Series A: Activity Guidelines

A4

BEST PRACTICE GUIDELINE

Pollution Control Dams

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

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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.

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

RESOURCE PROTECTION AND WASTE MANAGEMENT HIERARCHY

Step 1: Pollution Prevention

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

↓

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

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

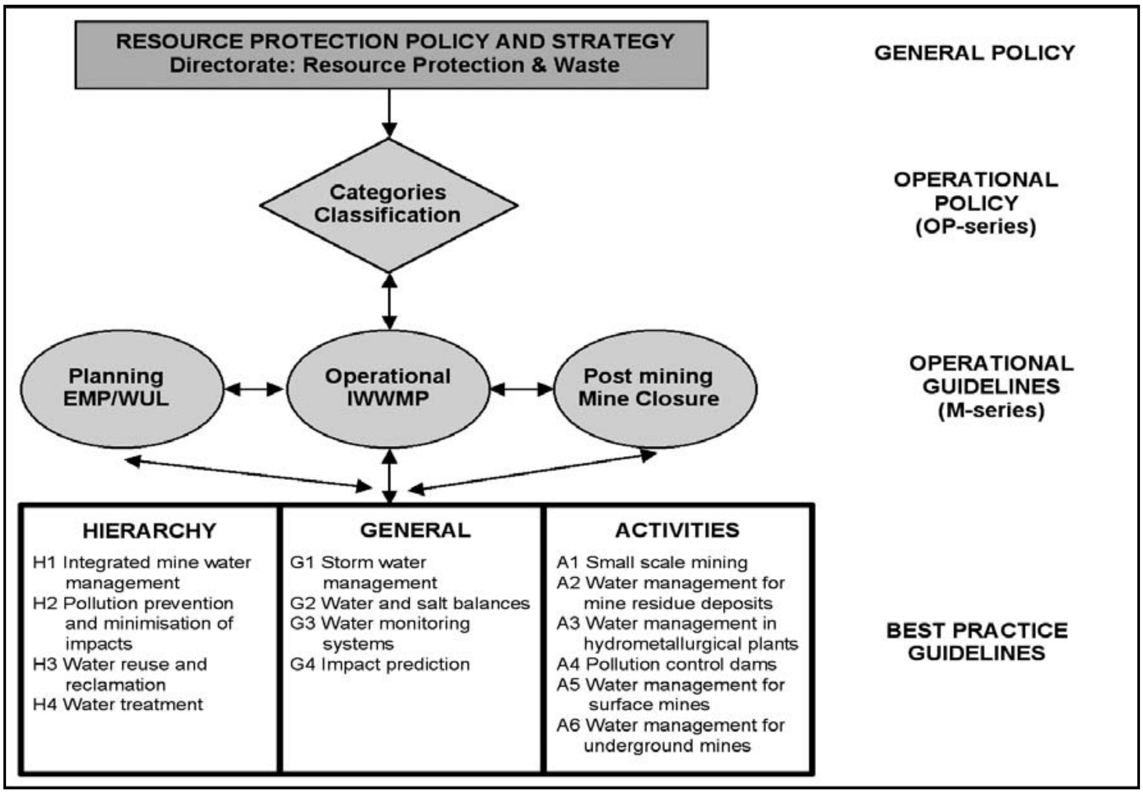
The overall Resource Protection and Waste Management Policy sets out the interpretation of policy and legal principles as well as functional and organisational arrangements for resource protection and waste management in South Africa.

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

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

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

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



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

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

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

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

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

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

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

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

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

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

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

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

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1 INTRODUCTION

Pollution control dams (PCDs) form an integral and important part of the water management systems on a mine. Different types of PCDs may exist on a mine site, such as process water dams, storm water dams, evaporation dams and other dams, possibly including excess mine water dams and natural pans.

The purpose of PCDs for the mine and in the water management circuits are to:

- Minimise the impact of polluted water on the water resource
- Minimise the area that is polluted as far as possible, by separating out clean and dirty catchments, and
- Capture and retain the dirty water contribution to the PCDs that can not be discharged to the water resource, due to water quality constraints, and manage this dirty water through recycling, reuse, evaporation and/or treatment and authorised discharge.

The design, operation and closure of PCDs are important aspects in the successful operation of a mine, given the inherent safety and environmental risks posed by structural failure, spillage or overtopping of these facilities. It is thus important that practitioners within this field have a good understanding of the management of water, both surface and groundwater, when designing and/or operating PCDs. To this end, the Department: Water Affairs and Forestry (DWAF) have prepared this activity-related Best Practice Guideline to focus on mine water PCDs.

Best practice for mine water PCDs is developed from a combination of the following requirements:

- Legislative requirements
- Industry norms and generally accepted good practices
- Technically and environmentally sound design practices
- Life cycle planning for the PCD
- Management of hazards and risks
- Effective water resources management, both for the mine site and within the regional Catchment Management Plan, and
- Other factors, such as site specific conditions.

Effective design, operation, management and closure of PCDs are ensured through adherence to the above requirements. This Best Practice Guideline therefore covers the full life cycle of a PCD, including design, construction, operations and closure.

2

GENERAL PRINCIPLES FOR WATER MANAGEMENT ON POLLUTION CONTROL DAMS

Best Practice water management for PCDs is based on the following general principles:

- All PCDs must comply with the legal and regulatory conditions within South Africa
- Worst-case conservative assumptions must be made in instances where the quality of water to be contained within the PCD cannot be established with certainty
- PCDs are to be sited, sized and operated to maximise the opportunities for water reuse and reclamation and to minimise the impacts on the water resource
- Designs should adhere to the generally accepted principles of sustainable development and Best Practice Environmental Option (BPEO), as defined in section 2 of NEMA, by integrating social, economic and environmental factors during the planning and implementation and closure phases
- Technical studies and the design of PCDs should be undertaken by suitably qualified personnel
- The full life cycle of the PCD must be considered in the design, operation and closure of PCDs
- Designs should adopt a holistic approach, including:
    - Sustainability
    - Full life cycle of the PCD
    - Water quantity and quality, and
    - Surface water and groundwater

3 OBJECTIVES AND KEY CONSIDERATIONS

3.1 Objectives of this guideline

The overall objective of this guideline is to ensure that a best practice approach is adopted by all industry stakeholders involved in the design, operations and closure of PCDs on a mine site within South Africa and to enable DWAF personnel to establish that best practice has been applied.

The specific objectives of the Best Practice Guideline are as follows:

- To provide guidance on water management best practice for PCDs
- To inform DWAF officials and other users of the BPG on the procedures involved in the specification and design of PCDs
- To provide guidance on the philosophy of the planning and operations of PCDs and the integration of these into the overall mine water management system
- To ensure that potential impacts on safety and the water resource are acceptable/managed over the life of the PCD, in a consistent manner throughout South Africa, through the use of best practice guidelines for water resource management, and
- To provide guidance on appropriate tools for the design and management of PCDs, to complement those that are covered in other BPGs.

3.2 Key considerations

Table 3.1 provides details on the general aspects that should be considered in the design, operation and closure of PCDs. In addition, the BPG has been developed, and should be used, taking into account the following considerations:

- The BPG is aimed at personnel with a basic understanding of water management aspects for PCDs.
- The BPG draws on established international best practice
- The BPG augments (and does not duplicate) existing literature on PCDs
- PCDs are likely to be listed and will form part of the waste discharge charge system
- The BPG refers to, summarises and expands (where necessary) on relevant water management areas not fully covered in the existing literature.

Table 3.1: General considerations in the design, operation and closure of PCDs

No.	Consideration	Description	Aspects to consider
1	Pollution prevention	Deterioration of water quality must be prevented wherever possible and minimised where complete prevention is not possible	• Identify and apply opportunities for the prevention of water pollution. • Implement the necessary management measures to minimise impacts in the case where pollution prevention is not possible, e.g. management of the spillage frequency from PCDs. • Ensure that the water use practices on a mine do not result in unnecessary water quality deterioration, e.g. separate clean and dirty storm water wherever possible. • Minimise contact between water and major pollution sources, where possible.
2	Conservation of water resources	Losses of water and consumptive use of water must be minimised	• Design PCDs to minimise the evaporative losses by limiting the exposed surface area. • Ensure that seepage and/or overflow losses from storage facilities are minimised, e.g. facilities that can impact on the water resource through seepage may have to be lined, and PCDs should be designed with sufficient capacity and operated at a level to allow it to accommodate storm events and hence manage the spillage frequency. • Use raw water only for processes requiring such good water quality and additional water requirements that cannot be supplied within the water network. • Assess the technology being used for the design, operations and closure of PCDs including whether alternative technologies could be applied (particularly important for new mines) or whether the technology could be modified or improved.
3	Sustainability	Water management practices and designs should be sustainable over the life cycle of the PCD	• Develop water and salt balance projections for future mining scenarios, including mine closure and post-closure (see *BPG G2: Water and Salt Balances*). • The design, operation and closure of PCDs should incorporate consideration of the risk of changes in the mining and plant operations, and hence the mine water balance, through the life cycle of the mine.

4 PHILOSOPHY OF WATER MANAGEMENT FOR POLLUTION CONTROL DAMS

PCDs are important elements of the management of mine water. PCDs are included in the mine water balance to capture and temporarily retain the dirty water contribution that can not be discharged to the water resource. The retained dirty water is managed through recycling, reuse, evaporation, treatment and/or authorised discharge. Figure 4.1 shows an example of a typical lined PCD.

Figure 4.1: An example of a typical lined PCD

4.1 Types of pollution control dams

Table 4.1 summarises the various types of PCDs, together with the primary functions and operational philosophy of each. These PCD types are covered in more detail in the sections below.

Note that a mixture of PCDs could be present on a mine and that PCDs may serve several functions. It is however recommended that the primary function of each PCD on a mine is identified, so that the PCD can be operated and managed accordingly.

Table 4.1: Summary of types of PCDs

No.	PCD type	Primary function	Operations
1	Process water/return water dams	Temporary storage of dirty water within the process water system	• Operate at a level to accommodate dirty water inflow, less outflow and losses and required freeboard • Divert clean Storm Water away from dam as far as practically possible • Return of dirty water to the process water system
2	Storm water dams	Retention of dirty Storm Water runoff	• Operate empty or at a storage level to accommodate Storm Water inflows, whilst meeting the required spillage frequency and freeboard requirements • Dynamically manage water quality; return of Storm Water to the process water system or release if water quality meets authorisation conditions
3	Evaporation dams	Storage and evaporation of dirty water	• Operate at a level to accommodate dirty water inflow, less losses (primarily evaporation) and required freeboard • Water generally not reused in the process water systems or discharged

4.1.1 Process water and return water dams

Process water dams typically serve as temporary storage facilities for dirty water within the mine and contain buffer capacity for surge or excess process water and/ or additional impacts within the process water circuits. These dams often perform a flow balancing or equalisation function. Process water dams are operated from a water conservation perspective in that the retained water is incorporated into the site water balance by returning to the process water systems where appropriate (e.g. as cooling water, make-up water or water for washing or solids transport). Treatment of the water may or may not be required.

It is important to ensure separation of process water dams from mine Storm Water systems, wherever practically possible. Process water dams should thus not overflow to internal mine Storm Water systems and Storm Water inflow to process water dams should be minimised.

The storage capacity requirements and potential reuse of the retained water in process water dams should be differentiated depending on the water quality. The management of these dams should also, as far as practically possible, be according to the different quality of the retained water.

The size, location and water quality of process water dams will be dependent on the water management and reticulation systems that apply on the mine.

Process dams may also include impoundments that are used for the storage of excess water from open pits or underground shaft dewatering. This water may be contaminated and may require dedicated collection and handling.

4.1.2 Storm water dams

Storm water dams serve as the receiving bodies for storm water run-off from dirty water systems on the mine site. Storm water dams should be dynamically managed, based on the water quality. Thus, where appropriate, water retained in the storm water dam may be returned to the process water systems. Alternatively, the water may be discharged if the water quality meets the water use authorisation conditions.

storm water dams should be linked into the overall mine water management strategy. Where possible, the design and operations of storm water dams should be differentiated depending on the different storm water qualities.

The design and operation of storm water dams must comply with the legal requirements, including the assessment of the required dam capacity, the location of the dam and the spillage frequency. These dams should, as far as practically possible, receive storm water inflow only and should be separated from spillage and/or process water inflow from the plant and other sources, which are likely to have different water qualities.

It is important to minimise, where possible, the catchments providing runoff into storm water dams. This can be achieved by locating storm water dams close to the source of dirty water runoff or through the use of diversion berms.

storm water dams should at all times be operated empty or at a storage level to accommodate storm water inflows whilst meeting the required spillage frequencies. The retained water in storm water dams should thus be removed as soon as possible after each storm event to achieve the design storage levels.

The design of storm water dams should consider the full life of the mine project, including potential expansions of the mine as well as future roofing and/or paved areas that could affect the storm water runoff quantity and quality. In addition, it is important to consider that storm water runoff often contains high sediment loads. This should be catered for in the design and operations of storm water dams, through the use of appropriately sized and located silt traps.

4.1.3 Evaporation dams

These dams are normally specific in design and function and may serve as a dedicated intervention to achieve a

Figure 4.2: Typical evaporation dam

desired water balance. Water which cannot be discharged to natural watercourses or recycled in the mine water processes may also be evaporated in these dams.

The use of evaporation dams in the mine water circuit should be avoided where possible. These dams should be seen as a last resort, as the operation of such dams does not comply with the principles of water conservation. Evaporation dams are typically the final step in water treatment as there is no water reuse from the dam.

Evaporation dams have an inherently high potential for impact on the water resource, either through seepage or spillage. These dams should thus be subject to stringent design, operational, maintenance and management conditions. Figure 4.2 shows an example of a typical evaporation dam.

4.1.4 Natural storage areas

Natural storage areas (e.g. pans and wetlands) have a high conservation value. Best practice is thus to manage these natural areas in a sustainable manner. The use of these areas as PCDs may therefore incur undue environmental liability. It is therefore not considered best practice to use natural storage areas for pollution control measures, unless this approach is justified through appropriate studies, research and economic evaluations, based on site-specific conditions.

4.2 Design and operational philosophy

The design of PCDs on a mine should meet the following broad requirements:

- PCDs should be appropriately sized to meet the requirement of Government Notice No. 704 in terms of spillage frequency. These requirements are described in Appendix A
- PCDs should adhere to the relevant dam safety criteria, based on the safety risk classification of the dam. This includes appropriate design and assessment of:
  - Geotechnical conditions at the dam site
  - Slope stability
  - Seepage analysis, and
  - Construction requirement, including the material selection for the dam wall
- PCDs should safely accommodate the appropriate design floods, based on the safety risk classification of the dam
- PCDs should be provided with a suitable liner system to limit/prevent contaminated seepage from entering the local groundwater system and/or the surface water catchments
- Appropriate water flow and water quality monitoring measures must be designed, implemented and audited in all PCDs so as to ensure effective water balance systems and the management of water on a mine.

5

LEGAL FRAMEWORK

5.1 Overview of legal requirements

Appendix A provides details of the legal requirements for water management on a mine within the prevailing mining, water and environmental legislation in South Africa. The following provides a summary of the principle legal framework for PCDs:

- National Water Act, 1998 (Act No.36 of 1998) stipulates that a water use authorisation or written authorisation must be obtained from the Regional Director of the relevant region, before construction of a PCD may commence. Some guidance on a water use authorisation application is given below.
- Government Notice No. 704, National Water Act, 1998 (Act No. 36 of 1998) dealing with regulations on use of water for mining and related activities aimed at the protection of water resources. Specific attention is drawn to the following pertinent regulations under this notice:
  - Regulation 2: Information and notification
  - Regulation 4: Restrictions on locality
  - Regulation 5: Restrictions on use of material
  - Regulation 6: Capacity requirements of clean and dirty water systems
  - Regulation 7: Protection of water resources
  - Regulation 8: Security and additional measures
  - Regulation 9: Temporary or permanent cessation of a mine.
- The Dam Safety Regulations (published in Government Notice R. 1560 of 25 July 1986) requires that every PCD with a safety risk shall be classified in accordance with regulation 2.4 on the basis of its size and hazard potential. An authorisation application and approval from the dam safety office is required before construction of a PCD commences.
- National Environmental Management Act, 1998 (Act No.107 of 1998) requires that an environmental impact assessment (EIA) must be carried out before the construction of a new PCD or the raising or re-construction of an existing PCD will be authorised.
- Mineral and Petroleum Resources Development Act, 2002 requires that an environmental impact assessment be undertaken for a mine, which will include PCDs. The EIA will include a scoping report and an environmental impact assessment report.

Although not legally binding, the Minimum Requirements for Waste Disposal by Landfill (DWAF, 1998) provides guidance on the design of various liner systems for various types of waste disposal sites and the design of monitoring systems.

5.2 Guidance for legal compliance

5.2.1 Dam safety

Legislation requires that an owner intending to build a new dam with a safety risk, or to enlarge or alter an existing dam with a safety risk, shall, after completion of the feasibility studies for the proposed project apply to have the dam classified. Table 5.1 provides the category classification of dams with a safety risk. This is based on the size of the dam and the hazard potential rating of the dam. The safety classification is used as a means to manage the risk of failure of PCDs. There is thus differentiation between Category I dams and Category II and III dams in terms of:

- The level of detail required in the authorisation application and in operation and management of the dam, and

- The level of expertise required for design; for Category II or III dams, the services of an approved professional person/engineer (APP) must be obtained.

For classification purposes, the owner should at least know the locality of the new dam, proposed height and storage capacity of the reservoir.

