services	Generally only suspended solids (SS) and Chemical Oxygen Demand (COD) to consider
	Administrative offices	Generally only SS to consider
	Tarred roads	Tarred roads are not expected to be contaminated by waste, coal or discard, but may have a run off volume implication.
	Newly rehabilitated areas Clean water dams	SS to be considered
Moderately dirty	Workshops and storage yards (where oil is not handled)	Specifically at gold mines. Coal mine workshops are included if the ground surface is not covered with coal fines.
	Poorly rehabilitated areas	SS and other contaminants to consider
	Roads *	If it carries traffic that bears coal, discard, slurry, waste rock, slimes, etc.
Dirty	Beneficiation plants and other plants	Special chemicals in use, e.g. cyanide, may also contaminate storm water.
	Workshops and storage yards where oil is handled or ground is covered in fines	Oils, grease and soap, dissolved and suspended contaminants
	Opencast pits	SS and other contaminants to consider
	Residue deposits	Includes coal discard, slurry facilities, slimes dams, waste rock dumps and sand dumps.
	Raw material or product stockpiles	Dissolved and suspended contaminants
	Unrehabilitated areas	Dissolved and suspended contaminants
	Haul roads	Dissolved and suspended contaminants
	Adit areas	Dissolved and suspended contaminants
	Pollution control dams	Depends on contents of dams

** The classification of roads may vary according to the material that is used for construction.*
SS = Suspended Solids; COD = Chemical Oxygen Demand

For ease of use, many mines enter the classified areas into some form of geo-referenced database such as GIS (Geographical Information System). If such a system is not available, it is advisable to develop a data and information system that will be easy to manage and to update. To prevent the loss of information and data, the structure, management and responsibility of managing the data and information system should be clearly defined at this stage.

For new mines, this process should be incorporated into the mine planning by attempting to group all the dirty land uses together and group all the clean land uses together, and to avoid placing dirty areas within large clean areas and vice versa. The placement of dirty areas must also be considered in terms of legislation, e.g. the minimum legal distance that the facility can be placed from the watercourse.

An example of dirty and clean water separation is given in Figures 4.2a to d. The illustration is intended to highlight: -

- Dirty areas should be kept as small as possible, but within practical constraints. While the scenario in (b) may be preferable, groundwater considerations or practical limitations may result in (c) being implemented.
- The final layout (d) may have clean areas within the dirty water system.
- Combination of dirty areas such as plants and dumps/ stockpiles is highly desirable.

For example, consider a hypothetical situation where a sub-catchment contains a dirty area in the upper reaches and all other areas are clean, as illustrated in Figure 4.2a. If the down slope clean area is separated from an upslope dirty area by a well-designed storm water drain that ensures that the upslope dirty runoff is diverted away from the clean area, then the clean area can be classified as clean, as presented in Figure 4.2b. However, if no such drain exists and the dirty runoff from the upslope dirty area will run over the downstream clean area, then the clean area will need to be included within the dirty area. If the clean area is large (either in absolute terms or relative to the upslope dirty area) then this should form the basis of a decision to consider the construction of such a dirty water diversion drain in Step 4 (Figure 4.2c).

If the clean portion of the sub-catchment is small (Figure 4.2d) then it may be appropriate to consider the whole sub-catchment dirty and collect runoff for reuse, provided that the downstream impact on the quantity of water is acceptable.

Figure 4.2a: Hypothetical scenario

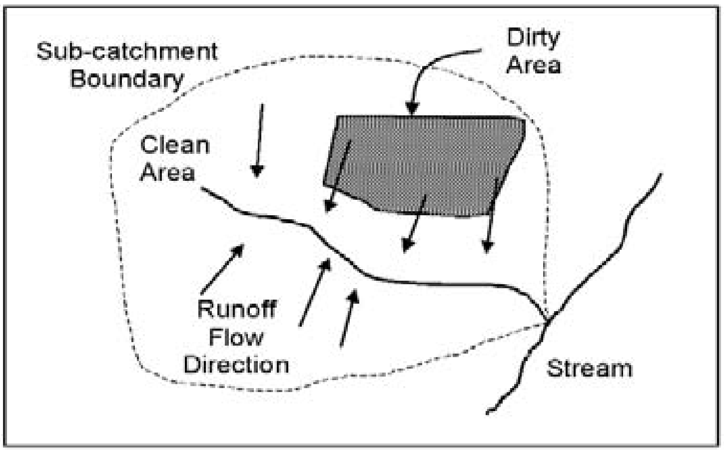


Figure 4.2b: Hypothetical scenario with storm water drain

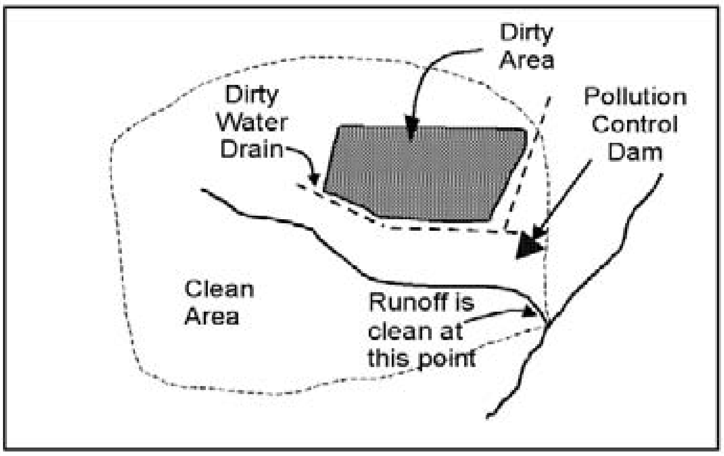


Figure 4.2c: Hypothetical scenario with reuse of pollution control dam water, whole area classified as dirty

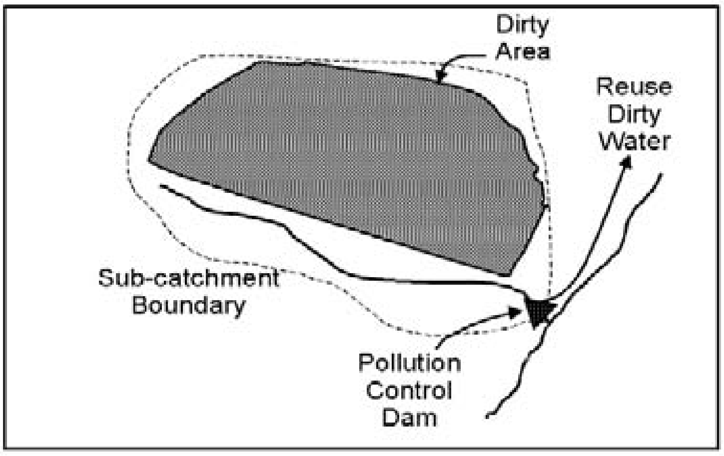
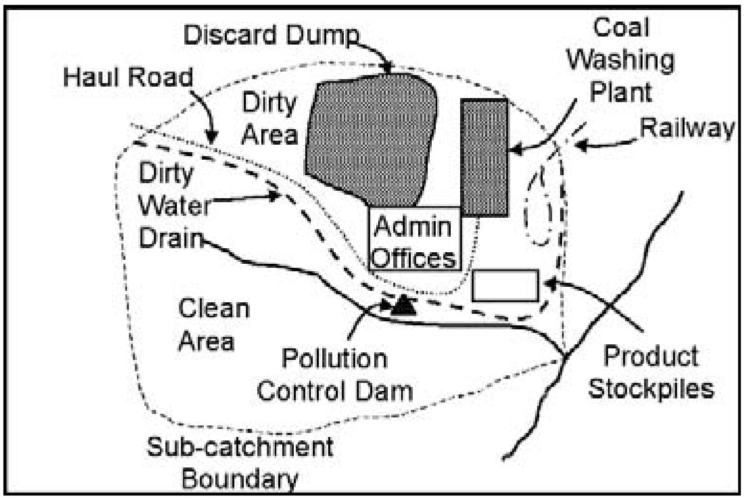


Figure 4.2d: Integration and rationalisation of clean and dirty water areas



Action 2.2: Identify areas where mining will affect surface hydrology

In terms of the National Water Act, 1998 (Act 36 of 1998), any activity that affects flow in a natural watercourse (impede or divert), or alters the characteristics thereof (bed, banks, course), amongst others, requires a licence.

Areas where mining impacts on the surface hydrology are often caused by alterations in the surface topography or the underlying strata. At underground mines, the surface alterations are often the result of surface subsidence and/ or cracking. Storm water runoff collects in the subsided areas to form ponds and seeps into the mine where it then becomes contaminated. The impact on surface topography depends on the mining technique, e.g. bord and pillar, long wall and stooping have different effects on the surface topography. It is therefore recommended to plan the mining such that the impact on surface topography is minimised, especially in high risk areas, for example close to a surface watercourse and near the foot of a catchment that drains a relatively large volume of clean storm water runoff. High-risk areas could also include areas of poor vegetation cover or rocky outcrop with a significant upstream catchment.

It is important to note that this BPG gives guidance on separating and collecting dirty water, but management of the dirty water balance is detailed in BPG G2: Water and Salt Balances.

Action 2.3: Identify physical location and characteristics of all existing water management infrastructure

The physical location of all existing water management infrastructure such as dams, pipelines, canals, drains, pumps, storage tanks, oil traps and other pollution control structures, etc. should be identified, together with the physical characteristics of these systems such as:

Dams:	underlying geology, location, surface area, depth, capacity, freeboard, overflow point, size and capacity of spillway, height of wall, lining, etc
Pumps:	type, rated capacity, number of operational and standby units, on/off control mechanism, etc
Pipelines:	length, diameter, construction material, lining, condition, inlet and outlet elevations, etc
Storage tanks:	location, capacity, construction material, lining, overflow point, level control mechanism, operating strategy etc
Open channels:	start and end point elevations, gradients, construction material, cross-section, erosion protection, condition, estimated maximum flow capacity

Table 4.2 indicates the typical elements of a storm water management system.

Table 4.2: Elements of a Storm Water Management System

	APPLICATION		
Element	Supply	Convey	Store/Other
Dams (clean)	√		
Boreholes	√		
Natural water bodies	√		
Pumps		√	
Pipelines		√	
Open Channels/canals/drains		√	
Dams (dirty)			Store and reuse
Storage tanks			Store and reuse
Evaporation Dams			Store and dispose
Controlled Releases (if applicable)			Discharge
Sediment Traps			Store & treat/dispose
Wetlands or Biological Treatment			Treatment
Chemical Treatment			Treatment

For a new mine, a preliminary layout of the water management infrastructure would be set out at this stage. Due to the fact that the water management infrastructure is still in its early phases of design for a new mine, it will be possible to optimise the location and capacity of the infrastructure.

The layout would not only separate run-off from dirty and clean areas as effectively as possible, but will also take account of possible erosion problems, staged development as the mine progresses allowing for modification as mining plans change or production increases requiring expansion, and management of erosion and sediments from rehabilitated areas.

Soil erosion is an issue at mine sites that requires management and inclusion in the SWMP. Erosion management should be integrated with drainage strategies and should address erosion control for stripped, spoil and recontoured areas during mining operations; how to manage bed and bank erosion in diversion channels; how to control erosion while mine infrastructure is being constructed. Areas of existing or likely erosion and proposed controls should already be identified during the preparation of the erosion control plan. Progressive rehabilitation will also minimize the effects of erosion.

Information must also be obtained on all man-made structures such as roads, railway lines, embankments, storm water drains, etc. that could have an effect on the volume and direction of storm water runoff. Where other water management infrastructure exists such as evaporation dams, controlled releases (if applicable), sediment traps, wetlands (or other biological treatment facilities), or chemical treatment, all available information should be collated. The primary aim of this is to plan storm water management infrastructure or allow an assessment or evaluation of the adequacy of the existing storm water management infrastructure.

All the collected information should be added into the data and information system referred to in Action 2.1.

Step 3: Conceptual Design and Review

At this point in the development of the SWMP, it is recommended that a conceptual design and review be undertaken. The designer has to balance the need to obtain preliminary sizes so that water conveyance systems and retention structures can be provisionally sized, without undertaking a detailed design that may have to be discarded due to inadequacies in the SWMP, or changes in the conceptual design.

It is suggested that at this stage of the process, the principles and objectives (Chapter 2 and Chapter 4 – Step 1) defined at the start of the SWMP be revisited to assess whether these can be met. The adequacy of the available information, such as the mine plan, can also be reviewed at this point.

The designer may also wish to review the following: -

- The implications of the conceptual SWMP on the mine water and salt balances (refer BPG G2: Water and Salt Balances).

- The impact of the SWMP on the mine's water reuse strategy (refer BPG H3: Water Reuse and Redamation)
- For existing mines, the performance to date of the existing infrastructure when compared to the rainfall experience since the start of mining may be reviewed.
- Potential fatal flaws may be highlighted at this point such as impacts on sensitive landscapes, the need to alter significant watercourses to accommodate the infrastructure, and issues such as land ownership or impacts on adjacent landowners.

An experienced designer may use rules of thumb and approximate calculations to obtain a preliminary sizing of some of the water management features. Some of these rules of thumb are given in step six under the detailed design, but should be used with caution by the inexperienced designer.

Even at this design stage, the conceptual SWMP must address the construction, operational, decommissioning, and post closure phases.

Step 4: Assess the Suitability of the Existing Infrastructure

For existing mines, the adequacy of the existing storm water infrastructure can now be assessed. The assessment should be undertaken by a suitably qualified person, and should assess the compliance of the existing system with the principles and objectives set out in chapter 2.

It is important that this review process address not only the physical parameters such as the condition, capacity, and suitability of the infrastructure, but also the level of training of those implementing the SWMP, and the success of the monitoring programme in ensuring the objectives set out are being achieved.

Deficiencies in the current storm water management infrastructure can then be addressed.

Step 5: Define the Infrastructure Changes that are Required

The required changes and additions to the existing or planned infrastructure need to be defined. These changes may include aspects such as constructing additional pollution control dams or drains, constructing sediment removal facilities ahead of pollution control dams, or increasing the carrying capacity of dams or drains. Aspects not directly related to the SWMP, such as modelling the mine water balance for an open pit, or increasing the rate of rehabilitation may also need to be addressed.

The required changes should be both practically and economically feasible, and the positive and negative impacts of the proposed modifications need to be assessed and detailed. An EMPR update and/or addendum or EIA may be required (for example for additional pollution control dams at an existing mine).

The designer is encouraged to assess all options, opportunities and constraints before selecting the most appropriate options for mine specific circumstances.

Step 6: Undertake Detailed Design of all Required Infrastructure

A brief summary of some of the more commonly used design techniques is given in the appendices. In this section, some guidance is given on the application of these principles, and the common pitfalls that need to be avoided in the design process. These aspects are discussed below.

Design of New SWMP and Infrastructure

The development of a new SWMP can be a complicated undertaking, depending on the complexity of the mine operations, particularly the interactions between clean and dirty areas. The details of the SWMP are also dictated by the objectives that were defined in Step 1. This step could also include more detailed technical assessments, such as modelling (hydrology, water quality and water and salt balances - also see *BPG G2: Water and Salt Balances*) and risk assessment, by a suitably qualified person. The mine's water reclamation strategy (see *BPG H3: Water Reuse and Reclamation*) is also a critical feature of the SWMP. The basic tasks that could be followed in developing the SWMP are as follows:

Task 1: Define the water quantity and quality requirements of all the water uses within the mine and the appropriate water reticulation system to address the water reclamation strategy defined by the mine (see *BPG H3: Water Reuse and Reclamation*). This step focuses on the uses within the mine, while the downstream water users and the set water quality requirements for the mine's discharge, e.g. the negotiated catchment's water quality requirements, should also be taken into consideration.

Task 2: Undertake hydrological calculations or modeling to determine runoff volumes for the different catchment areas defined in Step 2. The SWMP cannot only be based on average rainfall, or high intensity short duration events. Wetter than average years, or longer duration and less intense events may be more critical in terms of water management, particularly dirty water resulting from mining. Modelling allows an assessment of these risks and its importance cannot be underestimated. Examples of conventional and relatively quick calculation methods are the Rational and SCS methods, which are discussed in the Appendices.