Legislation does not prescribe who should design Category I dams. The owner can design the dam or use the services of an engineer, technician or contractor. "A permit to construct" must be obtained before construction may commence. A minimum amount of information is required for consideration of this permit. No control measures with respect to quality control during construction of the dam are prescribed and a "permit to impound" is also not required.

Failure in the case of a Category I dam should not expose lives to danger and minimal economic losses are incurred by third parties. Dam owners are however advised that further development downstream of a dam can lead to reclassification of the dam to a higher category and that higher standards may be required.

The design of Category II and III dams has to be done under the supervision of a professional engineer who has to be approved for the project.

The design drawings, design report and specifications for construction of the dam must be submitted with the application for a "permit to construct". The "content" and issues to be addressed in a design report are specified by legislation. The design report also includes results of design calculations, and evaluations of data used.

Table 5.1: Category classification of dams with a Safety Risk

Size class	Hazard potential rating		
	Low	**Significant**	High
Small	Category I	Category II	Category II ....
Medium	Category II	Category II	Category III ....
Large	Category III	Category III	Category III ....

5.2.2 Legal requirements for PCDs

Table 5.2 summarises the authorisation requirements for PCDs and provides guidance on the application procedures for these authorisations. It is important that the owner of a PCD liaise with the appropriate government departments, including DWAF, DEAT and DME, to ensure that all legal requirements for licensing of a PCD have been complied with.

Table 5.2: Summary of legal requirements for PCDs

Applicable Act	Section	Legal requirements	Guiding notes
National Water Act, 1998 (Act No.36 of 1998)	21	21(c) impeding or diverting the flow of water in a watercourse 21(f) discharging waste or water containing waste into a water resource through a pipe, canal, sewer, sea outfall or other conduit 21(g) disposing of waste in a manner which may detrimentally impact on a water resource 21(i) altering the bed, banks, course or characteristics of a watercourse.	A section 21 (g) water use authorisation is the primary authorisation that is required for all PCDs. This includes compliance with Regulation No. 704. A section 21(f) water use authorisation is required if discharge is envisaged from the PCD. Section 21 (c) and (i) authorisations are required if local or regional Storm Water diversion schemes are envisaged, as part of the development of the PCD. The water use authorisations, and the application therefore, are combined into an Integrated Water Use Authorisation for the mine.

Applicable Act	Section	Legal requirements	Guiding notes
The Dam Safety Regulations (published in Government Notice R. 1560 of 25 July 1986)	9C of the NWA	Classification of the dam Approval to construct a PCD	Use form DW 692E For Category I dams, use form DW 694E and submit construction drawings For Category II and III dams, the APP must apply for a authorisation to impound (this involves the submission of an operation and maintenance manual and emergency preparedness plan together with an application form DW 696E)
Environment Conservation Act (ECA), 1989 (Act 73 of 1989)	Gov Notice R1182 and R1183	Environmental impact assessment (EIA)	The EMP and EIA processes for licensing of a PCD on a mine site should be integrated
Mineral and Petroleum Resources Development Act, 2002 (Act No. 28 of 2002)	39, 48, 49, 50	Environmental management programme or plan (EMP) and environmental impact assessment (EIA)	

6 DESIGN OF POLLUTION CONTROL DAMS

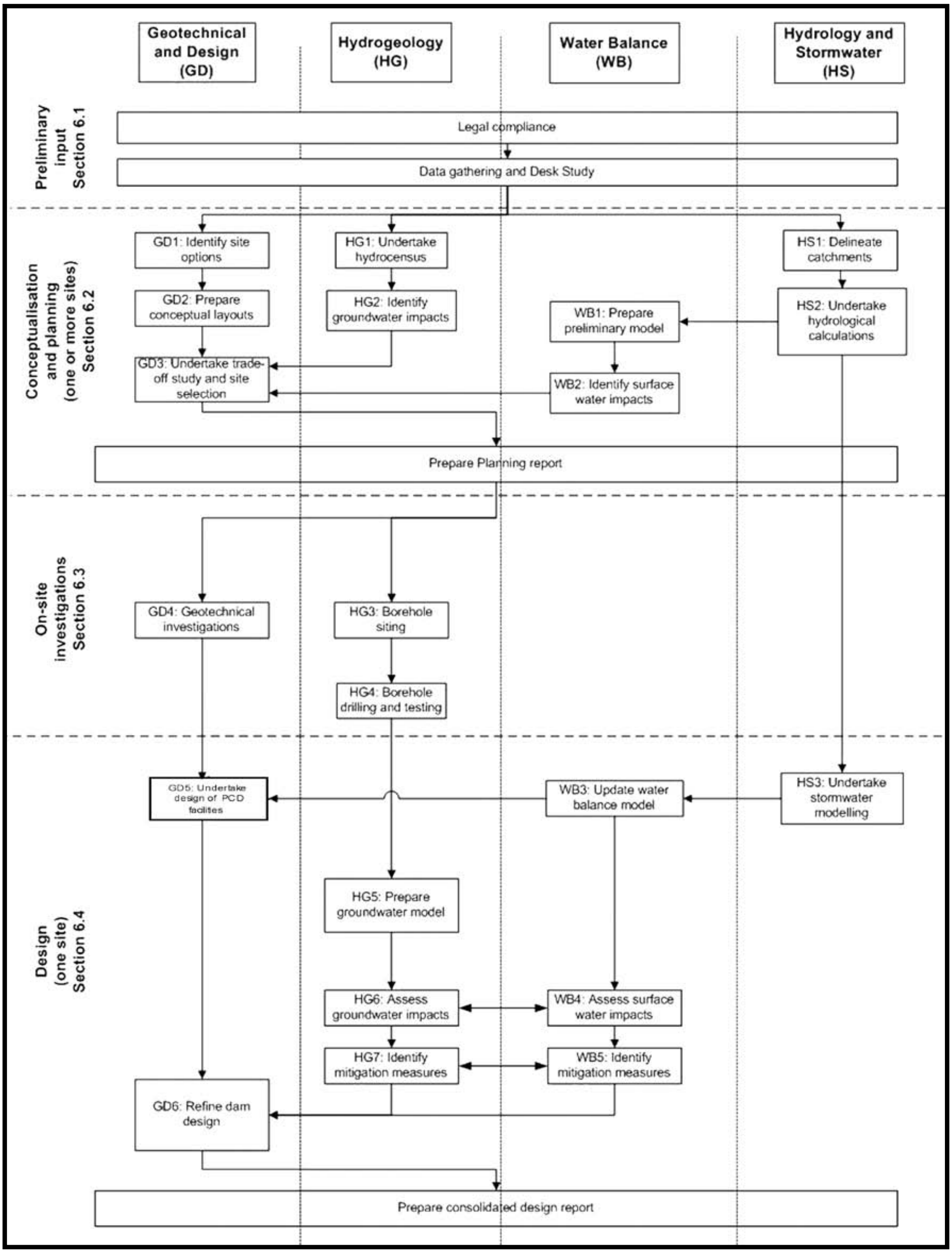
The design for PCDs includes the various tasks and activities set out on Figure 6.1. The design of PCDs is site-specific, and should thus include addressing some or all of the tasks indicated in Figure 6.1, over the various phases, in an interrelated manner. These include:

- Geotechnical assessments and dam design
- Hydrology and Storm Water design
- Dam water balance
- Hydrogeological assessments
- Authorisations.

The various steps identified in Figure 6.1 are described in the sections below, as follows:

- Section 6.1: Preliminary input
- Section 6.2: Conceptualisation and planning
- Section 6.3: On-site investigations
- Section 6.4: Design

Figure 6.1: Task/activity flow for PCD design



6.1 Preliminary input phase

6.1.1 Legal compliance

All necessary authorisations, as covered in Section 5 above and in Appendix A, must be obtained **before** construction of a PCD can commence.

6.1.2 Data gathering and desk study

Table 6.1 indicates the likely information requirements for the subsequent design phases. The likely output of this phase will be a desk study report which will:

- Summarise the available geotechnical, hydrological, water balance and hydrogeological information
- Identify gaps in the information, and
- Provide input and guidance to subsequent design phases.

6.2 Conceptualisation and Planning phase

Figure 6.2 indicates the various tasks that are likely to be undertaken during the conceptualisation and planning phase.

The conceptualisation and planning phase provides an opportunity to consider a wide range of options before a commitment is made to follow a particular option.

6.2.1 Geotechnical and Design (GD)

Step GD1: Identify site options

The objective of the site selection process is to identify the most appropriate site for the development of a PCD. The site selection should adhere to the general principles given in Section 2 as well as the philosophy for water management covered in Section 4 above. In general, the site selection for a PCD will be made on the basis of:

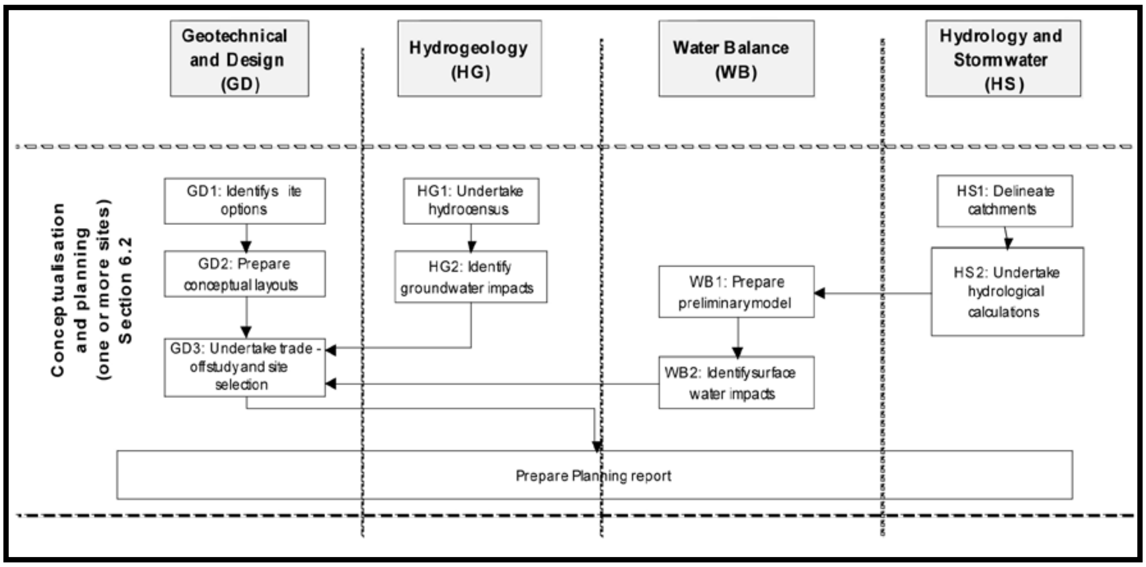
- Technical viability
- Economics (development, construction and operation costs), and
- Environmental impact.

Various options for the siting of the PCD should initially be made, based on the above criteria. A preliminary assessment of the storage requirements will be needed to identify likely locations for the PCD.

Table 6.1: Information requirements

Design area	Information Requirements
Hydrology and surface water	• Climate data: Patterns of temperature, rainfall, evaporation and atmospheric moisture for the area • Reports, documents and maps on hydrology • All available river flow data • Surface water quality information.
Water balance	• Reports and document on the mine water balance • Water flow and water quality measurements or predictions • Possible flows to and from the PCD • Ambient water qualities
Geotechnical	• Reports and documents on the geology and geotechnical conditions for the area
Hydrogeology	• Published and unpublished geological and hydrogeological reports, maps and documents • Boreholes positions and logs • Details of groundwater abstractions and groundwater users in the area • Conceptual and/or detailed groundwater model • Recharge estimations • Groundwater quality information
General	• Archaeological sites within the mine area • Wetlands and ecologically sensitive areas

Figure 6 .2: Tasks in the conceptualisation and planning phases



The conceptualisation and planing phase provides an opportunity to consider a wide range of options before a commitment is made to follow a particular option.

Step GD2: Prepare conceptual layouts

Conceptual layouts of the PCD at the various site location options should be prepared. These conceptual layouts should include the layout of the dam(s) on the available topographical information and a typical cross-section through the dam wall showing height of wall and likely construction method.

Step GD3: Undertake trade-off study and site selection

The preliminary water balance (WB) and hydrogeological (HG) studies will provide input into the trade-off study. This trade-off study is likely to be on a semi-quantitative basis and should assess the following:

- The cost for each PCD location, at a conceptual level of detail
- The technical issues associated with each location, and
- The potential environmental impacts associated with each location, including potential impacts on archaeological sites, any wetland areas and/or other ecologically sensitive areas.

The trade-off study will identify which location (or locations) for the PCD to take forward to the on-site investigation phase.

6.2.2 Hydrogeology (HG)

Step HG1: Undertake hydrocensus

A hydrocensus may have been undertaken as part of the EMP for the mine. This may need to be reviewed/ updated for the PCD. In this case, the design team will undertake a hydrocensus of all existing boreholes, dug wells and springs within the project area. The following information should be collected during this hydrocensus:

- Survey co-ordinates
- Owner
- Existing borehole equipment
- Current water use
- Reported yields (historical and current)
- Reported or measured depth
- The static water level, and
- Groundwater quality.

Step HG2: Identify groundwater impacts

If applicable for the PCD, the design team will use the results of the desk study and the hydrocensus to identify the potential groundwater impacts for each PCD location. Such impacts may be, amongst others:

- The impact on downstream water users
- Impacts on sensitive or protected areas
- Impacts on any open-cast or underground workings, shafts or occupied premises;
- Geological structures
- Effects of seepage, and/or
- Groundwater quality impacts.

In particular, potential fatal flaws in terms of groundwater impacts for each site location should be identified at this stage. Additionally, where the seepage water quality is not known for certain, conservative assumptions should be used in making the assessment.

The groundwater impacts identified as part of this step will be used in the trade-off study and site selection (Step GD3).

6.2.3 Hydrology and Storm Water (HS)

Step HS1: Delineate catchments

The determination of the catchments that need to be investigated, and the collection and routing of run-off, requires a base map. The base map should include the following information:

- 1 in 1000 to 1 in 5000 scale topographical map with 1m or 2 m contours. An aerial photograph as a background to the topographical map should also be considered
- The location of the rivers and streams
- The 100 year flood lines marked on the map, if available
- The mine lease area and mineral right boundaries
- The locations of the current and/or proposed mining and other general infrastructure. The infrastructure may include the office complex, plant/workshops, waste disposal facilities, product loading areas, mine shafts and mine workings
- Archaeological sites, and
- Any wetland areas or ecologically sensitive areas that may need to be considered in the development of the mine water plan.

The base map will be used to identify catchment areas whose runoff is considered to be “clean” and “dirty”. The areas that are typically considered to be “dirty” are:

- The plant/workshop areas
- The waste disposal facilities
- The product loading areas and
- The areas around the mine shafts and the mine workings.

The runoff from areas that are typically considered to be “clean” are:

- Office and administration areas
- Residential and social facilities, including mine villages, sports fields, golf courses, etc and
- Areas that are not impacted by mining.

Care should be taken in assessing the clean areas in and around the offices, as these areas can often be impacted by mining operations, e.g. impacts of wind-blown contaminants.

Additional guidance on this process can be obtained in *BPG G1: Storm Water Management*.

The runoff from the “dirty” areas must be captured, retained and managed within the mine water systems. The use of diversion berms and channels and PCDs are the typical methods used to manage the runoff. The berms and channels are used to isolate the dirty areas so as to:

- Prevent the runoff from the “clean” areas from entering the dirty areas, and
- Ensure that the dirty runoff enters the PCD.

Every effort should be made to maximise the clean area and minimise the dirty area when locating the PCDs and the diversion berms and channels. In the case of a new mine, the maximisation of the clean areas should influence the location of the mine infrastructure.

The recycling or reuse of the runoff and seepage water collected in the PCDs should be considered. The uses are typically dust suppression, irrigation of rehabilitation, re-use in the plant and/or the mine. The size and frequency of the abstraction for reuse will depend on the water use within the site wide water balance.

Step HS2: Undertake hydrological calculations

The sizing of the berms and the PCDs are governed by Regulation No. GN 704 of the National Water Act (1998). The size of the berms must be able to convey the 50 year flood peak without overtopping while the PCD must only spill on average once in 50 years. These two requirements need different hydrological considerations.

The determination of the 50 year flood peak for the sizing of the berms requires the application of standard flood peak calculation procedures such as :-

- Rational method: The rational method is suitable for most catchments that will be found on mine complexes. Calculation sheets have been developed for estimating the rational C factor that is needed for the calculations
- The application of kinematic rainfall-runoff models can be considered, depending on the level of detail required. Typical models include Hydrosim and PC-SWMM. These computer programmes are useful in that the diversion berms and channels can be included in the model and used for the preliminary sizing of the channels
- The Regional Maximum Flood (RMF) (Kovacs, 1988) empirical approach can also be applied. The 50 year flood peak can be determined using the factors relating the RMF peak to the 50 year flood peak.