Task 3: To define and understand the interaction between the facilities, it is recommended to develop water balances. With appropriate water balances, that take into account water losses through seepage, evaporation and abstraction (see *BPG G2: Water and Salt Balances*); calculate what dam capacities are required. With the calculation one should ensure that contaminated runoff is effectively captured and stored, taking account of legal requirements with regard to precipitation recurrence intervals and freeboard.

On the basis of experience and application of suitably conservative assumptions, pollution control dams could be designed without hydrological or water-balance modeling, provided that compliance with relevant regulations can be demonstrated. When designing and specifying pollution control dams, it is important to distinguish such dams from water storage dams. A water storage dam is normally operated to be as full as possible in order to give maximum assurance of supply, while a pollution control dam must be kept empty, or at a suitably low level, to be able to accommodate defined runoff events by storing the dirty water without overflowing. Thus safety measures such as freeboard allowances etc should be included in designs of storm water control facilities to allow for sufficient storage capacity and to ensure that risks of overflows or spillages are minimized and environmental impacts are therefore avoided.

When pollution control dams also serve as water storage dams, there is a risk that the water storage requirement will cause the dam to be operated at a level too high to accommodate dirty runoff from high rainfall events, leading to frequent overflowing with potential environmental impacts on the receiving stream and contravention of legislation. It is, therefore, important that this system be designed by a suitably qualified person and that the mentioned operating conditions and sufficient storage space be specifically addressed.

Task 4: Identify and define structures (dam, watercourse, canal, etc.) that would be required for the storm water runoff from each of the sub-catchments developed in Step 2. The principles discussed in Chapter 2 should be taken into consideration when structures are identified.

The alteration of watercourses should be avoided as far as possible. This action is not addressed in this guideline and if it were considered, a license from DWAF would be required.

Task 5: Undertake the above Tasks 1 to 4 for the different time frames over the projected life of the mine, i.e. from planning of new mine or current operation through to closure. Integrate these into a sustainable SWMP that will apply over the life cycle of the mine.

Rehabilitation Design

Although not an element of the SWMP directly, the rehabilitation design has a direct impact on the SWMP. Best practice includes designing rehabilitated areas to be free draining, and the provision of slopes that limit the risk of erosion.

The cover design (type of soil, nature of layers, thickness and compaction) also impacts on the potential for generation of contaminated mine drainage. Extensive research has been undertaken on covers and cover thickness and computer models are available to assist in the optimisation of these. These would include programmes such as SEEP/W, HYDRUS-2D, VADOSE/W and SoilCover and various geochemical models (see BPG G4: Impact Prediction). Covers should be designed to be low maintenance in order to ensure that they continue to perform according to design over the long term and that they can handle the design flood events.

Open Channels

Various techniques for determining the peak flow to enable sizing of open channels are given in the Appendices. A variety of hydrological and hydraulic techniques and models are commonly used for the design of open channels. The design of open channels is a specialist discipline.

When using hydrological techniques such as the Rational Method, SCS Method, Unit Hydrograph Method, or other empirical type techniques such as factoring from the Regional Maximum Flood, the designer should be aware that a single method is seldom if ever adequate to obtain a reliable answer. Several techniques would typically be used, from which an educated estimate of the peak flow would be made. Implicit in this approach is also the assumption that the consequences of larger floods will be assessed during the design process and that safety measures will be incorporated to accommodate these.

The simplest method to predict a water level in an open channel is by Manning's Equation (ref. Ven te Chow, Alexander). This is given in the Appendices. However it should be noted that:

- Manning's equation is only useful for estimating water level at a single location.
- Often the bed slope is not a good estimate of the hydraulic grade line. This is especially true along water way reaches affected by culverts, bridges or other constrictions to flow.
- The equation is not applicable under conditions of unsteady flow, where an open channel model will be required.

A number of open channel hydraulic models are available to estimate discharges and water levels along open channels. These include models such as HEC-RAS, XTRAN and RUBICON. These models should be used by those who have had training in the use of the specific model, or with suitable knowledge to know the pitfalls and problem areas that may exist.

Useful information on the design of waterways is given in the National Transport Commission Road Drainage Manual. The following should be noted:

- When using Manning's equation it is important to note that Manning's 'n' is a function of hydraulic radius, the hydraulic radius being the cross sectional area of flow divided by the wetted perimeter. Because of this, absolute roughness and the hydraulic radius are generally used to compute Manning's 'n'.
- The designer must take account of both the situation immediately after construction, when there is little to no vegetation established, and that later in the life of the channel when vegetation may be very well established. Using a low Manning's 'n' for the post construction phase will give the maximum flow velocity which can then be compared to the allowable velocity for the soil in which the channel is located. Most soil will erode significantly at velocities over 1,5m/s. The higher Manning's 'n' for the vegetated situation would then give the size of the channel required to have adequate capacity for the storm event once vegetation has established.
- A useful rule of thumb for an open channel is that the design velocity should seldom exceed 2m/s during extreme events, unless suitable protection is provided. Compound channels may be used as a means of limiting erosion during extreme events.
- Supercritical flow should be avoided in the channel systems, unless designed by a specialist with adequate erosion protection. To avoid supercritical or unstable flow, it is good practice to ensure the Froude number (refer Appendices) is less than 0,8.
- Designers should be aware of and take special precautions when dealing with dispersive soils. Although the determination of dispersivity is a fairly complex procedure, a simple (but not infallible) test is to place a sample of soil into distilled water. Gloves should be used to avoid affecting the soil. Dispersive soil normally displays fairly rapid and active breakdown under these conditions. Specialist advice should be sought where a soil is suspected as being dispersive.
- A range of erosion protection methods is available to the designer, ranging from the use of dump rock, through to commercial systems such as gabions, proprietary concrete erosion protection systems and various geotextiles. A suitably qualified person should preferably undertake the design of any such systems, due to the potential cost associated with implementation of these, and the need to minimise these costs.

Run Off/Routing

Where the inflows along a channel may vary due to additional catchments draining into a single channel, or where there is significant storage within a system, it may be necessary to undertake run off routing. Equations to undertake this are given in literature. When in doubt, a suitably qualified person should be used to assist with this.

Note that it is generally conservative to not take advantage of the storage available within a system, and for costing or preliminary sizing purposes, it may be practical (and conservative) to ignore the routing component.

Dams

A specialist in this field would normally undertake the design of dams. Also refer to Dam Safety Regulations with regards to storm water management and containment of water. Dams that are over 5m in height and store more than 50 000m^3 of water are required to comply with Dam Safety Legislation and require a water use license. An Approved Professional Person is required for the design of these dams. The following points should be noted in the sizing of dams for both clean and dirty water management: -

- Clean water should not be stored unless the volume of runoff poses a risk and it is contained within an attenuation facility designed to reduce the peak outflow of clean water and control this outflow back to the catchment.
- For the sizing of dams, daily catchment run-off volumes or run off depths are generally required. This can be determined from models such as AWBM, ACRU, or SCS based models. These models are generally used to compute daily run-off volumes over a long period (as long as the available rainfall records). This is because the SWMP cannot be based on average rainfall or even only high intensity short duration events. Wetter than average years, or longer duration and less intense events may be more critical in terms of water management, particularly dirty water management. A specialist in this field normally carries out modelling of this nature. Care should be taken when using models that only take account of a very short period of antecedent conditions (example 5 days).
- If extreme events such as cyclone Demoina and the extreme rainfall events of 1987 in Natal are analysed (ref. Appendices) it is interesting to note that there is a strong correlation between peak flows and flood volume. Further, the flood volume seldom exceeds more than 3 times the mean annual run-off from a catchment. This is a useful rule of thumb for initial sizing of a storage dam to ensure that it does not spill during any but the most extreme flood events.
- It is important to distinguish pollution control dams from water storage dams. A water storage dam is normally operated to be as full as possible in order to get maximum assurance of supply, while a pollution control dam must be kept empty or at a suitably low level, to accommodate defined run-off events without spilling. Thus, not only must the pollution control dam be properly sized, the operation of the dam must also be such that there is sufficient storage capacity between the normal or average operating level and the spillway (freeboard) so as to accommodate the extreme events.
- To define and understand the interaction between the storage facilities, it may be necessary to undertake a water balance calculation. The designer is referred to BPG G2: Water and Salt Balances for guidance in this regard. The water balance modelling should, for complex circumstances, preferably be dynamic, and should take into account water losses through seepage, evaporation and abstraction. Although a water and salt balance is not mandatory for a SWMP, it can assist with the optimisation of the water management and the implementation of the hierarchy of water management options.

Pipelines

The design of pipelines and pumping systems is outside of the scope of this best practice guideline, and a suitably qualified person must carry out the design of the systems. A useful rule of thumb in preliminary sizing of pipelines for costing purposes is to ensure a velocity of the order of 1,5 to 2m/s. Note that velocities over 3m/s are uncommon in pumping systems. It must be recognised that mining is an extremely robust environment, and pumps and management systems, including monitoring devices, need to be selected to accommodate this.

Step 7: Define Operational, Management and Monitoring Systems & Responsibilities

Management and monitoring systems need to be defined to ensure that even at the design phase, the infrastructure of the storm water management system functions properly and optimally.

The management system should contain operational, inspection and maintenance procedures that are properly defined and documented in a SWMP operational guideline to ensure that the storm water management system is fully operational and operates/functions reliably and effectively. One of the main functions of these procedures should be to maintain the design capacities of the various facilities. The maintenance of storm water facilities is of particular importance in order to control blockages, overflows, erosion and pollution.

Despite all the necessary plans in place, emergencies are likely to arise. It will thus also be necessary to develop emergency procedures, which should be clearly defined and documented. Emergencies should be investigated comprehensively to identify the magnitude (volume and discharge rate and quality), impact (on downstream receiving water bodies) and circumstances which caused them. Through risk management, possible emergencies can be identified and the appropriate monitoring strategies be implemented. This in turn can allow time for alerting downstream landowners and water users of such emergencies.

Regular inspections of the facilities should be undertaken to monitor the condition of each facility. For example, a person should walk along pipelines, etc. to evaluate the condition of the pipe and pipe connections and undertake pro-active maintenance or replacement. Dams should be inspected to assess their remaining storage capacity, the condition of their spillway, blockages in inflows, silting in the dam, etc. Operational efficiency can also be used as a monitoring method and an inspector with appropriate qualifications and experience (engineer) should be appointed to inspect the facilities and co-ordinate with operators to undertake the necessary maintenance. Maintenance is required to ensure that storm water management facilities are operating at the design capacity and with the efficiency and effectiveness initially intended and required to meet objectives. Maintenance may include desilting of dams, clearance of vegetation in canals and de-scaling of pipelines.

Visual inspections may be adequate for the assessment of some physical elements such as bank and bed erosion in open channels, damage to surface pipes and silt buildup in sediment basins. Inspections will alert mine personnel to actual or imminent emergencies such as pipe rupture or possible spillage and can ensure that corrective response measures are taken timeously.

Operational monitoring of the SWMP should include flow monitoring (pipelines and channels), assessment of hydraulic integrity of pipelines, monitoring water levels and quality (channels and storage areas), rainfall measurements, assessment or monitoring of silt build-up in silt traps, and erosion (channels). Flow and rainfall monitoring for example may be required on a real-time basis.

A set of procedures to describe the nature and frequency of performance checks is required. These should also specify actions required if the performance does not comply. Thus regular checks will compare actual performance to design performance through performance indicators which relate to monitoring equipment performance, maintenance, recording and reporting of data.

As part of any management system, an appropriate monitoring strategy is required. The monitoring programme needs to measure the success of the implemented system in meeting the physical design performance objectives of the infrastructure. The programme should also measure the resultant water qualities within mining water circuits and the public environment. In this regard, reference should be made to BPG G3: Water Monitoring Systems.

Personnel at the mine need to be allocated the responsibility of managing the different components of the SWMP and its associated infrastructure. This is particularly important for the large mines where different, yet interconnecting systems may be developed for different mining shaft areas, different pits, different beneficiation plants and different residue disposal sites. It is necessary, in such a situation, to clearly define and agree on individual responsibilities and on the coordinating and integrating responsibility. It is also important that the responsible personnel are committed to continual improvement of the management system.

Step 8: Document the SWMP

The SWMP needs to be documented to capture all the decisions and results that were obtained in the previous steps. The format of the documentation should be guided by its use, for example its inclusion in an Integrated Water and Waste Management Plan (IWWMP), an EMPR, a Water Use License Application (WULA), an ISO 14001 management system or as an independent report. The documentation should be accompanied by drawings that clearly indicate the entire SWMP infrastructure conceptually and with design details for all new components and "as built" plans for previously completed structures. The SWMP documentation will be used to guide the implementation, operation, monitoring, auditing and management of the storm water management system and should therefore address all these aspects in sufficient detail. It is recommended that the SWMP document should, as a minimum, contain the following information:

- The objectives that were defined for the SWMP.
- The procedure that was followed to develop the SWMP. This is especially necessary when there is a deviation from the process recommended in this guideline. The motivation for any deviation should be included in the document.
- Detailed technical situation analysis and evaluation with appropriate maps/plans showing all relevant features, classification of areas, catchments, etc.

Methodologies and assumptions must be clearly indicated.

- A description of the modeling that was done and how this information was used to develop the detailed SWMP.
- The infrastructure that has been specified and designed (drains, pipes, dams, berms, etc.) should be presented and discussed (with appropriate plans and drawings).
- A list of the legal aspects that are relevant for the implementation, design, construction and operation of the SWMP.
- Description of all maintenance and operating procedures that need to be implemented to ensure that the designed SWMP infrastructure is capable of continuing to operate at the design duty.
- A description of the monitoring programme, including maintenance monitoring as well as water quality and flow monitoring. Refer to BPG G3: Water Monitoring Systems.
- A description of the management structure (human resources) that is responsible for the implementation, operation and maintenance of the SWMP.
- Auditing and review procedures for future audits and assessments of the SWMP to ensure continued legal compliance and accommodation of changing legal and mining requirements.
- A description of the emergency procedures, where applicable.
- Reference to all the relevant documentation and information with an indication where it is obtainable.

4.3 Operational Phase

It is important to emphasize that those operational mines that do not have an appropriate detailed SWMP and that intend making use of this BPG should also start at Step 1 of the SWMP process.

Step 9: Implement, Manage and Monitor the SWMP

During the operational phase, the management and monitoring systems defined in the SWMP are implemented and managed on an ongoing basis. The plan defined during the design and construction phase provides the basis for effective and economic water management during the operational phase. However, the SWMP must be adaptable and needs to be formally reviewed at regular intervals. Modifications are required as conditions and circumstances dictate.

The normal monitoring of flows and water quality, should, as a minimum, function over a monthly time step except where biomonitoring is envisaged. Biomonitoring (also referred to as biological monitoring in this document) should be undertaken quarterly or bi-annually to accommodate seasonal changes and variations. Special measures may need to be taken to measure flows and quality associated with specific storm events. The performance of the SWMP should be subject to an annual review and reporting to authorities after a major flood/rain event is also recommended.

Biological monitoring is a procedure used for assessing the health of ecosystems and should be undertaken by a specialist. Goals for environmental protection are typically biologically based and achievements can best be assessed in terms of the effects on living organisms. The type, number and distribution of aquatic life (organisms and plants) in water bodies can provide a reliable and integrated measure of the "health of the water body.

Monitoring the effectiveness of the storm water facilities is a continuous requirement and could easily be incorporated into the water and salt balance (BPG G2). The water and salt balance will indicate malfunctions and serve as an early warning signal for ineffective management facilities requiring maintenance. Inspections of the facilities should be undertaken two- to three-monthly.

Effective liaison with the regulatory agencies and stakeholders, on a three-monthly to annual basis based on requirements or changes to operation, is important during the operational phase. The mine must be able to demonstrate that it is meeting its environmental obligations as well as the objectives set out in chapter 2.