Further details on the methodology to calculate flood peaks are covered in *BPG G1: Storm Water Management*. Details on the required input data are given in Technical Box 1

Technical Box 1: Calculation of flood peaks

The rational method and the kinematic rainfall-runoff models require short term rainfall as input. The following sources of rainfall data can be considered for use in these methods:

- The use of regional intensity-duration-frequency (IDF) rainfall curves. IDF curves have been developed for South Africa by Op Ten Noort (1987). These curves are used in the Hydrosim kinematic rainfall-runoff model
- The use of the rainfall information given in Adamson (1981). The 50 year 24 hour rainfall depths are given in Adamson (1981) together with factors to convert the 24 hour storm depths to shorter duration storms. This analysis is now dated with some 25 years of additional rainfall data available since the original analysis was undertaken
- The Weather Bureau runs a network of rain gauges which collect data at a daily time step. The daily rainfall data from nearby rain gauges can be analysed statistically to determine the 50 year recurrence interval 24 hour rainfall depth. The factors given by Adamson (1981) can be used to convert to shorter duration rainfall events that will be needed to compute the flood peak

6.2.4 Water Balance (WB)

Step WB 1: Prepare preliminary model

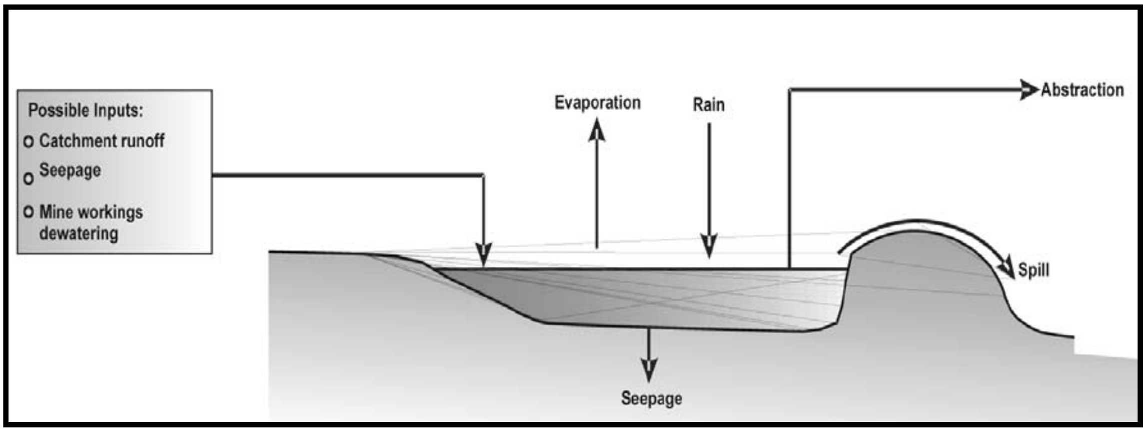
The design team will prepare a preliminary water balance for the PCD, which should be integrated into the overall mine water balance. Full details on setting up a mine water balance (as well as a water balance for a PCD) are included in *BPG G2: Water and Salt Balances*. The pathways that should be considered in developing the PCD water balance are shown in Figure 6.3. Typical inputs to the PCD can include:

- Catchment runoff
- Water delivered to the dam from the process water circuits
- Seepage from the groundwater or from the residue deposit, if the PCD is a return water dam,
- Rainfall.

Typical outflows from the PCD can include:

- Abstraction for reuse in the process water circuit
- Spillage
- Evaporation
- Seepage to the groundwater.

Figure 6.3: Pathways to consider in a PCD water balance



Step WB2: Identify surface water impacts

The design team will use the preliminary water balance to identify the potential surface water impacts for each PCD location. Such impacts may be, amongst others:

- The impact on downstream water users
- Impacts on sensitive or protected areas
- The requirements for Storm Water management for each of the delineated catchments, and/or
- Surface water quality impacts.

In particular, potential fatal flaws in terms of surface water impacts for each site location should be identified at this stage.

The surface water impacts identified as part of this step will be used in the trade-off study and site selection (Step GD3).

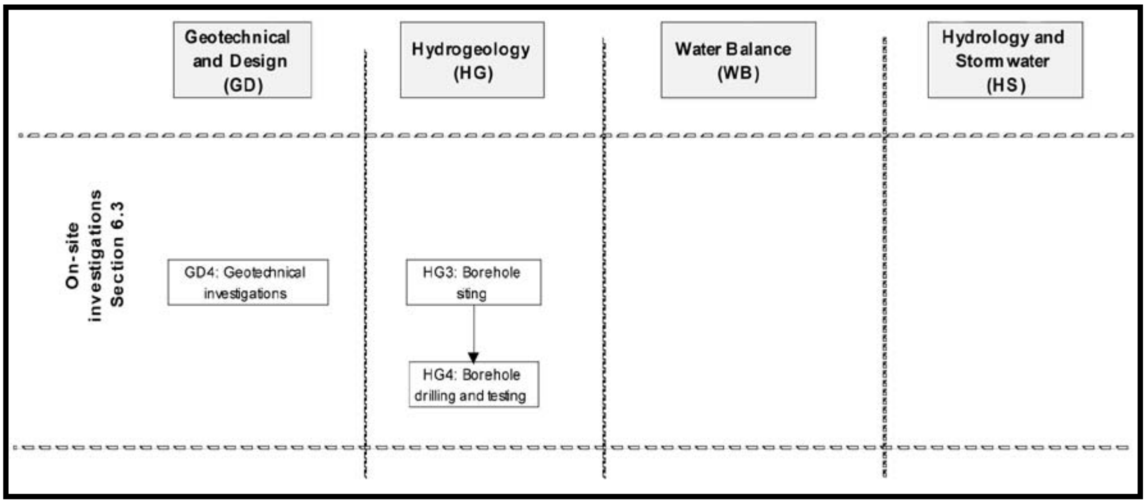
6.2.5 Planning Report

The output from the conceptualisation and planning phase will be a Planning report for the PCD. The report should include all the assumptions, parameters and alternatives considered and the justifications and reasons for the final site selection(s).

6.3 On-site investigations

Figure 6.4 indicates the various tasks that are likely to be undertaken during the on site investigations phase.

Figure 6.4: Tasks in the investigation phase



6.3.1 Geotechnical and Design (GD)

Step GD4: Geotechnical investigations

The extent and complexity of the geotechnical investigations required for a PCD will depend on the level of detail available and the site-specific nature of the location(s) of the PCDs. The geotechnical investigations should provide the design team with the following information for design:

- A general description of the nature of the sub-soil conditions at the PCD site,
- Details on the permeability and compaction of the sub-soils, particularly at the dam wall location
- The depth to bedrock at the dam wall location
- Recommendations on dam wall construction material and the source thereof.

6.3.2 Hydrogeology (HG)

Step HG3: Borehole siting

Boreholes may be required in strategic locations in the vicinity of the PCD, to obtain information on the groundwater regime. Borehole siting should be undertaken based on the following suggested steps:

- Stereo pair air photography interpretations and/or use of geological mapping to identify geological structures in and around the site which could act as preferential groundwater flow paths
- Site walk-over, and
- A geophysical survey around the proposed PCD to delineate any features identified from the air photo interpretation, as determined by a suitably qualified person. This survey may comprise frequency domain and magnetic techniques, supported by electrical resistivity, gravity or other applicable technique as warranted.

Step HG4: Borehole drilling and testing

The drilling of exploratory/test/monitoring boreholes may be required, unless sufficient information is currently available. The depth of the boreholes will be controlled by the depth of the water table and prevailing hydrogeological conditions. Additional details on borehole drilling and testing can be found in *BPG G3: Water Monitoring Systems*.

Boreholes must be positioned to ensure sufficient data are gathered to gain a thorough understanding of the hydrogeological situation, including correct definition of the groundwater flow mechanism in and around the site. The drilling of a sufficient number of boreholes to gain this understanding is therefore essential.

The boreholes should be completed for incorporation into the groundwater monitoring network, as appropriate.

Short term testing of the boreholes to gain an understanding of the aquifer hydraulics should be undertaken. The hydraulic parameters determined from the test data provide essential inputs to the numerical flow and solute transport model.

Samples should be collected from the newly drilled boreholes and submitted together with any samples collected during the hydrocensus to an accredited laboratory for analysis. The water samples should be analysed for the key water quality parameters relevant to the site-specific conditions, the mine EMP and the water use authorisation conditions.

The data should be included with any available existing chemical data and used to prepare the baseline groundwater quality assessment against which potential future impacts can be measured

The output of these hydrogeological investigations will be a characterisation of the prevailing hydrogeological situation around the preferred site, including:

- Determining the occurrence and depth of aquifers under and surrounding the site
- The depth to the static water level
- The groundwater flow network
- Identification of geological structure that could act as preferential flow paths for the movement of groundwater away from the site
- Assess where seepage will flow, and
- Determination of the baseline groundwater quality.

6.4 Design phase

Figure 6.5 indicates the various tasks that are likely to be undertaken during the design phase.for PCDs.

6.4.1 Geotechnical and Design (GD)

Step GD5: Undertake design of PCD facilities

The design phase for PCDs will utilise the information gathered in the conceptualisation and planning phase, together with the details for the on-site investigations. This phase will include the design of:

- The PCD wall, and the stability thereof
- The dam spillway
- The dam liner system
- Underdrainage and seepage control
- The pumps and pipelines, and
- Sediment management for the dam.

Details for these design aspects are provided below.

Dam wall design and stability analysis

The design team should consult recognised dam design manuals and handbooks for the dam wall design and stability analysis.

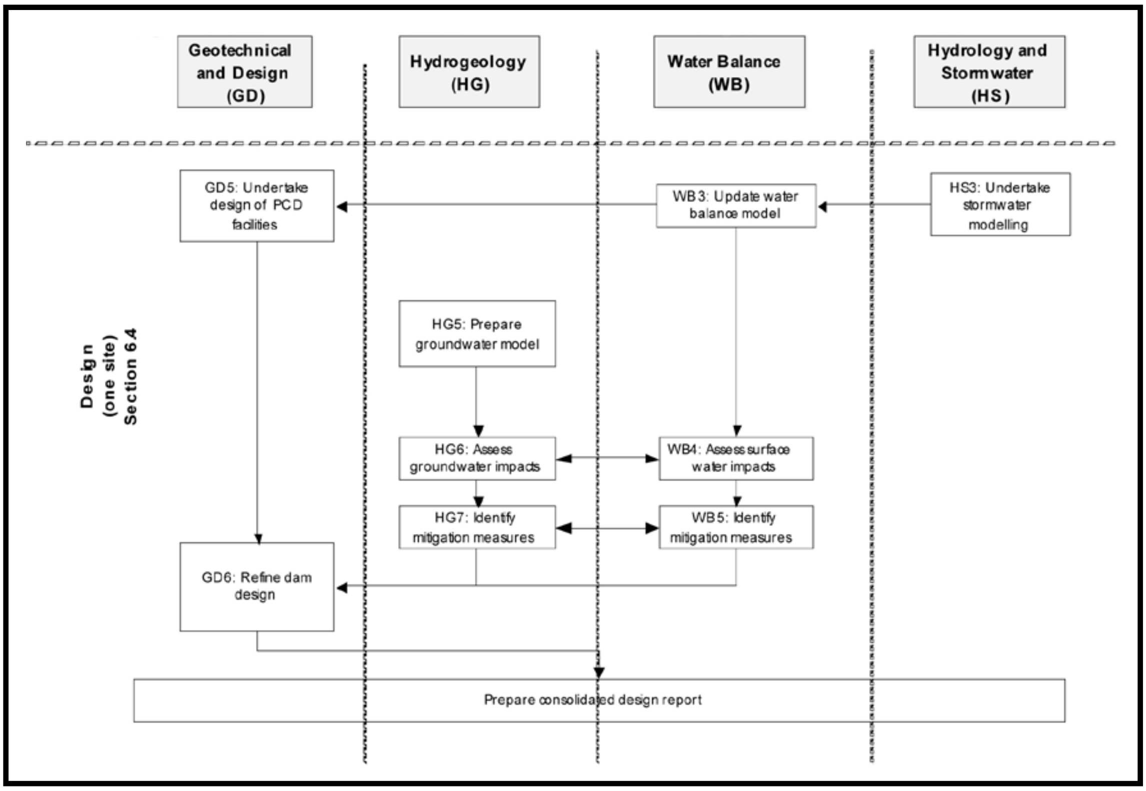
Figure 6.6 shows a typical example of an earth embankment for a PCD with upstream scour protection.

Spillway design

Spillway design should be based on the guidelines provided by the International Committee on Large Dams (ICOLD), as well as those provided by the South African National Committee on Large Dams (SANCOLD). The ICOLD has 85 member countries of which South Africa is one. South Africa is represented on ICOLD as the SANCOLD.

ICOLD produces guidelines in the form of bulletins which are used by the member countries to develop their own standards for use in their countries. SANCOLD has developed a set of standards for use in sizing spillways and calculating the free board. The SANCOLD standards

Figure 6.5: Tasks in the design phase



should be used to address the safety aspects of PCDs. The following design floods are applicable:

- The Recommended Design Flood (RDF) is the flood that the spillway must be able to pass with the required free board, and
- The Safety Evaluation Flood (SEF) is the flood peak that the dam must be able to handle without failure i.e. the dam can be damaged and require repair but the dam must not fail.

Extreme events could overtop the dam and cause a failure of the wall. This risk is managed by an appropriately sized and designed spillway with adequate free board to pass the RDF. The dam must also be sized not to fail during the SEF. The selection of the RDF and SEF are based on the height of the dam wall and the risk of flood damage downstream (hazard rating and dam category). The criteria are given in Table 6.2. Figure 6.7 shows the definition of freeboard.

Figure 6.6: PCD earth embankment with upstream scour protection

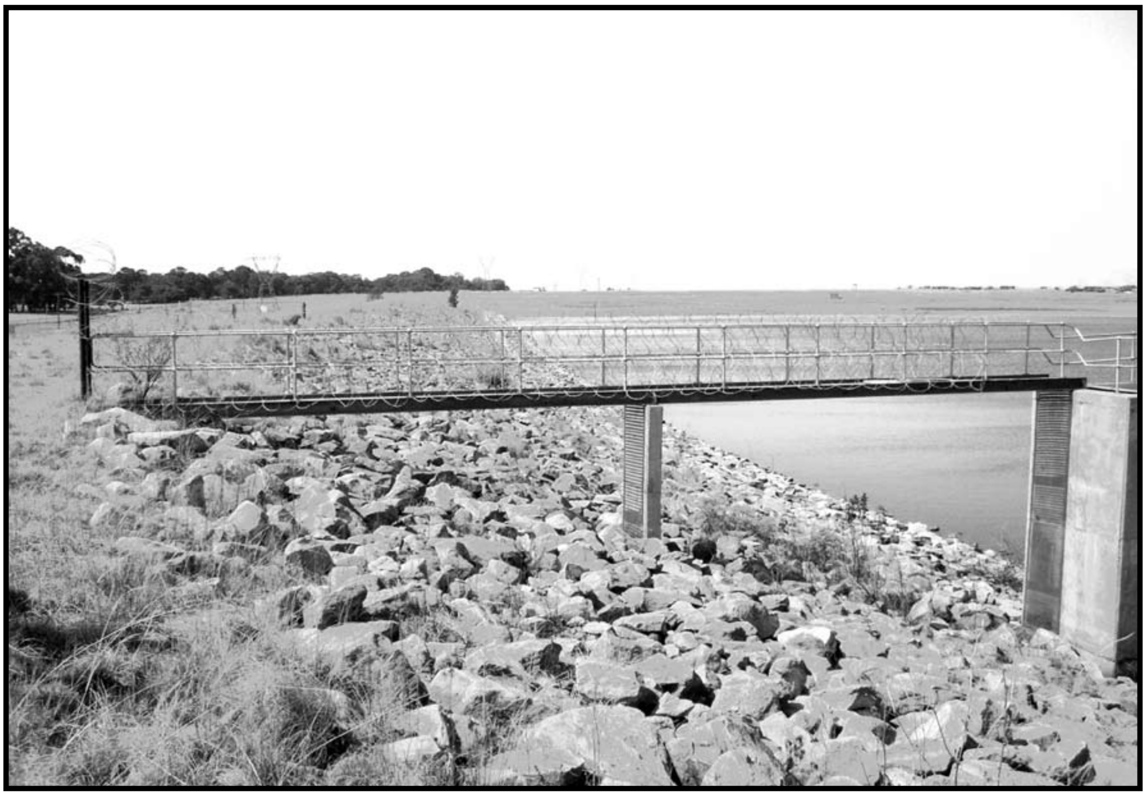
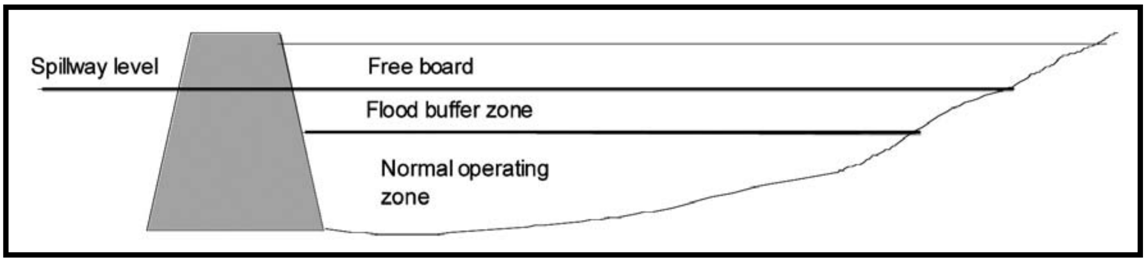


Table 6.2: Recurrence interval flood peaks for the RDF and SEF

Dam size	Hazard rating		
	Low	Significant	High
Small (5 m to 12 m high)	RDF 20 to 50 year SEF 100 year	RDF 100 year SEF 200 year	RDF 100 year SEF RMF
Medium (12 m to 30 m high)	RDF 100 year SEF 200 year	RDF 100 year SEF RMF	RDF 200 year SEF 1.3 RMF
Large (> 30 m)	RDF 200 year SEF RMF	RDF 200 year SEF 1.3 RMF	RDF 200 year SEF 1.7 RMF

Figure 6.7: Definition of freeboard



The dam freeboard, starting at the dam full supply level, is the greater of:

- The height of the RDF over the spillway plus wind and wave run up plus wind set up and surges
- Earthquakes, or
- The height of SEF over the spillway with no dry free board.

PCD liner system

The purpose of a lining system in a PCD is to minimise leakage of polluted water from the dam that could result in contamination of groundwater resources. It is important to note that a liner system will not be completely impervious.

The principle inherent in the design of a liner system is to minimise the rate of seepage into the unsaturated soil and rock layers beneath the dam, by providing an engineered layer (or layers) with low permeability. A lining system is required for a PCD for the following conditions:

- If the contained water is of such poor quality that it could have an unacceptably high polluting impact on the receiving water environment
- If the PCD overlies a groundwater resource of a strategic nature
- If the hydraulic conductivity of the in-situ soils and rock beneath the dam is sufficiently high that would allow seepage of polluted water to reach and pollute the aquifer.

For design purposes, determining the pollution potential of the PCD requires information regarding the concentration and chemical properties of the pollutants in the dam and the resultant hazard rating of the contained polluted water body.

The design of the liner system is based on the "Source – Pathway – Receptor" approach. This involves the following:

- Source characterisation of the contained polluted water
- Identification of the various water users within an agreed radius of the dam. This information will be provided from Step HG1: Hydrocensus
- Identification of the various flow pathways from the dam to the receiving water environment, and quantification of hydraulic conductivities
- Undertake a risk based approach to evaluate the effects of possible contaminants on the receiving environment. The risk assessment must ensure that the impact of the polluted water from the dam on the receiving environment is within acceptable risk levels. For the specific categories of water users in the receiving environment, the water quality at the

receptor must meet the Target Water Quality Ranges (TWQR) as detailed in the Department's "South African Water Quality Guidelines".

This method should be used to determine the effectiveness of different lining systems and under-drainage requirements with the use of appropriate leakage rates and permeabilities.

Additional details on the types and design of liner systems are provided in Technical Box 2 and in the Minimum Requirements for Waste Disposal by Landfill (DWAF, 1998).

Technical Box 2: Guidance for the design of liner systems

The lining system for a PCD can consist either of a natural geological liner, an engineered liner using natural and/or synthetic material or a combination of both systems. Natural liners are appropriate where the in-situ soils meet the required specifications. Alternatively, an engineered liner may be used.

Natural geological liners are appropriate when the hydraulic conductivity of the formation soils or rocks are sufficiently low that the rate of seepage is reduced to an acceptable value. Generally mass permeability values of less than $1x10^{-8}$ m/s are required. Fractures in and heterogeneity of the foundation soils are the main concerns. Typically natural geological liners would be used without an engineered liner, where the PCD contents represent an insignificant risk to the groundwater.

Engineered liners may either be a) an engineered low permeability clay liner, b) a geosynthetic clay liner (GCL), c) a geomembrane liner, or a combination of these barrier components.

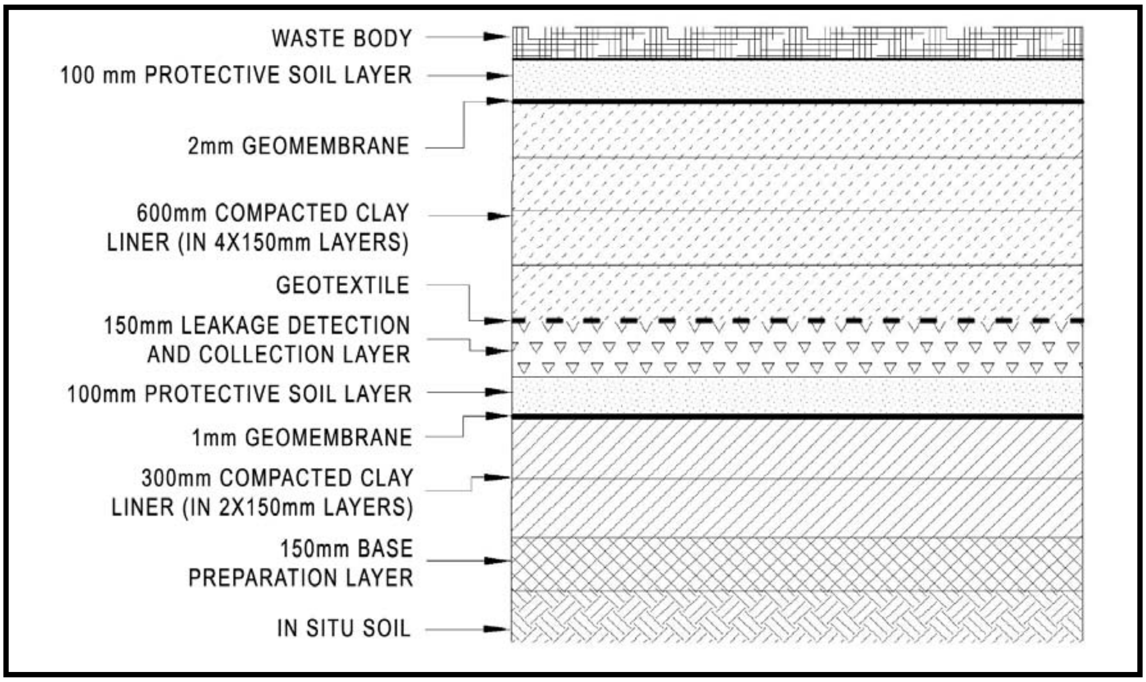
Compacted clay or low permeability soil liners may be used to form a core in the dam wall or to line the impoundment basin of the PCD. However, any soil used for a compacted soil liner must have a minimum Plasticity Index (PI) of 10 and a maximum that will not result in excessive desiccation cracking. The maximum particle size must not exceed 25 mm, and the soil shall not be gap-graded. Clay liners must be compacted to a minimum dry density of 95% Standard Proctor maximum dry density, at a water content of Proctor optimum to Proctor optimum +2%. Admixtures of bentonite or other natural material additives with low hydraulic conductivity may also be considered. Hydraulic conductivity values of less than $1x10^{-9}$ m/s can be obtained. Such liner materials must be checked to ensure that they are not degraded by the chemical properties of the impounded polluted water.

A GCL may be used if the in-situ soil is not suitable for use in a compacted soil liner. A GCL consists of two layers of geotextiles with a thin layer of bentonite powder or granules sandwiched between the geotextiles, and with the geotextiles needle-punched together to contain the bentonite. When the bentonite hydrates it swells within the geotextile containment and forms an almost impermeable barrier. It is important that, when a GCL is used as a liner in a dam, a ballast layer of soil at least 300mm thick is placed over the GCL to provide a confining pressure to the GCL. Rip-rap or other suitable protective layer should be placed over the soil ballast layer in areas of possible erosion, such as the inlet, dam edges, etc. It is also important to check the chemical compatibility of the polluted water with the bentonite in the GCL.

Geomembrane liners can also be used to line PCDs, either on their own, or in a geocomposite lining system with compacted clay or a GCL. The most commonly used geomembranes are High Density Polyethylene (HDPE) and Liner Low Density Polyethylene (LLDPE). These geomembranes have been used extensively in the waste management field and have excellent chemical resistant properties. A minimum thickness of 1.5 mm is recommended for geomembranes. The operative permeability of these liners is compromised by liner defects and expected values are around $1x10^{-12}$ m/s.

Although not very common in South Africa, asphalted liners can also be used to line PCDs. This liner consists of bitumen impregnated soil or a layer of pre-mixed asphalt placed on the dam surface. Permeabilities for asphaltic liners are also governed by defects, and values of around $1x10^{-10}$ m/s can be expected. Figure 6.8 shows typical details of a liner for hazardous waste lagoons.

Figure 6.8: Typical details of a liner for hazardous waste lagoons



Under-drainage and seepage control

The purpose of a drainage system in a PCD is to:

- Improve the stability of the dam wall by lowering the phreatic surface. Unsaturated material is more stable and less mobile (in the event of failure) than saturated material
- Reduce the long term seepage and hence facilitate a reduction in groundwater impacts

The principle inherent in the design of an under-drainage system is to prevent the stability of the slope from being threatened by the presence of the seepage/phreatic surface or to contain seepage that may discharge through the primary liner. The former is achieved by the under drain terminating the lateral migration of the seepage/ phreatic surface before it reaches the slope face.

The information requirements for design are as follows:

- The permeability of the dam wall and foundation materials
- Grading curve of the dam wall materials
- The geometry of the dam wall, and
- For the use of geosynthetic filter fabrics such as geotextiles the susceptibility to blinding by mechanical or chemical means must be determined.

Additional information on the design of an underdrainage system is provided in recognised dam design manuals and handbooks.

Pumps and pipe work

The design of the pumps and pipework for the PCD will be based on:

- The dam water balance and the integration with the mine water balance, and
- The need to recycle and/or reuse the retained water within the mine water circuits.

The dam and mine water balances will generally provide the details required for the design of the pumps and pipelines, including:

- The required water flow rates,
- The location of the discharge points, and
- The pipeline lengths and static heads.

The design of the pumps and pipelines will then follow generally accepted mechanical, electrical and instrumentation design procedures.

During the design, it is important that the design team consider the water quality of the retained water in the PCD, and the potential impact of this dirty water on the pump and pipeline material.

Sediment management

It is inevitable that sediment will be washed into the PCD, since one of the the primary purposes of mine PCDs is to contain polluted run-off from mine and process plant areas. If this sediment inflow is considered to be significant, e.g. in runoff from a coal handling or processing plant, it may be advisable to install a series of silt or sediment traps on the inflow pipeline or channel before the dam. Such sediment traps would typically consist of sedimentation boxes or tanks, which can be isolated from the channel, drained of water, and cleaned out as part of routine plant maintenance.

For large sediment traps, the design should make provision to enable equipment such as a front-end loader or similar machine, to drive into the structure to remove the accumulated sediment. Smaller traps could be cleaned manually using shovels.

Where significant sediment loads are anticipated duplicate sediment removal systems must be designed for PCDs. At least two dams would be used operating in parallel. When one dam needs to have sediment removed, it would be isolated from the inflow, water would be pumped into the adjacent dam, and sediment would be removed by mechanical means. If the dams are lined, care must be taken to prevent damage to the top of the liner system. This could include concrete or block paving over the liner, or a thick layer of sand over the liner.

It is important to note that sediment disposal from a PCD will be a waste management activity and will need to be undertaken according to the appropriate environmental legislation and regulations. Figure 6.9 shows a typical installation with the proximity of the silt trap (item 19) upstream from the return water dam (item 20). Figure 6.10 illustrates a typical layout of a double module silt trap.

Figure 6.9: Typical PCD installation showing proximity of silt trap (item 19) upstream of the return water dam (item 20)

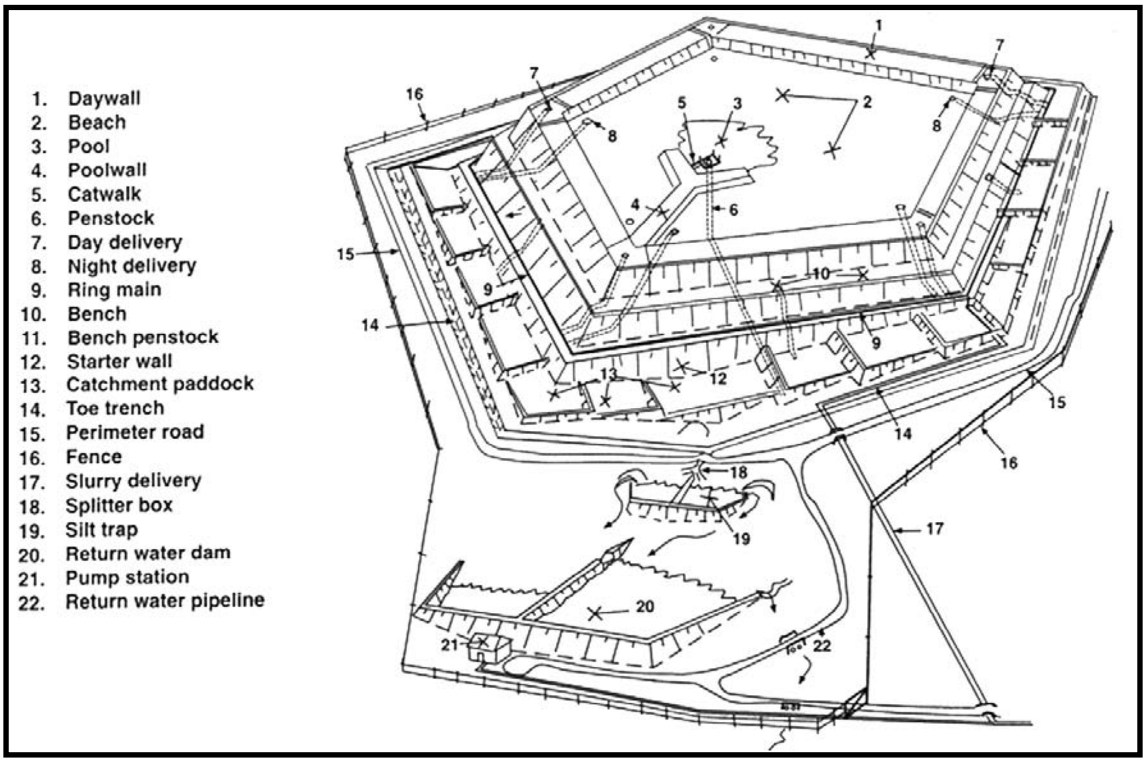
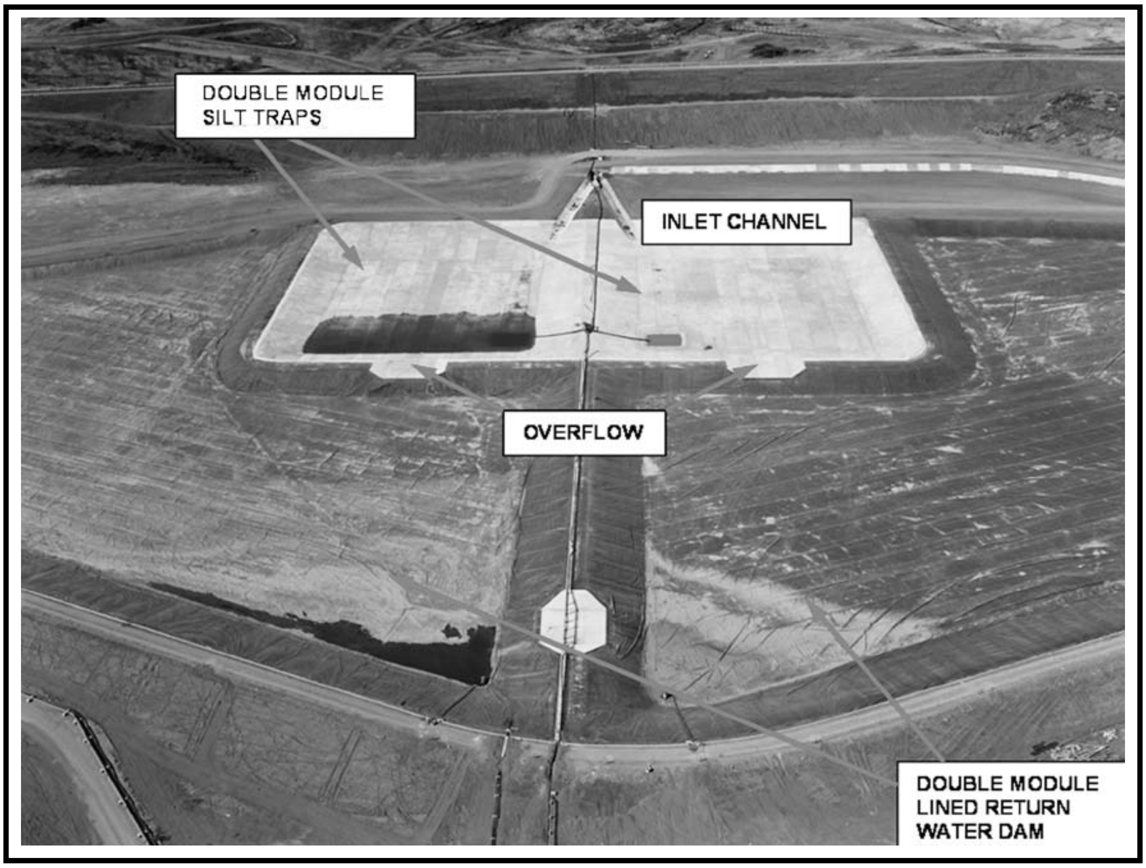


Figure 6.10: Typical layout of a double module silt trap



Step GD6: Refine dam design

The design team will refine the PCD design based on the mitigation measures identified in steps HG7 and WB5. These relate to the management of potential impacts from the PCD on the groundwater and surface water.

6.4.2 Hydrogeology (HG)

Step HG5: Prepare groundwater model

The data collected during this site investigation phase should be interpreted and used, under the direction of a suitably qualified person, to prepare a conceptual model of the dynamics of the groundwater system, including aquifer distribution and groundwater flow directions. The conceptual model provides the basic input to the groundwater modelling.

The potential impact of the PCD on the groundwater system may need to be assessed through numerical groundwater and/or contaminant (mass) transport modelling. A 3-D finite element or finite difference modelling package (such as MODFLOW or FEFLOW) should be used, depending on the complexity of the hydrogeological situation. The models can be used to describe the spatial and temporal distribution of groundwater contaminants, to estimate the duration and travel times of pollutants in aquifers, to plan and design remediation strategies and interception techniques, and to assist in designing alternatives and effective monitoring schemes.