In addition to the regular monitoring and auditing, more detailed and intensive audits may be required on complex systems where safety and/or water quality impacts associated with system failure are high. This could be undertaken three-monthly by suitably qualified mine personnel, although for specialist work, an external audit may be necessary. This would apply, for example, to dams that fall within the Dams Safety Legislation, or other areas of high risk.

Problems in a SWMP are normally only detected when failure occurs. While a system is functioning adequately, it tends to be out of mind. Because of the costs and risk associated with water management, consideration should be given during the operational phase to: -

- A regular training programme that describes the need for water management. The water management system itself and the roles and responsibilities of the various groups on the mine should be considered. Ideally staff should feel that they are contributing to decision-making in terms of water management.
- Components such as the management of wastes, geochemically unstable materials, erosion, and water monitoring systems may require additional management during the operational phase.
- Research and development is often excluded from the mines SWMP. However, many mines are depending on new technologies to provide cost effective solutions to water management issues. Active research and evaluation of techniques used on other mines can result in potential savings for the mine. However, this is not a mandatory component of an SWMP.

Step 10: Formally Review/audit the SWMP and Systems at Regular Intervals

In addition to the regular monitoring undertaken as part of Step 9, it is recommended that the complete SWMP and its infrastructure be formally reviewed and audited annually for the first three years and thereafter at regular intervals of between 1 and 3 years. This review/audit should focus on ensuring that the SWMP and its infrastructure are still adequate and appropriate for the mine, both in terms of changing circumstances and needs at the mine, as well as changing regulatory requirements. Although these audits can be undertaken by suitably qualified mine staff, it may be advantageous to involve outside personnel (either from other mines within the mining Group or from external consultants) in such an audit.

As indicated previously, the SWMP is an iterative process. At various points in the mine development, the SWMP will be re-assessed, and evaluated as to whether it is still appropriate and suitable. If not, then the mine may need to revisit Steps 3 onwards in order to bring the SWMP back into line with the revised requirements.

4.4 Decommissioning, Closure and Post-Closure Phases

Water management has the potential to be a major cost associated with decommissioning and post closure management of the mining areas. Even during the design and operational phase, the water management measures should be aimed at facilitating successful decommissioning, closure, and post closure management of the area.

Discussions with the regulatory authorities and IAPs are recommended to establish that the proposed final landforms, vegetation and land use, and water management structures will be acceptable at closure. As far as possible, systems that manage the water should not be active, e.g., systems requiring pumping are not desirable. Active systems require maintenance and supervision, which is undesirable and costly after closure.

Further, the sustainability of water management measures needs to be demonstrated, e.g. the impact of floods larger than the design flood on the need to reconstruct or repair structures. This can already be assessed during the operational phase but monitoring during the post closure phase will also be required, and allowance for this must be made in the financial provision.

Compliance monitoring could include meteorological data, surface water flow and quality monitoring, groundwater behaviour and quality, biological monitoring, and erosion monitoring. Where settlement or subsidence may affect water management structures, monitoring of this may also be required.

4.5 SWMP Checklist

Table 4.3 summarises some of the main requirements in the development and operation of an SWMP in the form of a checklist.

Table 4.3: Main Requirements in the Development and Operation of a Storm Water Management Plan as per Australian guide (modified from McQuade & Riley, 1996)

Stage	Important water management elements
Exploration	erosion control from temporary roads and drill pad construction management of drilling fluids (oils and greases) management of camp wastes (sewage and domestic-type solid waste) collection of hydrogeological data (baseline or background information) collection of rock samples for environmental geochemical analyses (see BPG G4)
Resource	erosion control from semi-permanent roads and additional drill pads
Development	management of camp wastes, allowing for increased personnel for longer periods commence baseline data collection: • hydrological and hydrogeological • climate • biological • geochemical
Design	ongoing refinement of data collection determine the expected water requirements for the operation – quality and quantity - from the proposed mining and processing methods develop an expected mine site water balance (see BPG G2) undertake an audit of potential mine-related contaminants quantify the potential pathways of contaminant transport and the expected rate and chemical alterations during transport define the physical locations, types and timing of potential environmental impacts undertake a risk assessment in terms of water management develop strategies to minimise the risk of water contamination develop a preliminary runoff drainage system to manage high-rainfall events, and wetter than average seasons develop contingency procedures develop a data collection programme for design performance validation validate design predictions and collect data to reduce the uncertainties in design, where necessary
Operation & Rehabilitation	validate design predictions and collect data to reduce the uncertainties in design, where necessary monitor the environmental and operational performance of the SWMP develop accountabilities for the maintenance and operation of the physical and mechanical components of the water management system and in implementing contingency procedures train operators in these areas and define roles and responsibilities continue with system investigations, that take account of new technologies, to minimise the risk of environmental impacts and maintain flexibility for the mining operation identify and manage risks develop techniques for and implement progressive rehabilitation develop a data collection programme for rehabilitation performance post mining
Post-mining	collect data and determine the performance of the post-mining landform activity against the agreed post-mining land use/environmental values publish the information so that governmental authorities and the mining industry can improve their environmental performance

5 LEGISLATIVE ASPECTS

As indicated in previous chapters, it is necessary to consider the relevant legislation (including regulations) and policies for different aspects of a SWMP. This chapter references the main legislation and policies that are applicable to a SWMP. It should be noted that this is not an all-inclusive list and the user of this guideline should ensure that all other applicable legislation and policies are adhered to. The legislative aspects are addressed in the following categories:

- DWAF legislation (Table 5.1)
- Other legislation (Table 5.2)

Table 5.1: DWAF Legislation

Act/Government Notice/Policy	Relevant Section(s)/Regulation(s)
National Water Act, 1998 (Act 36 of 1998)	19; 20; 21; 22; 23; 26; 27; 28; 29; 30; 31; 36; 39; 40-48 (licensing procedures); 49–52 (review of licenses); 117-123; 145; 151 and 154
GN 704 of 4 June 1999 Regulations on use of water for mining and related activities aimed at the protection of water resources.	4, 5, 6, 7, 8, 12
GN R991 of 18 May 1984	
GN R1560 of 25 July 1986	
Water Quality Management Policies and Strategies in the RSA. (April 1991)	

Table 5.2: Other Legislation

Act/Government Notice/Policy	Relevant Section(s)/Regulation(s)
Environment Conservation Act, 1989 (Act 73 of 1989)	20 (1); 21 and 22
Minerals and Petroleum Resources Development Act (Act 28 of 2002)	17, 23, 38, 39, 43, 48
GN R992 of 26 June 1970	2.10.14; 2.14.3; 5.1.1; 5.1.2; 5.5; 5.6.1; 5.6.2; 5.6.3; 5.9.1; 5.9.2 and 5.14.3;
National Environmental Management Act, 1998 (Act 107 of 1998)	23, 24, 28 ,30, 31, 32, 33 and 34
Health Act 2003 (Act 61 of 2003)	37 and 38
Municipal By-laws	
Nuclear Energy Act, 1993 (Act 131 of 1993)	
Conservation of Agricultural Resources Act (Act 43 of 1983)	5 and 6
Mountain Catchment Areas Act (Act 63 of 1970)	2 and 3
Dumping at Sea Control Act, 1980 (Act 73 of 1980)	
Nature Conservation Ordinance (No 12 of 1983)	
Constitution of the Republic of South Africa (Act 108 of 1996)	22, 24; 25; 32; 34; 36; 38 and 39