The modelling inputs should include:

- The conceptual model
- Water levels, hydraulic gradients and flow directions
- Quantified aquifer hydraulic parameters
- Groundwater quality
- Site layout
- Surface topography (x,y,z co-ordinates)
- Source term derived from the geochemical modelling.

The first step in the modelling study is the development of a conceptual flow model. This is an idealisation of the real world that summarises the current understanding of site conditions and how the groundwater flow system works. It should include all of the important features of the flow system, while incorporating simplifying assumptions. The conceptual model will rely on the information gathered during the field investigation phase.

Model set–up and calibration often constitute 50% to 70% of the total modelling effort. This entails selecting the model domain, discretizing the model domain, discretizing data in space and time, defining boundary and initial conditions, and assembling and preparing model input data.

Model calibration is the process of varying uncertain model input data over likely ranges of values until a satisfactory match between simulated and observed data is obtained. The measured values may include water levels, rainfall and hydraulic conductivity of the different aquifers which should be used to calibrate the model for steady–state (pre-mining) water levels.

A sensitivity analysis of the input parameters in the model is often required, as there is always uncertainty in the input parameters used in a modelling exercise, mainly because of heterogeneity and the fact that parameters are measured at specific locations which may or may not be representative of the aquifers in general. The results of a sensitivity analysis can be used to:

- Identify sensitive parameters for the purpose of guiding additional field data collection and, perhaps, focussing calibration efforts,
- Define parameters to be used in uncertainty (risk) analysis.

Step HG6: Assess groundwater impacts

The calibrated groundwater flow and contaminant (mass) transport models (where available) will be used to address the objectives of the hydrogeological investigation, including an assessment of the potential groundwater impacts from the PCD. All activities and potential contamination facilities must be taken into account in an integrated manner, and where known, future facilities and activities should be included. The calibrated model should also be used to simulate various scenarios to determine the impact of the PCD on the groundwater system and the need for mitigation measures.

Step HG7: Identify mitigation measures

Various management alternatives, including various mitigation measures, should be generated and simulated using the calibrated groundwater flow and contaminant (mass) transport models. These mitigation measures will be used to refine the PCD design (step GD6).

6.4.3 Hydrology and Storm Water (HS)

Step HS3: Undertake Storm Water modelling

The determination of the size of the PCD so as to only spill once in 50 years requires the application of a continuous model (not single event) at an appropriate (preferable daily) time step. A typical model for a PCD consists of a component that models the sources of the water entering the PCD and the water balance for the dam itself. The sources could be catchment runoff, mine working dewatering or seepage and runoff from waste disposal facilities. The modelling of these sources requires different types of models. The mine dewatering may require a detailed groundwater model (see above) as opposed to a rainfall-runoff model applied to generate the runoff from a catchment. The output from these models can be used as input to the balance for the PCD if required.

Additional details on Storm Water modelling are provided in Technical Box 3 and can be found in *BPG G2: Water and Salt Balances*.

Technical Box 3: Details on Storm Water modelling

The key characteristics of the model needed for sizing a PCD are:

- A daily rainfall record in excess of 50 years (preferably closer to 100 years) should be used to drive the model of the PCD water balance. Consideration should be given to the use of stochastic rainfall models to generate sequences of sufficient length for the modelling
- An appropriate model accounting for the sources should be used to generate the inputs for the dam water balance. For modelling the runoff from a catchment, the model should account for the water budget i.e. infiltration, runoff, soil moisture content changes, evapo-transpiration and percolation must be accounted for in the catchment modelling. Typical models for this application are ACRU and HSPF.
- The direct rainfall and evaporation from the PCD surface
- Seepage from the dam basin
- Abstractions considered from the PCDs.

The spillage frequency from a PCD is on average a spill every 50 years. This means that the rainfall record should be at least 50 years and preferably 100 years. If the rainfall record is 50 years long then a single spill event is allowed while for a 100 year record two spill events can occur. The definition of an event is defined as a sequence of spill days occurring during a 30 day window.

The spillage frequency depends on the size of the dam (capacity) and the abstraction and reuse rate. The dam sizing should be undertaken in the following sequence:

- Initial designs and dam sizing based on the computed 1:50 year run-off volumes, and
- Confirmation of the dam sizing (based on spillage frequency), by means of continuous modelling. This includes routing of the inflow from the upstream catchment into the dam, accounting for direct rainfall on the dam basin, abstraction from the dam, evaporation from the dam surface area, infiltration through the wall (if any) and other losses. Evaporation from the dam should account for the variations in the dam surface area as a function of depth.
- Resizing of the dam, if necessary, to ensure that desired design spillage frequency is attained at the appropriate level of risk.

It is important to consider the loss of storage due to sediment build up in the PCD when sizing the dam.

The PCD water balance will be used to specify a minimum storage level. This ensures that adequate freeboard is maintained so that the storm water inflow can be accommodated and the spillage frequency met. The management of the PCD should be according to this minimum level. The dam volume should be reduced to this minimum level as soon as possible after storm events.

It is important to consider that, in general, it is not the single events that result in spillage, rather prolonged wet conditions.

6.4.4 Water balance (WB)

Step WB3: Update water balance model

The design team will update the water balance model based on the updated storm water modelling. Specific aspects that should be considered in reviewing and updating the PCD water balance include the following:

- Calculations of the inflows and outputs from the PCD are based on a list of assumptions. A sensitivity analysis should be included in the water balance calculations, to assess the level of variance in the design calculations
- Abstraction from the PCD will invariably rely on a power source at the PCD. The impact of a power failure on the PCD water balance should be assessed.

Step WB4: Assess surface water impacts

The storm water modelling will be used to address the potential surface water impacts from the PCD. The modelling should also be used to simulate various scenarios to determine the impact of the PCD on the water resource and the need for mitigation measures.

Step WB5: Identify mitigation measures

Various mitigation measures should be identified to address the surface water impacts. These mitigation measures will be used to refine the PCD design (step GD6).

6.4.5 Monitoring

The design phase should include detailing the recommended monitoring system for the PCD. Further details on monitoring are available in *BPG G3: Water Monitoring Systems*. This should include monitoring systems for:

- Meteorological monitoring, including aspects such as rainfall depth and intensity, evaporation, evapo-transpiration, wind speed and wind direction. These measurements are likely to be taken at a central position on the mine
- Water levels in the PCD over time
- Storage capacity of the PCD
- Water quality within the PCD over time
- Details on the water returned from the PCD
- Details on spillage from the dam, including number of events, flow velocities, flow volumes and water quality per event.

It is important to consider practical aspects in the design of the monitoring system, such as ensuring ease of access to the monitoring equipment and the likely growth of vegetation in and around the PCD.

6.5 Consolidated design report

A consolidated design report should be prepared, incorporating the design details from the sections above. The consolidated design report should, in general, be submitted together with the water use authorisation application.

6.6 Impacts of the authorisation process on design

6.6.1 Water use authorisation application

Normally, as part of a water use authorisation application, the engineering design of key measures to manage possible adverse effects on the water resource need to be submitted as part of the application. PCDs are generally regarded as management measures where the design details need to accompany the water use authorisation application. Specific requirements relating to the engineering design of the PCD could be stipulated, either in the finalisation of the relevant water use authorisation and/or included in the conditions of the authorisation. These requirements could have a direct effect on the engineering design and/or could affect the eventual decommissioning and closure planning of the dams.

Specific attention is required during the design phase to possible conditions likely to be stipulated in the water use authorisation that relate to dam closure. These will also be taken into consideration during the closure planning of the PCD.

The design should thus be undertaken as an iterative process to include the water use authorisation requirements.

6.6.2 Environmental Management Programme Report (EMPR)

The closure plan for a PCD would normally be an extension of the EMPR and hence, would take cognisance of its content. Specific measures could be stipulated in the EMPR which would need to be considered with the final rehabilitation and closure of the PCDs and related areas.

6.6.3 Closure and Financial provisions

The closure of the mine site would be based on a conceptual closure plan, from which the quantum for the financial provisions would be identified. Any specific aspects relating to the closure and post-closure use of the PCD, if available, should be considered during the design phase.

6.7 Assessment of existing PCDs

The investigations and design process covered in the sections above should be used to assess the operations, safety and potential/actual impacts of existing PCDs. The Departmental personnel should use existing legal instruments, e.g. regulations and directives, to manage any non-conformance evident in these PCDs.

7

CONSTRUCTION OF POLLUTION CONTROL DAMS

7.1 Quality control

During the construction phase involvement of the APP is essential (if a Category II or III dam) to ensure that the dam is built to specification, make appropriate design changes (taking safety considerations into account), and that any "permit conditions" are adhered to. The specific advantages in using an APP include the following:

- The APP can ensure that the PCD design is suitably amended, if applicable, to account for possible changes due to site conditions not identified during the design phase
- Dam construction material conditions may vary between laboratory tests and on-site conditions. The APP can ensure that suitable materials are used during construction
- The APP can ensure suitable and adequate quality control during construction.

7.2 Definitions

The following definitions taken from the ICOLD Bulletin "Quality Control for Fill Dams" (1986) are given:

- *Quality programme* – the overall programme should ensure achievement of the quality standard required by the design in earth and rock materials during construction of fill dams. The quality programme consists of two separate and specific aspects – quality assurance and quality control
- *Quality assurance* is that aspect of the quality programme that ensures that quality control and quality standards are valid for the dam; tests or inspection procedures are implemented and correctly preformed and records and reports are verified and maintained. The Contract, Design, Specification, and Procurement Procedures aimed at fixing responsibility and ensuring a competent contractor is a major part of quality assurance.
- *Quality control* is that aspect of the quality programme that defines the quality standard, establishes a quality control plan, establishes the test or inspection procedure for the measurement or attainment of the required quality standard, involves the execution of the test or inspection procedures for determining the attainment or non-attainment of the quality standard and has the authority to enforce the achievement of the quality standard or reject non-conforming work.

There are two possible approaches in specifying the quality control procedure required to ensure that the basic assumptions made by the designer are not invalidated by construction methods and conditions on site during construction, namely:

- **Specification of method or procedure:** In the case of the method or procedure-related specification, the owner or the engineer will have completed a comprehensive series of field tests to satisfy him/herself of the suitability, not only of the materials to be used in the dam but also of the procedures to be adopted to achieve the required product on the embankment. The contractor is given little scope to use his/her own experience and initiative. Method specification procedure would rely heavily on inspection and requires special techniques of checking and record-keeping usually to be carried out by a full-time site inspection crew.
- **Specification of performance or end product:** The performance or end-product specification requires that the contractor achieves certain specified results from material selected in the designated borrow areas and processed according to his/her own experience and capability. The specifications are directly related to the design requirements.

7.3 Contractual aspects

Small to medium dams are normally constructed according to one or other of the following contractual relationships:

- Owner-designed and built, where the owner selects the site and materials and constructs to their own design, using own labour and construction plant
- The owner acting as contractor, constructing the dam to a design and specification prepared under his/her instruction. This arrangement can result in extreme difficulties. Designers considering this kind of contractual relationship would be well-advised to ensure clearly specified roles and fixed responsibilities.
- Owner/consultant/contractor relationship, where the contract between owner and engineers is the standard form of agreement of the South African Association of Consulting Engineers (SAACE: 1007) and that between owner and contractor is according to the General Conditions of Contract (SAICE: 1990). These General Conditions of Contract (GCC) also formalise the relationship between the engineer and contractor, and
- Turnkey, where the employer contracts a party to design and construct a dam to previously agreed size and specification. Various documents including one by the Federation Internationale des Ingenieurs-Conseils (FIDIC: 1992) provide guidelines in preparing a contract document. Should this route be followed, the services of a professional engineer with appropriate experience are strongly urged to provide assistance in drafting the contractual agreement.

7.4 Specifications

The following suite of South African Bureau of Standards (SABS) specifications (selected as required) is recommended for use in small to medium dam construction:

- SABS 1200 AD: General (small dams) (1986)
- SABS 1200 DE: Small Earth Dams (1984)
- SABS 1200 DL: Gabions and Pitching (1996)
- SABS 1200 GA: Concrete (small works) (1982)
- SABS 1200 HA: Structural Steelwork (sundry items) (1990)
- SABS 1200 L: Medium-pressure Pipelines (1983).

In most cases, these specifications suffice and modifications are seldom required.

7.5 Procurement

Appropriate experience and access to the right equipment are vital. Prequalification of a number of tenders and invitation to tender/quote from contractors with a proven track record in construction are advisable.

It is imperative that the contractors duties and responsibilities according to the specifications should be clearly defined prior to the contract award being made.

7.6 Construction planning and programming

7.6.1 Planning

The first step following the award of contract or the decision to commence with work is to ensure the proper planning of the intended construction procedures is in place, including:

- Planning of site establishment, including storage space, access roads, and water to site
- Method and stages of river diversion (if applicable)
- Layout and development of borrow areas, with irrigation as required
- Method statements for the main activities i.e. clearing and stripping, excavation, foundation preparation, development of borrow areas, transportation, placing, compaction and final finishing, and
- Assessment of equipment availability and requirements (resource allocation).

The planning phase should also assess the impact of construction of the PCD on local water quality and ensure that all relevant authorisations are in place prior to construction.

7.6.2 Programming

Programming the construction of a small earthfill dam is usually dominated by one or more of the following factors:

- Flood probability in the watercourse in which the dam is being built
- The effect of rain on earthworks operations, and

- Availability of resources
- Completion of dam in time to contain the dirty runoff.

Ideally, construction should be completed during a single dry season.

An earthfill dam is constructed in two distinct phases, requiring different programming techniques i.e. the establishment/development phase and production phase.

The establishment/development phase usually spans from site establishment to completion of the diversions and river excavation work. A number of interrelated activities have to be catered for during the establishment/ development phase, which are normally programmed using one of the critical path methods. This involves a logical diagram including the identification and sequencing of activities. This allows these activities to be scheduled and resources allocated.

There are normally fewer activities to sequence and programme once bulk earth placing commences, and programming techniques developed in the production management field, such as line balancing, may be more appropriate at this stage.

7.7 Chain of responsibility

7.7.1 Role of the Approved Professional Person

Category I dams do not require the services of an Approved Professional Person (APP). Although the Dam Safety Office (DSO) of DWAF exerts pressure on the owner to institute some form of quality control, there are no requirements by law to have any quality assurance during construction.

In these cases it is advised that the owner makes use of the services of an experienced engineer to ensure that the agreement provides good quality assurance and that a specification addressing performance or end product is used.

In the case of a Category II dam, the owner is required by regulations promulgated under Section 9C of the National Water Act (1998) to employ the services of an APP. The APP is responsible for ensuring that quality control is carried out and signed-off. Notwithstanding the responsibilities of the APP, the contractor remains responsible for the execution long-term quality of the structure.

The General Conditions of Contract (Clause 26, SAICE: 1990) places the full responsibility for quality in the hands of the contractor. The authors of the ICOLD Bulletin on “Quality Control for Fill Dams” (1986) as well as the well known “Design of Small Dams” (USBR 1987) realised that this is generally not possible in the construction of large fill dams and that the quality programme should be carried out jointly between the contractor and owner/ engineer. The dam safety regulations reinforce this approach by including responsibility for the quality control programme as one of the responsibilities of the APP.

7.7.2 Role of the professional engineer

The contributions that the professional engineer can provide are as follows:

- Assist the owner in the selection of a contractor (if required)
- Assist in drafting an agreement with appropriate conditions of contract
- Explain and clarify the responsibilities of each of the parties involved
- Instruct the parties on key technical issues in the construction of small earthfill dams
- Quality control and quality assurance during construction
- Preparation and submittal of the “As-built” drawings, as part of the authorisation process.

8 OPERATION OF POLLUTION CONTROL DAMS

The following activities should be undertaken during the operations of a PCD:

- Routine inspections,
- Monitoring of the water management aspects, and
- Preparation and updating of an Operations Management Plan.

These aspects are covered in the following sections.

It is important to note that the frequency of inspections for PCDs is governed by the dam safety classification.

8.1 Routine inspections

Regular routine inspections of PCDs should be carried out either by the dam owner or a suitably qualified person appointed by the owner. An inspection form which is part of the Operations Manual and should be completed during each routine inspection is enclosed in Appendix B. If the space for detailed comments is inadequate, a separate sheet of paper should be used. The inspection form must then be signed by the observer and the owner or the person in control of the dam. Any changes in circumstances should be recorded, monitored and rectified, if necessary.

It is recommended that the inspection route to be followed should include the following:

- The full length of the wall crest and toe
- Observation of upstream and downstream slopes
- Spillway crest and downstream spillway channel
- Pumps stations and pipelines
- Control and instrumentation,
- Outlet works,
- Functioning of the liner system
- Functioning of sediment control systems, and
- The area downstream of the dam wall.

The areas of particular importance to the DWAF officials are the PCD freeboard, monitoring data and the water quality within the PCD.

Circumstances may arise when more frequent inspections of the dam are required, as follows:

- At first filling as well as during the refilling of an empty dam after a drought period, the water level should preferably rise at a rate of no more than 1000 mm per day. If this is not possible, a record should be kept of the daily rise in the water level. During this period the dam wall should also be inspected visually once a day. Attention should be given to signs of leakage, movement of the wall and instability. The water level, at which leakage suddenly increases, should be recorded. The emergency plan should be consulted for a description of emergency situations and emergency procedures.
- When the dam spills strongly, the spillway and outlet channel should be inspected daily for signs of significant erosion in the outlet channel and for possible undercutting of the toe of the wall
- It is good practice to visit the dam regularly (e.g. weekly) between routine inspections and carry out a brief visual inspection.