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7 GLOSSARY

carrying capacity:	The maximum water capacity, either volume or flow rate that a facility can accommodate.
catchment:	In relation to a watercourse or watercourses or part of a watercourse, means the area from which any rainfall will drain into the watercourse or watercourses or part of a watercourse, through surface flow to a common point or common points. (National Water Act, 1998 (Act 36 of 1998)).
clean water:	Water that complies with a negotiated standard.
continual improvement:	Process of enhancing the management system to achieve improvements in overall performance in line with the objectives and principles of storm water management as defined in this guideline.
design storm:	Storm water management systems are usually based on runoff for a design storm, which is a particular combination of rainfall conditions. The magnitude of a design storm is generally expressed as a total quantity of precipitation, expressed as mm of rainfall, or as a short-term intensity, expressed as mm per hour, together with a defined recurrence interval.
dirty water:	Water that is not clean water.
drainage area:	The total land area that drains to a specified point comprises the drainage area for that point.
ecology:	The study of the relationships of organisms to their environment and to one another.
evaporation:	Evaporation occurs when the water liquid phase is changed into the vapour phase due to the addition of energy.
Geographical Information Systems (GIS):	GIS is a term loosely used to describe a variety of combinations of databases and graphical computer systems and range from simple mapping software on the low end of complexity to sophisticated graphical and database systems at the high end. A true GIS can relate many layers of information to each other and perform any number of complex data manipulations and analyses from any combination of information and then display the information graphically to any scale (Debo, 1995).
geology:	The study of the Earth as a whole, its origin, structure, composition, and history (including the development of life), and the nature of the processes which have given rise to its present state. (Whitten, 1978)
groundwater:	Water that occurs in the voids of saturated rock and soil material beneath the ground surface is referred to as groundwater.
hydrograph:	A plot of water flow rate, either runoff or discharge, against time.
hydrological data:	Data generated from the various components of hydrology, like rainfall, evaporation and runoff.
hydrology:	The study of all waters in and upon the Earth. It includes underground water, surface water, and rainfall, and embraces the concept of the hydrological cycle. (Whitten, 1978)
infiltration:	The movement of water through a solid medium like soil, ash or discard.

life of mine:	The life of mine includes all the phases of the mine's existence from the conceptual and planning phases, through design, construction, operation and decommissioning to the post-closure and aftercare phases.
peak flow runoff:	During a storm event the runoff from an area follows a hydrograph curve. A maximum runoff rate is experienced during the storm event and this rate is referred to as the peak flow runoff.
pollution control dam:	The main purpose of a pollution control dam within a storm water management system, is to control and retain contaminated runoff for a design storm event. If the dam is also used to store water the additional storage capacity required needs to be considered in the design of the dam.
precipitation:	The discharge of water (as rain, snow or hail) from the atmosphere upon the earth's surface. (Gary, 1977)
recharge:	The process of supplying a water resource with water.
reclamation strategy:	Strategy to make water, usually contaminated, available for use on a mine.
recurrence interval:	Recurrence interval refers to the average time between storms of a given magnitude in a local rainfall record and defines the probability that a given type of storm will occur at the site. A 10-year (1:10) storm indicates that a storm of the specified magnitude has recurred on average in one of every 10 years in the record.
residue:	Residue includes any debris, discard, tailings, slimes, screenings, slurry, waste rock, foundry sand, beneficiation plant waste, ash and other waste product derived from or incidental to the operation of a mine or activity and which is stockpiled, stored or accumulated for potential reuse or recycling or which is disposed of. (Government Notice 704 of 4 June 1999.)
residue deposits:	Residue deposits include any dump, tailings dams, slimes dams, ash dump, waste rock dump, in-pit deposit and any other heap, pile or accumulation of residue. (Government Notice 704 of 4 June 1999.)
runoff:	Surface runoff is defined as the water that finds its way into a surface stream channel without infiltration into the soil and may include overland flow, return flow, interflow and base flow.
sediment removal facilities:	Facilities that are designed to contain and remove sediments that are present in water.
seepage:	The act or process involving the slow movement of water or another fluid through a porous material like soil, slimes or discard.
slope:	Slope is a dimensionless number and is defined by the vertical distance (drop) divided by the horizontal distance.
storage dams:	Dams that are used to store water and should not be used to control storm water for storm events smaller than the design storm conditions, unless the dam is specifically designed as a combined storage and pollution control dam, which is generally not recommended. (See also pollution control dam)
storm water quality:	Runoff water most likely will contain contaminants from precipitation, deposits, surface weathering and seepage, and is commonly referred to as storm water quality.
surface subsidence:	Slow or rapid sinking down of part of the Earth's crust that is not slope related. (Miller, 1993) In the context of this BPG, subsidence is often associated with shallow mining activities and rehabilitated open cast areas. Surface subsidence may also occur as sinkholes from dewatering of the dolomites.
suitably qualified person:	Suitably qualified means a person having a level of training and experience with the type of work to be done and recognised skills in the type of work to be done.
synthetic hydrograph:	If actual flow data is not available to compile a hydrograph, a synthetic hydrograph can be compiled with estimated flows.

time of concentration:	It is the time required for rain falling at the furthest point of the catchment to flow to the point where the discharge is being calculated. The time is thus associated with the hydraulic length and is used in hydrology calculations.
watercourse:	Watercourse means – (a) a river or spring; (b) a natural channel in which water flows regularly or intermittently; (c) a wetland, lake or dam into which, or from which, water flows; and (d) any collection of water which the Minister may, by notice in the Gazette, declare to be a watercourse, and a reference to a watercourse includes, where relevant, its beds and banks. (National Water Act, 1998 (Act 36 of 1998)).
water system:	Water system includes any dam, any other form of impoundment, canal, works, pipeline and any other structure or facility constructed for the retention or conveyance of water. (Government Notice 704 of 4 June 1999.)

8 SYMBOLS AND ABBREVIATIONS

A	effective drainage area of catchment
BPG	Best Practice Guideline
C	run-off coefficient
COD	Chemical Oxygen Demand
DWAF	Department of Water Affairs and Forestry
EMPR	Environmental Management Programme Report
GIS	Geographical Information Systems
GN	Government Notice
I	average rainfall intensity over catchment
IWWM	Integrated Water and Waste Management
IWWMP	Integrated Water and Waste Management Plan
MAR	Mean Annual Runoff
Q	peak flow
RMF	Regional Maximum Flood
SCS	U.S. Soil Conservation Service
SS	Suspended solids
SWMP	Storm Water Management Plan
WRC	Water Research Commission

APPENDIX A: PEAK FLOW AND FLOOD VOLUME DETERMINATION

This section provides summarized information obtained from the NTC Road Drainage Manual and other sources. For more detailed information and design tools or aids the reader is referred to the original sources.

A1 Rainfall Intensity Determination

Rainfall intensity-frequency-duration data are necessary to estimate peak discharges for drainage and flood analyses. Such data can be obtained from references such as Alexander (1990) or Adamson (1981).

Methods such as the Rational Method are highly sensitive to the time of concentration determined for a particular rainfall event, the time of concentration being the duration it takes for the majority of water from the catchment to report to the channel being designed. The following cautions should be noted when using the Rational Method: -

- The adopted value of the run off coefficient (c) will always be uncertain, especially when applied to a "large" catchment. The coefficient reflects both rainfall losses and the effects of storage routing in reducing peak discharges.
- The formula was originally developed for catchments smaller than 15km^2 in area. Although it can be used on larger catchments, a considerable amount of experience and judgement is required to obtain reliable estimates.
- The Rational Method only provides an estimate of peak discharge, and if the rate of rise or recession of the hydrograph is of interest, a run off routing model would be more applicable.

A2 Peak Flows

Various hydrological methods are available to determine the peak flow of a catchment. Some of the more commonly used methods are detailed.

A2.1 Rational Method

The Irish Engineer Mulvaney first proposed this method in 1851. Since then it has become one of the most widely used and best known techniques for determining peak flows from small catchments.

The peak flow is obtained from the following formula:

$Q = 0{,}278CIA$

where
- Q = peak flow (m^3/s)
- C = run-off coefficient (dimensionless)
- I = average rainfall intensity over catchment (mm/hour)
- A = effective area of catchment (km^2)
- 0.278 = conversion factor (convert $mm.km^2/hour$ to m^3/s)

The rational formula is based on the following assumptions:

- The rainfall has a uniform distribution across the catchment.
- The rainfall has a uniform time distribution during the time of concentration.
- The peak discharge occurs at the end of the critical storm duration, or the time of concentration.
- The run-off coefficient remains constant throughout the duration of the storm.
- The return period of the peak flow is the same as that of the rainfall intensity.