The emergency plan described in Appendix C "Upset Conditions" should be consulted for a description of emergency situations and suitable emergency procedures which should be carried out. Any sign of circumstances which may threaten the safety of the dam should be reported to the Director-General as described in the regulations.

8.2 Water management monitoring requirements

The sections below provide details on aspects to consider for routine water monitoring and inspections during the operations of PCDs. Inspections forms are included in Appendix B. Details on critical issues that may constitute upset conditions and hence an emergency situation are provided below and in Appendix C.

8.2.1 Hydrological data

The hydrological and water balance information that should be collected and assessed during the operation of PCDs is as follows:

- Rainfall and climate data
- Runoff measurements for inflows into the PCD
- Process water and other water flows into and out of the PCD
- Seepage flows.

8.2.2 Wall and spillway inspections

Spillways

The full spillway structure, spillway channel and sides up to where these join the river should be inspected. Undesirable plant growth such as trees, shrubs and reeds which obstruct and decrease the spillway capacity should be recorded and cleared from the spillway channel. Erosion of the spillway channel and undercutting of concrete or brickwork structures should be recorded and reported if of a serious nature. Erosion of the spillway channel should be repaired as soon as possible by backfilling with a suitable earthfill material which should be compacted in thin layers (in the case of bywash earth spillways), concrete or riprap, depending on circumstances. The cultivation of grass should be maintained by replanting, regular cutting and/or irrigation, where necessary. Undercutting or damage to concrete or masonry structures should be repaired as soon as possible.

Dam walls: Earthfill and rockfill dam embankments

The slopes of the wall should be inspected for any sign of seepage, cracks, movement, erosion, ant nests and burrows by animals or reptiles. Plant growth on embankment slopes should be kept short in order to carry out a meaningful inspection.

The extent of wet patches which appear on the downstream slope of the wall should be marked with suitably long pegs in order to observe and note any changes which may occur. The presence of seepage water should be watched and the clarity observed for the presence of soil particles. The position relative to the crest and the distance along the crest should be recorded. It is recommended that fixed reference beacons be installed along the wall crest for inspection purposes.

The position, width and length of significant cracks at any place on the dam wall should be marked and recorded. Longitudinal cracks (that are parallel to the centreline of the wall) less than 3.0 m in length and not wider than 0.5 cm are usually not of a serious nature. Transverse or diagonal cracks running from upstream to downstream or any rapidly changing cracks should particularly be noted. The appearance, location and extent of any movement, erosion and caving should be observed and recorded. It should be mentioned if survey beacons are disturbed.

It may be necessary to moderately raise and fill in low spots on the non-overspill crest from time to time, so as to maintain the freeboard of the dam. Low points should also be filled to prevent rain water from accumulating in pools or vehicle tracks on the wall crest. Filling should be carried out using suitable material, compacted in thin layers.

The dam wall as well as a 10m wide strip downstream of the toe should be cleared from trees, shrubs, undergrowth and weeds. Trees with a trunk diameter of more than one hundred millimetres should only be removed under supervision of the APP.

The dam wall should be cleared from all ant nests and rodents (moles, mice, meercats, iguanas, etc.). Cattle paths can often cause erosion furrows. Cattle should therefore be kept off the dam wall at all times.

Open cracks, sink holes and pipe tunnels on the crest and the upper half of the dam wall should be filled with a suitable material (e.g. liquid bentonite mixture) under the supervision of the APP. Holes and pipe tunnels on the lower half of the downstream slope should be filled with a sand/gravel mixture. However, if there is a presence of flowing water (strong seepage) from the holes, a filter and drainage system should be installed under the supervision of the APP.

Slope protection must be maintained. It may be necessary to establish grass on the downstream slope and to cut, fertilize and irrigate frequently. Runner type grass like couch or kikuyu is better than tuft for this purpose. Erosion should be repaired as soon as possible. It may also be necessary to repair erosion or subsidence of riprap on the upstream slope.

Dam walls: Concrete and/or masonry dam walls or structures

The position, width and length of significant cracks should be marked with paint and changes be recorded. Relative movement at joints or cracks should be marked, measured and recorded. Sudden changes in the above regard can point at a serious condition and should be reported. Crumbling or unusual erosion of the concrete should be recorded. It is important to inspect upstream concrete surfaces when the water level is low. The interface between concrete structures and earthfill should be carefully inspected for cavities and cracks. Undercutting or erosion of the foundations of concrete structures can be critical to the stability and should be recorded and reported if of a significant extent.

Undercutting or erosion at the toe of these structures should be repaired, using good quality concrete, before the stability of the structure is impaired. Damage of concrete surfaces should also be repaired before serious erosion occurs.

Pressure relief holes should be kept in a working condition by knocking off calcite deposits with a steel rod. Care should be taken not to compact the deposits in the hole and where possible loose material should be blown out by air or water.

The grouting or filling of cracks should be considered, where necessary in consultation with the APP. The sealing of leakages should be carried out, when possible, using a suitable sealant on the upstream side of the dam. Contraction joints should be filled with an approved compressible sealant where necessary in order to prevent ingress of water and impurities. The above work is considered to be of a specialised nature and should be done under supervision of an APP.

The interface between concrete and earthfill structures requires special attention. Gaps between the earthfill and the concrete structure should be filled with a suitable material, under the supervision of the APP. Cracks in the concrete structure through which water and earthfill material can migrate, should also be repaired according to the APPs instructions.

8.2.3 Outlet works

The condition of the outlet pipes and valves should be inspected for signs of leakage and corrosion. Leakage within or outside the outlet works should be measured when the valves have been shut for at least a week and if no rain has fallen since the previous week. Valves should be opened and shut with each inspection to determine whether these function correctly. Also observe for vertical cracks in ancillary concrete structures. Erosion downstream of the outlet works should be recorded.

Valves should be opened and shut at least four times per year (during routine inspections). Maintenance work such as painting of pipes, and servicing and lubrication of valves should be done regularly. Such routine measures can prevent expensive repairs at a later stage. The intake structure/trash screen should be cleaned and repaired, if necessary, when the dam is empty and the screen is exposed.

8.2.4 Seepage control

A strip with a width equal to two or three times the wall height, measured from the toe of the dam should be inspected. The presence of seepage water, swamps, pools, cracks or any displacement and its position should be observed and recorded. Where necessary seepage water should be channelled to be gauged. The presence of trees and shrubs within a 10 m wide strip downstream of the toe of the wall should be recorded. Plant growth should be kept short in this strip for access and to enable observation of any leakage or unusual conditions. Flow measuring points and manholes should be kept clean. Measuring boxes and V-notch plates should be waterproofed in order to ensure that seepage can be accurately measured.

8.3 Operations Management Plan (Operation Manual)

8.3.1 Preparation of an Operation Manual

In terms of the dam safety regulations (Government Notice R.1560 of 25 July 1986), as promulgated by the Minister of Water Affairs and Forestry in terms of Chapter 12 of the National Water Act, (1998), the owner of a dam with a safety risk is required to operate and maintain the dam in a safe and responsible manner.

The purpose of an Operations Manual is to provide guidelines to the owner for operation and maintenance of the dam to ensure the safe usage thereof during its full life-span. Appendix B contains details of an Operations Manual. The Operations Manual should consist of:

- Background details of the dam
- Applicable design and water balance details
- Operating rules for the PCD. These should include:
  - Details on the required minimum dam storage level (that ensures that adequate freeboard is maintained so that the Storm Water inflow can be accommodated and the spillage frequency met) and the pumping rates and pumping duration to obtain this storage level after storm events. This is particularly important for Storm Water PCDs
  - Detail on pumping rates for the withdrawal of water from process control and return water PCDs and the discharge point in the mine water circuit for the water
  - Details on the maximum allowable inflows to evaporation PCDs to balance evaporative losses and hence maintain freeboard requirements and meet the required spillage frequencies.
- Details of the monitoring undertaken to ensure that the operating rues for the PCDs are met
- Emergency procedures for upset conditions (see Appendix C).

This manual should be kept up to date and be available for use at the dam. The Director-General of the Department of Water Affairs and Forestry must be notified within 30 days of any change of particulars of responsible persons.

It should be stressed that regular inspections and regular maintenance are considered essential for the successful operation of a dam.

8.3.2 Update of the Operation Manual

The Operations Manual should be reviewed and updated on a regular basis. Specific conditions that may prompt the update of the Operations Manual include the following:

- Changes in the PCD water balance and/or the overall mine water balance
- Sedimentation within the PCD and the resultant loss in dam capacity
- A significant change in the mining infrastructure, e.g. greater areas are paved
- A change in the water quality reporting to the PCD
- Changes in the water use authorisation conditions.

9

CLOSURE OF POLLUTION CONTROL DAMS

9.1 Introduction

Site decommissioning for the PCD generally commences at the cessation of operations. Some surface infrastructure will be removed, site areas made safe and final reclamation and re-vegetation operations begun to ensure disturbed areas can sustainably meet the adopted final land uses. The post-operational period is important to both the regulatory authorities and the proponent since it affects the timing of both site relinquishment and the applicable rehabilitation funds and/or the transfer of unused funds.

Closure planning and operational processes put in place during the operational period would determine the post-operational success (or otherwise) of rehabilitation and re-vegetation operations.

Discussions with regulatory authorities and associated closure planning, addressing matters such as site reclamation and final land forms, vegetation and land use, must commence during the operational period. Interim closure plans arising from this planning must be reviewed at regular intervals (say 3 to 5 years) to ensure that the closure plans are appropriate and modified when necessary to account for changed circumstances. This will ensure that a comprehensive and up-to-date closure plan is in place at the cessation of operations.

9.2 Final land use and role of the PCD in the closure plan

Normally, the spatial area occupied by PCDs would comprise a small portion of the larger complex of surface infrastructure which it served during the operational period. The final land use and/or land use patterns assigned to the broader surface infrastructural area would thus most likely also apply to the PCD areas.

It is important that the role and use of the PCDs are defined in the post-closure scenario, as this will impact on the closure objectives and closure design requirements. The options for post-closure use of the PCD could include one of the following:

- Demolish the PCD wall and return the area back to free-draining. The likelihood exists that the PCD will be associated with wetlands and/or marshy areas, as PCDs are generally located along the topographical low areas of the infrastructural complex. There is thus an option to adapt the final land use patterns to integrate the PCD area, as well as other suitable areas, into the surrounding adjacent wetland areas
- Keep the PCD for beneficial long-term use of the PCD, such as:
    - A farm dam or water supply dam for the local communities, or
    - Long-term use of the PCD for pollution control measures
- Provide an in-situ cap for the PCD.

9.3 Closure objectives

The specific closure objectives stipulated for the PCD area must take account of the post-closure role of the PCD and be aligned to the overall closure objectives and final land use pattern set for the infrastructural complex. The closure objectives for the PCD area must address at least the following:

- Land use/land capability requirements for the area

- Final shaping and surface drainage of the PCD area
- Soil clean-up and safe disposal
- Likely long-term water quality impacts and objectives
- Re-vegetation and the sustaining of this
- Long-term dam safety and stability, should the PCD have a beneficial post-closure use.

More detailed/specific, measurable objectives would most likely be required within each of the above categories of closure objectives, as dictated by specific circumstances.

9.4 Design considerations for closure

9.4.1 Demolish PCD and return area to free-draining

Although the PCDs could comprise a small portion of the infrastructural complex that it served, it could in this case comprise a meaningful portion of closure planning. Key aspects requiring attention and consideration include:

- Safe disposal of impounded contaminated water
- Decontamination of embankment material, including rip-rap and spillway material
- Removal and safe disposal of liner material
- Assessment and possible soil clean-up underneath the liner system
- Reinstatement of drainage patterns, including the breaching and shaping of embankments, silt/sediment traps and routing channels
- Disposal of demolition waste and salvage of equipment (pumps, pipelines, etc.).

Each of the above aspects requires specific attention in the closure planning and needs to be integrated/clustered with aspects from the remainder of the infrastructural complex. For example, contaminated soil arising from the PCD basin area, could be addressed with contaminated soil arising from elsewhere on the complex. The safe disposal of synthetic liner requires specific attention, as follows:

- On mining sites, these could be buried deeply in open pits, and
- On industrial/plant sites these will most likely have to be shredded and disposed on an appropriate land fill site.

Under no circumstances must these liners be punctured and left behind on the site, as:

- Such a practice would most likely violate the desired final land use, and
- The possibility exists that these liners could be used by local communities for informal housing, placing users/inhabitants at risk of the contaminants accumulated on the liners.

The closure design should include an assessment of post-closure flow velocities and flood management once the pollution area has been made free-draining. Dedicated flow control measures should be provided should excessive post-closure flow velocities be evident.

The long-term water quality from the area, and the impact thereof on the surrounding drainage areas, is important. This will be of particular importance in the instances when the PCD is to be incorporated into existing wetlands of other environmentally sensitive areas.

9.4.2 Long-term beneficial use of the PCD

The following possible long-term impacts require attention should the PCD be applied for post-closure beneficial use:

- Residual contamination associated with the liner system, the rip rap along the inner slope of the dam embankment liner system and the soils below the liner system
- Long-term stability of dam embankments, since in most cases PCDs are constructed with a pre-determined life in mind and normally require attention and maintenance during the operational period of the mine. However, the dams could become isolated during subsequent beneficial use and receive limited or no maintenance. Hence, prior to hand-over for subsequent beneficial use the long-term stability of the dam embankment should be checked and improved as required for the subsequent beneficial use
- As in the case of the dam embankment, the dam spillways could also have been designed for pre-determined conditions. The post-closure situation could notably differ from the original design conditions. Hence, the spillways need to be checked whether these are appropriate for the foreseen post-closure use
- Aspects that could pose a safety risk will require attention, such as upslope silt traps, gangways

to outlet control structures, disused pipework and associated structures, etc.

An authorisation process through DWAF will invariably be required for the instances of post-closure beneficial use of the PCD. This will be particularly important should the dam be retained in a pollution control function.

9.4.3 Provide in-situ cap

The PCD may be capped in-situ for the closure conditions. Details for the types and design of a suitable cap fort he PCD are covered in *BPG A2: Mine Residue Deposits*.

9.5 Closure risk assessment

The MPRDA stipulates that a series of risk assessments are required to demonstrate that all reasonable risks that could be associated with closure have been identified, understood and suitably addressed. The following aspects related to the PCDs require attention in the risk assessment process:

- Latent soil and groundwater contamination and resultant adverse effects on the local water resource
- Surface erosion of the reclaimed areas and subsequent sedimentation of local surface streams
- Severe surface erosion conditions and/or remaining surface infrastructure that could pose a safety risk.
- Risk of PCD failure should the PCD be retained for post-closure use.

9.6 Rehabilitation and closure plan

It is likely that the rehabilitation and closure of the PCD would be addressed as part of the overall rehabilitation and closure plan for the infrastructural complex. The component of this plan addressing the closure of the PCD does however need to be aligned to the overall plan by addressing at least the following aspects:

- Final land use and the alignment with the rest of the infrastructural site as well as surrounding/adjacent land use
- Closure objectives and the measures for the achievement of these objectives
- Inspection, measurement and monitoring measures/ actions to control/demonstrate the achievement of the stipulated closure objectives
- Typically the component of the closure plan addressing the PCDs could have the following content:
  - Introduction
  - Regional and overall site context
  - Description of the PCD site
  - Relevant legislation and its applications
  - Role of the PCD in the closure plan
  - Possibility for progressive closure and/or post-closure beneficial use
  - Findings of risk assessment
  - Closure objectives
  - Measures for achievement of closure objectives
  - Inspection, measurement and monitoring
  - Corrective action
  - Conclusion.

9.7 Financial provisions for closure

The costing for the reclamation and closure of the PCD area would form a key component of the overall closure costing for the infrastructural complex, should the PCD be removed in the closure scenario. In this instance, the closure objectives and associated measures to attain these objectives must be clearly defined so as to arrive at accurate closure costs and to make appropriate financial provision. In some cases basic engineering could be required to improve the resolution on the required closure measures.

The determination of an appropriate closure cost quantum for PCDs that meaningfully contributes to financial security needs attention to at least the following:

- A list of closure cost items relevant to the PCDs. This should include the earthworks related to removal of the wall and making the area free-draining, removal of infrastructure such as pumps and pipelines, removal and safe disposal of the liner systems and the disposal of the retained water (including water treatment, if applicable)
- Properly determined quantities for the closure cost items.
- Realistic unit rates for the closure cost items. These are generally obtained from recent tender prices.
- The time value of money related to ongoing and/or recurrent costs, and

- Levying of fees and charges, in particular the application of waste discharge charges that are currently being developed by the DWAF.

9.8 Post-closure phase

9.8.1 After-care and maintenance

After-care and maintenance must give attention to at least the following:

- Inspection of vegetated areas and re-establishment of vegetation, where required
- Eradication of weeds/exotic/alien vegetation
- Implementation of measures to prevent the grass/ vegetation cover becoming moribund
- Checking whether drainage lines are free-draining and institute corrective action if unnecessary impoundment or scouring is identified
- Regular inspections and maintenance should the PCD have a beneficial post-closure use.

9.8.2 Long-term monitoring programme

The long-term water quality monitoring programme will be designed and implemented on a site specific basis, guided by the findings of the closure risk assessment.

9.8.3 Financial arrangements and contractual agreements

The financial arrangements and associated contractual agreements for the post-closure situation are likely to be included in those devised for the infrastructural complex. The financial arrangements and contractual agreements specific to the PCDs would entail the following:

- Allowance for ongoing water quality monitoring until success has been demonstrated
- Allowance for care and maintenance until self-sustaining conditions have established
- Possible transfer of responsibility for the above to a third party.

10 PRACTICAL CONSIDERATIONS AND ISSUES WITH REGARD TO POLLUTION CONTROL DAMS

Appendix D provides details on practical considerations and issues in the design, construction and operation of PCDs, including:

- Dam failure issues
- Observations from good and poor planning, and
- Examples of dam failures.

12 GLOSSARY OF TERMS

Activity	Any mining related process on the mine including the operation of washing plants, mineral processing facilities, mineral refineries and extraction plants, and the operation and the use of mineral loading and off-loading zones, transport facilities and mineral storage yards, whether situated at the mine or not, in which any substance is stockpiled, stored, accumulated or transported for use in such process or out of which process any residue is derived, stored, stockpiled, accumulated, dumped, disposed of or transported.
Approved professional person (APP)	A professional engineer approved by the Minister of Water Affairs and Forestry after consultation with the Engineering Council of South Africa (ECSA), for the purposes of executing certain "tasks" relating to dams.
Clean water system	Any dam, other form of impoundment, canal, works, pipeline and any other structure or facility constructed for the retention or conveyance of unpolluted water.
Dam*	Any settling dam, slurry dam, evaporation dam, catchment or barrier dam and any other form of impoundment used for the storage of unpolluted water or water containing waste.
Dam with a safety risk*	A dam with a storage capacity in excess of 50 000 cubic meters and a vertical height in excess of 5 meters. The design of new dams, alterations to existing dams, quality control during construction, dam safety inspections and dam safety studies are described as "tasks" relating to dams.
Dirty area	Any area at a mine or activity which causes, has caused or is likely to cause pollution of a water resource.
Dirty water system	Any dam, other form of impoundment, canal, works, pipeline, residue deposit and any other structure or facility constructed for the retention or conveyance of water containing waste.
Environmental management programme	An environmental management programme submitted in terms of section 39 of the Mineral and Petroleum Resources Development Act, 2002 (MPRDA).
Facility	In relation to an activity, includes any installation and appurtenant works for the storage, stockpiling, disposal, handling or processing of any substance.
Height of dam*	In the case of a dam situated across a water course, the maximum wall height is measured from the natural level of the bed of the water course on the downstream face of the dam to the top of the dam, which is the level of the roadway or walkway. In the case of any other dam the height is measured from the lowest elevation of the outside limit of the dam to the top of the dam which is the level of the roadway or walkway. In the case of a dam consisting of a spillway across the full dam width, the height is measured to the crest level of the spillway.
Manager, mine and mineral	The meanings assigned to them in the Mine Health and Safety Act, 1996 (Act No. 29 of 1996).

Person in control of a mine or activity	In relation to a particular mine or activity, includes the owner of such mine or activity, the lessee and any other lawful occupier of the mine, activity or any part thereof; a attributer for the working of the mine, activity or any part thereof; the holder of a mining authorisation or prospecting permit and if such authorisation or permit does not exist, the last person who worked the mine or his or her successors-in-title or the owner of such mine or activity; and if such person is not resident in or not a citizen of the Republic of South Africa, an agent or representative other than the manager of such a mine or activity must be appointed to be responsible on behalf of the person in control of such a mine or activity.
Residue	Includes any debris, discard, tailings, slimes, screenings, slurry, waste rock, foundry sand, beneficiation plant waste, ash and any other waste product derived from or incidental to the operation of a mine or activity and which is stockpiled, stored or accumulated for potential re-use or recycling or which is disposed of.
Residue deposit	Includes any dump, tailings dam, slimes dam, ash dump, waste rock dump, in-pit deposit and any other heap, pile or accumulation of residue.
Stockpile	Includes any heap, pile, slurry pond and accumulation of any substance where such substance is stored as a product or stored for use at any mine or activity
Suitably qualified person	A person with suitable professional expertise for the task who can be accountable for the output of the task.
Water system	Any dam, any other form of impoundment, canal, works, pipeline and any other structure or facility constructed for the retention or conveyance of water.

* *Definition from the National Water Act 1998 (Act No.36 of 1998)*

13 LIST OF ACRONYMS AND ABBREVIATIONS

APP	Approved Professional Person
BPEO	Best Practical Environmental Option
BPG	Best Practice Guideline
CMA	Catchment management agency
DEAT	Department: Environmental Affairs and Tourism
DME	Department: Minerals and Energy
DSO	Dam Safety Officer
DWAF	Department: Water Affairs and Forestry
ECA	Environment Conservation Act, 1989 (Act 73 of 1989)
EIA	Environmental impact assessment
EMP	Environmental management plan
GCC	General conditions of contract
GCL	Geosynthetic clay liner
GN704	Government Notice No. 704, National Water Act, 1998 (Act No. 36 of 1998)
HDPE	High Density Polyethylene
ICOLD	International Commission on Large Dams
IDF	Intensity-duration-frequency rainfall curves
LLDPE	Liner Low Density Polyethylene
MPRDA	Mineral and Petroleum Resources Development Act, 2002 (Act No. 28 of 2002)
MRD	Mine residue deposit
NEMA	National Environmental Management Act, 1998 (Act No.107 of 1998)
NWA	National Water Act, 1998 (Act No. 36 of 1998)
PCD	Pollution control dam
RDF	Recommended design flood
RMF	Regional maximum flood
SAACE	South African Association of Consulting Engineers
SANCOLD	South African Commission on Large Dams
SEF	Safety evaluation flood

APPENDIX A
LEGAL FRAMEWORK

The following documents comprise the principle legal framework for PCDs:

- National Water Act, 1998 (Act No.36 of 1998)
- Government Notice No. 704, National Water Act, 1998 (Act No. 36 of 1998) dealing with regulations on use of water for mining and related activities aimed at the protection of water resources
- The Dam Safety Regulations (published in Government Notice R. 1560 of 25 July 1986)
- National Environmental Management Act, 1998 (Act No.107 of 1998)
- Mineral and Petroleum Resources Development Act, 2002 (Act 28 of 2002).

A.1 National Water Act, 1998 (Act No.36 of 1998)

Any new water use as defined in section 21 of the National Water Act (NWA) is subject to licensing. The issuing of a licence is subject to a number of conditions and constraints in the NWA, as follows:

- Before construction of a new dam or alterations/raising/re-construction of an existing dam may start, a water use licence or written authorisation must be obtained from the Regional Director of the relevant region. The applicable sections of the NWA are as follows:
  - 21(b) storing water
  - 21(c) impeding or diverting the flow of water in a watercourse
  - 21(f) discharging waste or water containing waste into a water resource through a pipe, canal, sewer, sea outfall or other conduit
  - 21(g) disposing of waste in a manner which may detrimentally impact on a water resource
  - 21(i) altering the bed, banks, course or characteristics of a watercourse.
- In the case of dams that have failed, existing lawful water use (subject to verification) will normally be acknowledged but it is essential that confirmation is obtained in writing from the Regional Director, and
- Existing dams: Section 21(b) of the NWA defines storage of water as a water use. The general authorisation covers this water use for dams with a capacity of up to 10 000 m^3 or more than 1,0 hectare of water stored. Above this limit, the water use must be registered on a form that will be supplied by the Regional Director for this purpose. However, in some Water Management Areas the general authorisation does not allow any dam, irrespective of size, outside the licensing procedure. All dams must thus be registered in these areas.

A.2 Government Notice No. 704, National Water Act, 1998 (Act No. 36 of 1998)

This document should be consulted in its entirety for the purposes of determining the legal framework for the establishment of PCDs. However, specific attention is drawn to the following pertinent regulations under this notice:

A.2.1 Regulation 2: Information and notification

Any person intending to operate a new mine or conduct any new activity must notify the Department of such intention not less than 14 days before the start of such operation or activity.

Any person in control of an existing mine or activity must:

- Submit a copy of all amendments of their environmental management programme to the Department
- Notify the Department in writing 14 days before the temporary or permanent cessation of the operation of a mine or the conducting of an activity, or the resumption of such operation or activity
- Notify the Department by the fastest possible means of any emergency incident or potential emergency incident involving a water resource at or incidental to the operation of a mine or the conducting of any activity, furnishing information regarding:
  - the date and time of the incident
  - a description of the incident
  - the source of the pollution or potential pollution
  - the impact or potential impact on the water resource and the relevant water users
  - remedial action taken or to be taken by the person in control of the mine or activity to remedy the effects of the incident, and
- Within 14 days after the date of an incident contemplated in paragraph (c) inform the Department in writing of measures taken to correct and prevent a recurrence of such incident.

A.2.2 Regulation 4: Restrictions on locality

No person in control of a mine or activity may:

- Locate or place any residue deposit, dam, reservoir, together with any associated structure or any other facility within the 1:100 year flood-line or within a horizontal distance of 100 metres from any watercourse or estuary, borehole or well, excluding boreholes or wells drilled specifically to monitor the pollution of groundwater, or on water-logged ground, or on ground likely to become water-logged, undermined, unstable or cracked
- Except in relation to a matter contemplated in regulation 10, carry on any underground or opencast mining, prospecting or any other operation or activity under or within the 1:50 year flood-line or within a horizontal distance of 100 metres from any watercourse or estuary, whichever is the greatest
- Place or dispose of any residue or substance which causes or is likely to cause pollution of a water resource, in the workings of any underground or opencast mine excavation, prospecting diggings, pit or any other excavation, or
- Use any area or locate any sanitary convenience, fuel depots, reservoir or depots for any substance which causes or is likely to cause pollution of a water resource within the 1:50 year flood-line of any watercourse or estuary.

A.2.3 Regulation 5: Restrictions on use of material

No person in control of a mine or activity may use any residue or substance which causes or is likely to cause pollution of a water resource for the construction of any dam or other impoundment or any embankment, road or railway, or for any other purpose which is likely to cause pollution of a water resource.

A.2.4 Regulation 6: Capacity requirements of clean and dirty water systems

Every person in control of a mine or activity must:

- Confine any unpolluted water to a clean water system, away from any dirty area
- Design, construct, maintain and operate any clean water system at the mine or activity so that it is not likely to spill into any dirty water system more than once in 50 years
- Collect the water arising within any dirty area, including water seeping from mining operations, outcrops or any other activity, into a dirty water system
- Design, construct, maintain and operate any dirty water system at the mine or activity so that it is not likely to spill into any clean water system more than once in 50 years
- Design, construct, maintain and operate any dam or tailings dam that forms part of a dirty water system to have a minimum freeboard of 0.8 metres above full supply level, unless otherwise specified in terms of Chapter 12 of the Act
- Design, construct and maintain all water systems in such a manner as to guarantee the serviceability of such conveyances for flows up to and including those arising as a result of the maximum flood with an average period of recurrence of once in 50 years.

A.2.5 Regulation 7: Protection of water resources

Regulation 7 places an obligation on the person in control of a mine to take reasonable measures to protect any water resources. The reasonable measures must be able to protect such resources in the following manner:

- Prevent water containing waste or any substances which causes or is likely to cause pollution from entering water resources, either by natural flow or seepage and must retain and collect such substance or water containing waste for use, re-use, evaporation or for purification or disposal in terms of the alteration of flow characteristics
- All water systems, including residue deposits must be capable of preventing pollution of any water resource and restrict the possibility of damage to the riparian or in-stream habitat through erosion or sedimentation, or disturbance of vegetation or the alteration of flow characteristics
- Any dam, residue deposit or stockpile for tailings, slimes, ash, etc., must be designed, constructed and maintained such that the waste or water contained therein will not result in the failure thereof or impair the stability thereof
- Prevent the erosion or leaking of materials from residue deposit or stockpile, which could pollute any water resource (barrier dams or evaporation dams, etc.)
- Recycle water as far as practicable and prevent the spillage, seepage or release of water containing waste; and
- Any water system must be kept free of obstructions to ensure continued efficiency thereof.

A.2.6 Regulation 8: Security and additional measures

Regulation 8 places an obligation on a person in control of a mine to take certain security and additional measures, which include:

- Fencing off of impoundments or dams containing poisonous, toxic or injurious substances and the erection of warning notice boards to warn person of hazardous contents
- Ensure access control in stockpile areas or disposal areas for residue/substances which has or may cause pollution of a water resource so as to protect the measures taken; and
- Protection of existing pollution control measures or replacement of damaged or destroyed measures and establishment of additional measures.

A.2.7 Regulation 9: Temporary or permanent cessation of a mine

Regulation 9 stipulates that:

- All pollution control measures must be designed, modified, constructed and maintained so as to comply with the requirements of GN704 at the time of cessation of operations
- The in-stream and riparian habitat of any water resource, which may have been affected by the mine or activity, is remedied so as to comply with the requirements of GN704.

A.3 The Dam Safety Regulations (published in Government Notice R. 1560 of 25 July 1986)

A.3.1 Introduction

The Dam Safety Regulations (published in Government Notice R. 1560 of 25 July 1986) became fully effective in January 1987 and are still in force under the National Water Act, 1998 (Act 36 of 1998).

Dam safety in South Africa is implemented by means of section 9C of the National Water Act and the Regulations in Government Notice R.1560 of 25 July 1986. Dam owners, including the State, are legally responsible for their dams and have to comply with specific requirements. A category classification based on size and potential hazard is used to distinguish between the conditions and requirements to be adhered to, and are more stringent and comprehensive for large and high hazard dams.

Government authority for dam safety control lies with the Minister: Water Affairs and Forestry while the Director-General of Water Affairs and Forestry has executive authority to ensure that legislation is complied with, assisted by the Dam Safety Office.

The Advisory Committee on Safety of Dams is available to advise the Minister on any issue related to the safety of dams, or the making, amendment or withdrawal of regulations. The Engineering Council of South Africa (ECSA) Committee on Professional Engineers for Dams evaluates the qualifications and experience of professional engineers who have requested approval from the Minister to perform certain "tasks" and advises him of its recommendations. A technical review committee may be appointed to advise on technical matters related to dam safety or in cases where a person is aggrieved by a directive issued by the Director-General.

The following sections provide a very concise summary of these regulations.

A.3.2 Classification of dams

Every dam with a safety risk shall be classified in accordance with regulation 2.4 on the basis of its size and hazard potential. This will determine the level of control over the safety of such structures that is applicable in terms of these Regulations.

The size classification of a PCD with a safety risk shall be based on the maximum wall height in accordance with Table 3 below.

Table 3: PCD size classification

Size class	Maximum wall height in metres
Small	More than 5 but less than 12 m;
Medium	Equal to or more than 12 but less than 30 m;
Large	Equal to or more than 30 m.

The classification of a dam with a safety risk by hazard potential shall be effected in accordance with the hazard potential classification in Table 4 below.

Table 4: Hazard potential classification

Hazard potential rating	Potential loss of life	Potential economic loss
Low	None	Minimal
Significant	Not more than ten	Significant
High	More than ten	Great

The hazard potential rating for a given dam shall be the highest level as determined by the separate consideration of the potential loss of life and potential economic loss.

The Director-General or an officer of the Department designated by him shall in accordance with Regulations 2.2 and 2.3 carry out the size and hazard potential classification of each dam with a safety risk on the basis of its size and hazard potential in his opinion, and shall notify the owner or other person in control of the dam of the classification.

The Director-General or such officer may from time to time, or when new information comes to his attention, revise the classification of any dam with a safety risk, and shall notify the owner or person in control of the dam concerned of any alteration in the classification.

The owner or other person in control of a dam with a safety risk shall, when requested to do so by the Director-General, furnish any information needed for the revision of the classification of the dam.

When an owner intends to build a new dam with a safety risk or to enlarge or alter an existing dam with a safety risk, he shall, after completion of the feasibility studies for the proposed project, furnish the Director-General with the following information for classification purposes:

- Name and address of the owner and that of the person in control concerned
- Situation of the dam (description as contained in the title deed of the property concerned, magisterial district, nearest town, the distance thereto, the name of the river or watercourse wherein situated (if any) and the location in terms of longitude and latitude to the nearest minute of accuracy)
- Object to the scheme, with an indication of the users of the water

- In the case of an alteration to or enlargement of an existing dam, a description of the nature and extent of the intended alteration or enlargement
- Maximum proposed height of the wall
- Gross storage capacity of the dam basin, and
- Particulars on a plan of a suitable scale of the nature and situation of development downstream of the dam in the area that would be threatened by a failure of the dam.

A.3.3 Use of the classification of dams with a safety risk

The requirements to be compiled with relating to a dam with a safety risk in respect of the design, construction, putting into operation, operation, maintenance and abandonment of any such dam shall be determined in accordance with the category classification in the Table below.

Table 5: Category classification of dams with a Safety Risk

Size class	Hazard potential rating		
	Low	Significant	High
Small	Category I	Category II	Category II ....
Medium	Category II	Category II	Category III ....
Large	Category III	Category III	Category III ....

The Director-General may, where he considers that circumstances justify it, assign to a dam a category classification other than that indicated by the Table contained in dam safety regulation 3.1.

A.3.4 Legal requirements

The details below provide the legal requirements that must be met **before** a person may construct/alter/repair a dam, namely with regard to (1) dam safety, (2) water entitlement and (3) environmental legislation. These requirements, as well as those for owners of existing dams, are summarised below.

New dams, alterations to existing dams or repair of dams that failed

The first step is to apply for classification of the dam on form DW 692E. The Department will then inform the applicant of the classification of the dam and of further procedures.