Despite its shortcomings as set out in the text, the Rational Method can give realistic results if it is used with care, and has given good results in studies where it has been compared with other methods. It is generally recommended that the method only be applied to catchments smaller than 15 km^2, but in some cases it can be used by an experienced person for larger catchments.

The time of concentration of the catchment from which the rainfall intensity is determined can be estimated according to either the Kerby formula for overland flow, and the US Soil Conservation Services equation for water course flow, or the Bransby William formula. The Bransby William formula is.

$$T_c = \frac{L}{A^{.01} . Se^{0.2}}$$

where T_c = time of concentration (hours),
L = length of the mainstream channel to the catchment divide (km),
Se = 'equal area' slope (m/km) of the mainstream channel to the catchment divide (km)
A = catchment area (km^2)

The Kerby and US Soil Conservation Services equations are given in the National Transport Commission Roads drainage manual. Determination of C is also given in this reference. A correction factor F_t is also sometimes applied for the more extreme flood extents.

A2.2 SCS Method

The SCS method is based on the basic principle that run-off is caused by the rainfall that exceeds the cumulative infiltration of the soil. The method is particularly suitable for computing flood peaks and run-off volumes for catchments smaller than 10 km^2 and with slopes of less than 30 %. The method requires a considerable amount of calculation, which can be greatly reduced by using nomograms or programs.

The SCS method takes into account most of the factors that affect run-off, which includes quantity, time distribution and duration of rainfall, land use, soil type, prevailing soil moisture conditions and characteristics of the catchment. One of the main advantages of the SCS method is that it enables empirical hydrographs to be fully calculated.

A detailed description of the SCS method and its application in South Africa is given by Rooseboom (1983) and Schulze and Arnold (1979).

Although the SCS method is based on physical principles and some generalisations must be used, the results are less dependent on personal judgment and are reliable if based on sufficient information. Some of the practical advantages of the SCS method are that it offers a graphical solution and it has been adapted to South African soil types. It is not as sensitive to the time of concentration as many other methods.

A2.3 Synthetic Hydrograph Method

The synthetic hydrograph method is based mainly on regional analysis of historical data and is suitable for the determination of flood peaks as well as hydrographs of medium-sized catchments (15 to 5 000 km^2). The recommended methods to develop synthetic hydrographs are discussed in Midgley (1972), Rooseboom (1983) and Alexander (1990). The concept and application of the synthetic hydrograph can be extended to catchments larger than 5 000 km^2. This should only be done by a suitably qualified person, but will not be an issue with a SWMP because the catchments are so much smaller.

The physical characteristics become increasingly complex and difficult to describe empirically in large catchments. The role played by many of the characteristics of a catchment changes in importance as the size of the catchment increases. The constant physical parameters of a catchment can be established by using the concept of unit hydrographs. A unit hydrograph is defined as the hydrograph of one millimetre of run-off following rainfall of unit duration with uniform spatial and time distribution over the catchment, and is a characteristic of a specific catchment. The duration of the hydrograph is in proportion to the duration of the rainfall and its volume is proportional to the intensity of the rainfall.

The Hydrological Research Unit has derived from historical data, unit hydrographs for river measuring stations in South Africa. From the unit hydrographs, synthetic hydrographs have been derived for regions in South Africa with similar catchment area characteristics such as topography, soil type, vegetation and rainfall characteristics.

Synthetic hydrograph results are independent of personal judgement and generally reliable. It should be noted that some natural variability in the hydrological occurrences is lost through the broad regional divisions and the averaged form of the hydrographs, which is especially relevant for catchments smaller than approximately 100 km^2. For small catchments with times of concentration of less than half an hour, this method may be problematic to apply.

A2.4 Empirical Methods: Regional Maximum Flood

The regional maximum flood (RMF) is an empirically established upper limit of flood peaks that can be reasonably expected at a given site. The application of this methodology is as set out in TR137/Regional Maximum Flood peaks in South Africa by Z. Kovács. The relative flood peak and magnitude is expressed by the Francou-Rodier regional co-efficient k.

When determining peak flows for extreme events, typically in excess of 1 in a 1 000 years, both deterministic methods (employing principles such as probability maximum precipitation) and probabilistic methods (statistical prediction of low probable events from relatively short periods of record) have often resulted in inconsistent figures. The use of empirical methods such as the RMF has given more consistent figures, and has been largely validated by the more recent extreme events.

TR137 gives empirical coefficients for catchments as small as $10km^2$, although the main use of the RMF method is in medium sized to large catchments, typically in a range from 3 $000km^2$ and up. Nevertheless, Appendix 6 of TR137 is useful for checking the order of magnitude of the predicted flood peak for catchments of $10km^2$ or greater. The designer should be cautioned against using it as a once-off computation, and it is recommended as an order of magnitude check.

A2.5 Statistical Methods

Statistical methods are an extremely useful tool for hydrologists. However, they will seldom be applicable on a mine site due to: -

- The specialised nature of the use of these methods, which is more applicable to a specialist in this field.
- Statistical methods rely on available stream flow records, and this data is normally only available on larger catchments and major river systems which the designer of an SWMP should not be affecting without the input of a specialist in this field. For this, reason no further information is given on these methods.

A3 Hydrological Modelling

Use can also be made of different hydrological models that operate on daily, weekly or monthly time steps. This approach is very useful when it is combined with water quality modelling approaches. This provides simulation tools that allow the evaluation of various water management practices, especially for legal compliance at downstream water quality points.

A4 Flood Volumes

Determination of flood volumes is important in instances where clean water facilities are used to store and attenuate floods, where flood routing is undertaken, or where storage dams are used to control dirty water make. Generally, this is a specialised field, but the information given here may be of use for provisional sizing during conceptual planning.

A4.1 Flood Hydrograph Determination

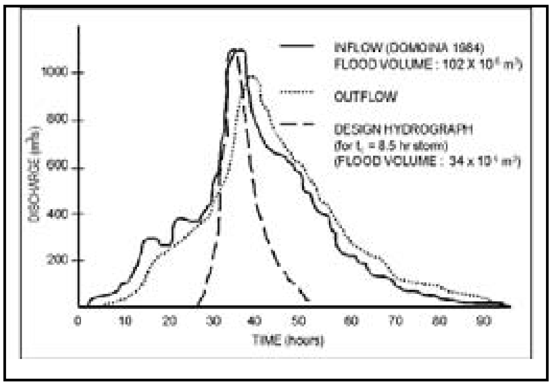
Take as an example the typical problem of a clean water holding or attenuation dam, upstream of a discharge canal. To optimise the design, the designer is looking for the optimal combination of dam size and canal capacity. There are several ways of doing this, but the most technically correct would be to determine the incoming flood hydrograph, or the relationship between flow and time for the flood event. From this, the incoming hydrograph can be routed through the dam to determine the expected peak outflow rate in the canal.

Detailed information on rainfall hydrograph determination (rainfall time relationship), the application of this to a catchment (generally using a computer programme), and the routing of the subsequent flood hydrograph can be found in most hydrology text books, with a good example being Alexander, 1990.

A4.2 Empirical Determination

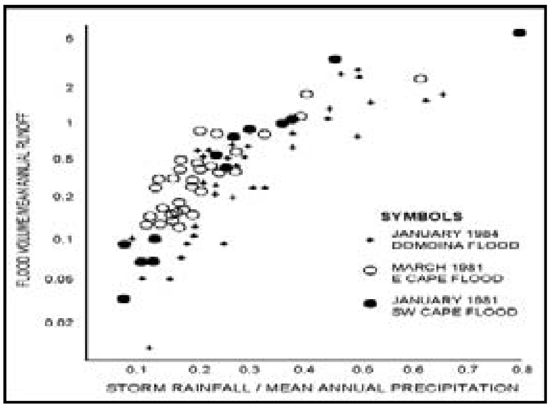
For the designer who has neither the knowledge nor the need to go into this level of detail, there are alternatives. The most conservative would be to size the attenuation facility to accommodate the full volume of the expected flood event, whereafter the canal downstream can be relatively small, although there may also be a catchment downstream that has to be catered for.

Fig A1: Flood hydrographs at Klipfontein Dam



A common mistake is to assume that the worst case is represented by the rainfall event giving the highest peak flow, but with a small volume. Figures A1 and A2 indicate that there is often a high correlation between flood peak and flood volume during extreme events (see Du Plessis et al, 1988).

Fig A2: Storm runoff volume estimation



Attenuation effects are thus often overestimated, due to the volume of the flood event being underestimated.

For large dams, a preliminary estimate of attenuation is given below: -

$Q_{out}/Q_{in} = 0.99 – 5.56(A_r/A_c)$

where A_r = area of the reservoir at full supply level

A_c = area of the catchment in similar units

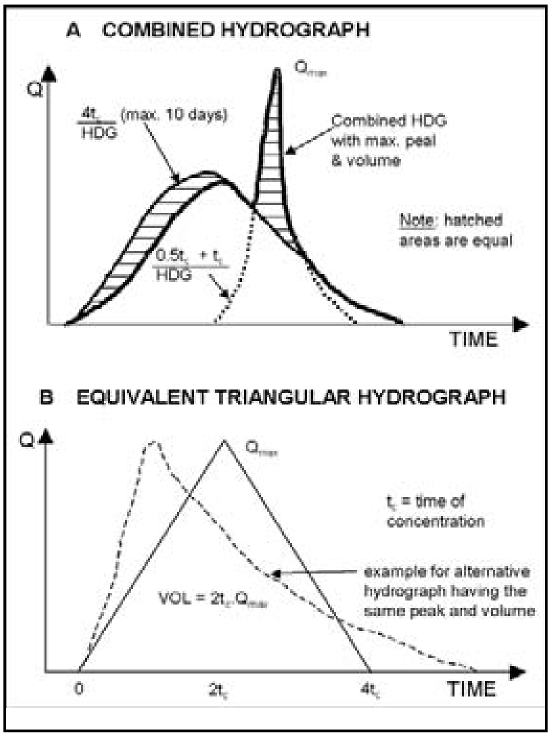
Kovacs suggests the following: -

If at the beginning of a flood the dam is more than 90% full, and the volume of the flood is larger than the Full Supply Capacity of the Dam, then the ratio of peak outflow to peak inflow will seldom be less than 0.75. Expressed differently, the outflow peak will be in the range of 75 to 100% of the inflow peak.

For a provisional hydrograph, combine the design hydrographs calculated for a storm duration of 0.5 x the time of concentration (t_c), and that of 4 x t_c. The storm duration of 4 x t_c should not be too long (i.e. less than 7 days), but this will seldom be an issue for the catchments being assessed during an SWMP.

These two hydrographs can be combined into a triangular hydrograph with a peak equal to that determined from 0.5x t_c, and a volume of $2t_c.Q_{max}$. This is illustrated in the figure A3. It may also be useful to compare the flood volume to the MAR when determining extreme events (such as in excess of 1:200 years or more), and comparing this to the graph given in Figure A3.

Fig A3 Equivalent triangular hydrograph



The following cautions should be noted: -

Flood hydrology is not an exact science, and there are aspects of flood determination that are subject to ongoing research. For example, while the mountainous regions of the Western Cape and Drakensberg with a high mean annual rainfall show a good correlation between observed and theoretical data, that in the Karoo (with a low mean annual rainfall but significant outliers) is less satisfactory.

Similarly, the coastal belt and adjoining interior between Port Elizabeth and the Mozambique border shows a characteristic upward curve between the 1:5 year and 1:10 year return periods that highlights the presence of two different types of flood generating mechanisms i.e. the cyclonic heavy rainfall results in a non-linear relationship. The relationship between observed and theoretical data requires specialist knowledge in these areas (refer paper by Pegram and Adamson [1988]).

The information given in this BPG should thus be used with due care, taking cognisance of the risks associated with failure, and the level of knowledge of the designer.

APPENDIX B COMPUTER MODELS

In the text, at various points, reference is made to computer models for different purposes. The use of modeling and simulation techniques in dealing with storm water issues on mines has been found to be valuable. Since the modeler using the model is assumed to have specialist knowledge, the information given in this appendix is intended to give an understanding of the issues from a mine management perspective.

Models used in the development of a SWMP would potentially include the following:

Runoff Routing models

These models simulate the rainfall runoff process for a selected storm event over the catchment of interest. The routing process delays and reduces the peak flow to take account of transient storage. The models used differ mainly in their treatment of the "loss" of rainfall into the soil, so as to determine the runoff from a particular soil under a particular set of conditions (rainfall before the event, vegetation, soil type, etc.)

Daily rainfall runoff models

These models are used to determine runoff from rainfall, but not for a specific storm event, but rather from a daily rainfall record over many years. Their value is that this data can be input to a System Model for the mine, or for use in Water Quality models.

Channel flow or floodline determination models

A number of open channel hydraulic models are available. Based on the equations of momentum and continuity, they simulate the behaviour of water as it flows down a watercourse, that is, the velocity, water level, and various other parameters and characteristics of the flow. For a SWMP or floodline determination, `steady flow' models would generally be adequate, that is, the model assumes a constant flow for each of the different defined reaches. `Unsteady flow' models (which model the variation in discharges and water levels with time) would seldom have application in a SWMP or floodline calculation.

Ground water models

These models attempt to represent the groundwater flow. The models make use of numerous assumptions such as boundary conditions, aquifer characteristics, and various other parameters. Models can be either two or three dimensional in their representation of the groundwater regime. While modelling is accepted as best practice for the assessment of groundwater impacts on a SWMP for cases where the groundwater is a significant component or resource, without meaningful data and proper calibration the results may be of little value.

These models are outside of the scope of this BPG, and the reader is referred to publications on groundwater given in Section 6 and to BPG G4: Impact Prediction.

Systems models

A system model would refer to a model that simulates the behaviour or operation of the water management on the mine. It would take account of the various dams, water make areas, inflows and losses on the site to allow the assessment of the adequacy of the water management system. Outputs include frequency and volume of spills, shortfalls in water supply, and can also be linked to quality models. Most consultants have their own in-house models.

Water quality and salt balance models

Refer to BPG G2 on water and salt balance models.

Specialised water quality and geochemical models

Models could include: -

- Catchment flow type models that integrate water quality of runoff in to hydrology, more typically used for a catchment analysis model as per that developed for Witbank Dam.
- Mine water quality models that predict for example, the expected geochemistry within spoils, or a discard dump. This is a highly specialised field that is covered in detail in BPG G4: Impact prediction

All of the models detailed above can be of significantly greater value when calibrated. In some cases (such as groundwater modelling and geochemical modelling), calibration is essential. Because much of the data is not collected on a mine site, the reliability of simulated results is often difficult to assess.

Table B.1 provides some useful information on models that have seen widespread application in South Africa.

Table B.1: Information on surface runoff models:

Name of model	ACRU-HSPF LINK	HSPF
	Includes ACRU and HSPF programme with integration routines)	Hydrological Simulation Program – FORTRAN
Description	A procedure links hydrological output from the model ACRU into the water quality routines of HSPF, via a Water Data Management programme. Variables such as surface runoff, interflow, baseflow, as well as sediment load can be simulated with ACRU, and input into HSPF, to estimate the fate of the variables.	Models quantity and quality of runoff from a catchment (including point sources). Also simulates the in-stream processes. Used to model urban and rural catchments from field size to several catchments.
Input	Climatic data (e.g. rainfall and evaporation), land use, topographical and soil data.	Rainfall, evaporation, point source data, catchment parameters such as soil type; soil cover; slope and land use. Receiving-reach dimensions.
Output	Water quality and hydrology data	Water quantity and a large number of water quality parameters at user specific points in a reach.
Use of output	Used for simulation of variable (phosphorus, nitrates, sediment and E. Coli)	Can be used to determine mean and total loads of various pollutants, total outflow and a profile of outflow rate at various points in the catchment. Output can be obtained as an ASCII file. The ANNIE software can be used for this process.
Databases accessed	None	User-created database (a "time series store") and, through a software package called ANNIE, use of a Watershed Data Management file.
Developer/ vendor	Department of Agricultural Engineering, University of Natal and CCWR	CEAM (Obtain from CSIR)