If the dam is classified as a category I dam, apply for a licence to construct on form DW 694E and submit construction drawings. Construction may only commence after the licence to construct has been issued.

If the dam is classified as a category II or III dam, the services of an approved professional person/engineer (APP) must be obtained. The APP must apply for a licence to construct on behalf of the dam owner (this involves the submission of an application form, design report, engineering drawings and construction specifications). Construction may only commence after the licence to construct has been issued. The APP must also ensure that an adequate quality control programme is in place during the construction period. Before starting with storage of water, the APP must apply for a licence to impound (this involves the submission of an operation and maintenance manual and emergency preparedness plan together with an application form DW 696E). After completion of all construction work, the APP must submit a completion report, completion drawings and a completion certificate stating that the work has been completed according to his/her specifications.

On completion, dams with a safety risk must be registered on form DW 693E.

Existing dams

All dams with a safety risk must be registered on form DW 693E.

The Department must be notified of any changes of particulars (dam owner, address, telephone numbers, person in control, etc.).

The dam must be operated and maintained in a responsible manner. This requires that the owner, or the person appointed by the owner, will visit and inspect the dam on a regular (at least weekly) basis. Maintenance work must be done regularly. In the case of unsafe conditions, emergency procedures and safety measures must be taken and the Department informed thereof.

The dam owner must arrange for the execution of a formal dam safety inspection when instructed to do so by the Department (at intervals between 5 and 10 years). In the case of category II and III dams the inspection must be done by an APP. In the case of category I dams it is not prescribed by whom the inspection must be done but it is in the owner's interest to appoint an experienced person to perform this task. If necessary, the inspection report will indicate what work should be done to upgrade the dam to acceptable safety standards.

A.4 National Environmental Management Act, 1998 (Act No.107 of 1998)

The requirements of Regulations published in Government Notice R. 1182 and R. 1183 of 5 September 1997 in terms of the Environment Conservation Act, 1989 (Act 73 of 1989) must be complied with. Normally it will be required that an environmental impact assessment (EIA) must be carried out before construction of a new dam or raising/re-construction of an existing dam will be authorised. Written authorisation must be obtained from the relevant provincial department before commencing with the project.

A.5 Mineral and Petroleum Resources Development Act, 2002 (Act No. 28 of 2002)

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

A.6 Mining Authorisation

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

A.6.1 Prospecting rights

If the application for a prospecting right is accepted by the Regional Manager, the Regional Manager must within 14 days from the date of acceptance notify the applicant in writing to *inter alia* submit an environmental management plan (section 16(4)(a)). The granting of a prospecting right only becomes effective on the date on which the environmental management plan is approved in terms of section 39 of the MPRDA (section 17(5)). The application for renewal of a prospecting right must *inter alia* be accompanied by a report reflecting the extent of compliance with the requirements of the environmental management plan, the rehabilitation completed and the estimated cost thereof (section 18(2)(c)) and the Minister must grant the renewal of a prospecting right if the application complies with sections 18(1) and 18(2) and the holder of the prospecting right has *inter alia* complied with the requirements of the approved environmental management plan (section 18(3)(c)). The holder of a prospecting right must comply with the requirements of the approved environmental management plan in terms of section 19(2)(c). In the case of a retention permit, the environmental management plan approved in respect of the prospecting right remains in force as if the prospecting right had not lapsed in terms of section 32(2) (section 32(3)) and the holder of the retention permit must give effect to the approved environmental management plan (section 35(2)(a)). The specific requirements for environmental management plans and monitoring and performance assessment requirements are further dealt with in 3.2.3.

A.6.2 Mining rights

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

Minister must grant the renewal of a mining right if the application complies with sections 24(1) and 24(2) and the holder of the mining right has *inter alia* complied with the requirements of the approved environmental management programme (section 24(3)(c)). The holder of a mining right must comply with the requirements of the approved environmental management programme in terms of section 25(2)(e). The specific requirements for environmental management programmes and monitoring and performance assessment requirements are further dealt with in 3.2.3.

A.6.3 Mining Permits

If the Regional Manager accepts the application for a mining permit, the Regional Manager must, within 14 days from the date of acceptance, notify the applicant in writing to *inter alia* submit an environmental management plan (section 27(5)(a)). The Minister must issue a mining permit if *inter alia* the applicant has submitted the environmental management plan (section 27(6)(b)). The specific requirements for environmental management plans and monitoring and performance assessment requirements are further dealt with in 3.2.3.

A.7 Environmental management

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

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

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

Section 39 of the MPRDA deals with the requirements of an environmental management programme or plan, whichever is applicable, as described in more detail in 3.2.1 under the relevant authorisations. Section 40 allows for the consultation with other State departments that administers any law relating to matters affecting the environment.

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

Section 42 deals specifically with the management of residue stockpiles and residue deposits, and stipulates that these must be managed in the prescribed manner on any site demarcated for that purpose in the environmental management programme or plan in question only.

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

A.8 Mineral and Petroleum Resources Development regulations

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

In terms of regulation 48, an environmental impact assessment contemplated in section 39(1) of the MPRDA (refer to 3.2.1) is a process which results in the compilation of:

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

The contents (framework) of an environmental management programme or plan, whichever is applicable (refer to 3.2.1), is described in regulations 51 and 52, respectively, while the requirements for monitoring and performance assessments of these programmes/plans are described in detail in regulation 55. The methods and quantum of financial provision for the rehabilitation, management and remediation of negative environmental impacts (including those associated with mine residue deposits) are given in regulations 53 and 54. Regulation 56 deals with the requirements for mine closure, including the principles for mine closure, closure objectives and the contents (framework) of the environmental risk assessment report and closure plan.

APPENDIX B
EXAMPLE OF AN OPERATION MANUAL

OPERATION AND MAINTENANCE MANUAL AND EMERGENCY PLAN

NAME OF DAM: ____________________

REFERENCE NUMBER: ____________________

OWNER: ____________________

ADDRESS: ____________________

____

____

TEL. NO.: ____________________

PERSON IN CONTROL OF DAM: ____________________

ADDRESS: ____________________

TEL NO.: ____________________

PARTICULARS OF DAM

The most important particulars of the dam are given below:

Name of dam: ____________________

Date of completion: ____________________

Original name of farm: ____________________

Common name of farm if different from the above: ____________________

River or water course: ____________________

Nearest town: ____________________

District: ____________________

Classification: ____________________

Category: ____________________

Maximum wall height: ____________________

Hazard potential: ____________________

Non-overspill crest level: ____________________

Full supply level (FSL): ____________________

Spillway crest level (if different from FSL): ______________________________

Gross storage capacity at FSL: ______________________________

Water surface area at FSL: ______________________________

Catchment area: ______________________________

Upstream slope: ______________________________

Downstream slope: ______________________________

Flood peak: Before attenuation After attenuation

Recommended Design Flood (RDF): ______________________________

Safety Evaluation Flood (SEF): ______________________________

Q100 (1 in 100 year flood): ______________________________

Q50 (1 in 50 year flood): ______________________________

Crest length of wall (excluding spillway): ______________________________

Spillway width: ______________________________

Type of spillway (e.g. side spillway): ______________________________

Total freeboard: ______________________________

Maximum discharge capacity (without flood absorption): ______________________________

Outlet works: ______________________________

Number of outlet pipes: ______________________________

Diameters: ______________________________

Type of pipes (Steel, asbestos, etc.): ______________________________

Upstream valve (Type and diameter): ______________________________

Downstream valve (Type and diameter): ______________________________

Purpose of dam: ______________________________

Description of dam wall materials and drainage system: ______________________________

Description of dam wall foundations: ______________________________

Directions for Completion of the Routine Inspection Form

A competent person who should be well acquainted with the contents of this full manual, should be appointed to carry out the routine inspections on a quarterly basis. A supply of blank routine inspection forms should always be available at the dam site. Fill in “yes”, “no”, “slightly”, “none”, “n/a”, “unchanged” etc. where applicable on the form. Do not leave blank spaces.

Where unfavourable conditions exist, more particulars should be furnished on the reverse side of the form or on separate pages, for example:

(a) Cracks: State crack width, length and position.

(b) Hollows, subsidence and erosion: Record extent, depth and position.

(c) Wet Patches: Record size and position.

Any positions should be indicated in chainage/distance with the aid of reference beacons or as the distance from a fixed point such as the spillway wall. The distance upstream or downstream from the centreline of the wall should also be indicated. The description should be clear enough to determine the degree of change between subsequent inspections. Specific problems should be photographed.

The inspection route should cover the full crest length of the wall, toe of wall, spillway area and slopes. Observations should not merely be made from a distance. The downstream area includes a strip with a width equal to the wall height downstream of the toe of the wall. Valves should physically be opened and closed to see if they are in good working condition.

Completed inspection forms should be kept for record purposes and be shown (together with the record book) to the approved professional person (APP) during the regular inspections.

A record book should also be kept for recording the items listed below. The list of items and frequencies suggested should be chosen to suit this specific dam.

Item	Frequency of measurement
Rainfall	Daily
Water level in dam	Weekly
Water level in dam during floods	Daily/hourly
Leakage or seepage (flow rate)	Weekly
Flow released by outlet works	Weekly/daily
Piezometer readings	Quarterly
Height of settlement beacons	Yearly/five yearly
- New dams	Yearly
- Old dams	Five yearly
Dam capacity	Yearly to five yearly
Repair work (Details of important repair work including the date should be recorded in the record book.)	Ad hoc

The emergency plan (Appendix C) should be consulted for a description of emergency situations and emergency procedures.

Routine Inspection Form (Consult preceding section as to how form should be completed)

B.1 General

B.1.1 When last did it rain and rainfall depth: ____________________

B.1.2 Water level in dam: ____________________

B.1.3 Earthfill/rockfill dam walls: ____________________

- Wall crest: ____________________
- Upstream slope: ____________________
- Downstream slope (including downstream area): ____________________
- Hollow or low points? ____________________
- Settlement or subsidence? ____________________
- Bulges/wall movement? ____________________
- Undercutting hollowing in? ____________________
- Cracks? ____________________
- Holes (ants, animals, other)? ____________________
- Trees or shrubs? ____________________
- Grass in good condition? ____________________
- And rip rap? ____________________
- Any erosion? ____________________
- Wet patches? ____________________
- Amount of seepage water? ____________________
- Seepage water dirty/ turbid? ____________________
- Any swamps? ____________________

B.2 Concrete and/or masonry dam walls or structures

(Note: If space is insufficient, please attach separate pages)

B.2.1 Is the concrete in a good condition? ____________________

B.2.2 Is there serious erosion or undercutting at the wall? ____________________

B.2.3 Any serious cracks? ____________________

B.2.4 Any movement or relative movement at joints or cracks? ____________________

B.2.5 Any pressure relief holes blocked? ____________________

B.2.6 Any wet patches on wall or downstream thereof? ____________________

B.2.7 Amount of leakage? ____

____

B.2.8 Are there any signs of material particles moving through cracks or drainage, including holes?

____

B.3 Spillways or spillway structures

B.3.1 Is there serious erosion in the spillway or spillway channel? ____________________

____

B.3.2 Is the spillway channel blocked by reeds, shrubs, trees or anything else? ______________

____

B.3.3 Is there any undercutting of concrete structures or masonry? ____________________

____

B.3.4 Are concrete structures or masonry in a good condition? ____________________

____

B.4 Outlet works

B.4.1 Are there any leakages in or outside the outlet works? ____________________

B.4.2 Are pipes, valves, all equipment and paintwork in a good condition? ______________

B.4.3 Are all valves in smooth working condition? ________________________

_

B.4.4 Is there serious erosion downstream of the outlet works? ____________________

B.5 Recommendations

Which above-mentioned points or any other should urgently be rectified? ________________

____

____________________ ____________________

SIGNATURE OF INSPECTOR: DATE:

____

HIGHEST QUALIFICATION:

____________________ ____________________

Any upset conditions at a pollution control dam require swift and appropriate action. The response must be prompted by observation or a signal. The urgency and steps to be followed must be aligned to the level of seriousness of the upset condition.

The following points outline an emergency situation and procedures which should be followed when an emergency situation arises at the dam. This is only a general guideline and should be adapted for each specific dam. The required particulars as indicated must be furnished.

Emergency Situations and Actions

The emergency procedures become operative when an emergency situation arises. One of the following actions must be taken, depending on the gravity of the situation:

Emergency situation A: Evacuation: the warning system to evacuate the downstream area is set into operation.

Emergency situation B: Preparedness: persons involved are alerted to be prepared to possibly evacuate.

Emergency situation C: Advice: If the observer is unsure of the degree of gravity professional advice should be obtained.

Emergency situation A (evacuate): When does an emergency situation arise?

A1 Dam wall has failed and water is flowing downstream

A2 There is a large flood and water is flowing over the non-overspill crest of the wall or will do so shortly

A3 There is a flood and the spillway channel of the dam is seriously damaged, so much so that a breach can occur through the spillway

A4 There has been an earthquake and the dam wall is damaged

A5 The dam wall is going to fail or is showing signs of serious damage as listed below:

- Large cracks have appeared and they are still growing. Crack widths for instance increases by more than 5mm (0.5cm) per day at concrete walls or by more than 50 mm (5cm) per day at earth walls, are regarded as very serious
- Movement has taken place (sink holes, displacement, sliding, slipping, subsidence, holes, overturning, etc.) Relative movement of 50 mm (5cm) at concrete walls or 200 mm (20cm) at earth walls since the previous inspection is for instance regarded as very serious
- Earth wall is unusually damp or boggy and appears unstable
- Erosion tunnels or boils appear on the downstream side and flowing mud is visible

Action: What should be done?

- Warning system (Table 6) should be put into action. Authorities/persons threatened by the dambreak flood (Table 7 and Table 8) should be warned to evacuate immediately (by telephone, radio, car, etc.) Tick off systematically as each person is warned
- Guards with red flags and/or warning signals should be placed at road crossings downstream of the dam until authorities can take over
- Place an observer at the dam. Provide him with a means of communication as soon as possible
- Open the outlet valves fully to draw down the water level of the dam
- Provide lighting to the problem area.
- Implement a monitoring program so that changes in the situation could be noted and measured. Mark cracks with pegs or paint and take readings of crack length, crack width or any relative movement on a daily/hourly basis.

Emergency situation B (preparedness): When does an emergency situation arise?

B1 Turbid or dirty seepage water with soil particles and leaking at more 1 l/s

B2 Water level of dam is unusually high, that is, near the non-overspill crest and it is still pouring with rain

B3 Less serious situation of the items mentioned in A3 to A5 above

B4 Blockage of spillway during a flood which can not be corrected immediately.

Action: What should be done?

- Put warning system (Table 6) into action. Authorities/ persons threatened by dambreak flood (Table 7 and Table 8) should be warned to be prepared to evacuate if necessary.
- Further actions are the same as Emergency Situation

A.

Situation C (uncertain - get advice): When does an emergency situation arise?

C1 Turbid or dirty seepage water is leaking at less than 1 l/s

C2 Unusual increase in leakage of seepage water without it having rained or that the water level of the dam has risen

C3 Development of wet patches on the downstream slope

C4 Deep erosion of downstream slope or upstream slope

C5 Deep erosion in spillway channel after it came into operation

C6 Damage of abutment walls between spillway channel and dam wall

C7 Person in charge is unsure of the gravity of the situation

C8 Outlet valves are defective.

Action: What should be done?

- During situation C (if person in charge doubts the gravity of the situation), professional advice should be obtained. Furthermore, the situation should be monitored continuously as mentioned in the last point of Emergency Situation A.

Communication Aids

Communication aids to issue warnings should be mentioned, for example telephone, radio, road transport, television, etc. The time it takes for the dambreak flood to reach downstream development, should be estimated with the aid of a dambreak flood analysis to provide information during the issuing of warnings. If more accurate information is not readily available, the flow velocity of 15 km/h can be accepted for dams up to 20 m high if the river channel is not too steep. For higher dams and steep river slopes the flow velocity can be much higher. The flow depth for the first kilometre downstream can be accepted as 2/3 of the wall height and thereafter as 1/2 of the wall height for a distance per kilometre equal to the maximum wall height per metre.

Table 6: Warning system: List of Responsible persons/authorities who **should issue warnings and take certain** actions in the event of an emergency situation

Name and address and tel. no.	Responsibility
Head of warning system: (Dam owner or appointed capable person)	Evaluate gravity of emergency situation and issue warnings to evacuate (emergency situation A) or to be prepared (emergency situation B). Consult list of addresses. If unsure about the seriousness of the situation, obtain further advice.
Head: Civil Defence:	Co-ordinate evacuation in urban areas. Consult list of addresses and map.
Town Clerk:	
Chief of Fire Department:	
Road and Rail Authorities:	Close, man or place warnings signs at river crossings.
SAP:	
Defence Force:	
Other:	

Note: The above-mentioned list is only an example and should be amended to suit circumstances. Each person's responsibilities should be cleared/agreed beforehand. A copy of the emergency plan should be given to each person.

Table 7: Persons/authorities threatened by **a dambreak flood who should be evacuated** or warned to be prepared

The location and entrance route to the persons listed below should be indicated on the map (refer to map of threatened area)

Name	Home address

[redacted]

Regional Director of the Department of Water Affairs and Forestry	
Director-General Department of Water Affairs and Forestry, Private Bag X313, Pretoria	

Name and Address	Telephone number
[redacted]:	

An emergency should be reported to the Director-General (DWAF) as soon as possible, during, or after the incident.

Map of threatened area

A map which indicates the dam wall, and dambreak floodlines, should be included.

In most cases a copy of the 1:50 000 map, upon which all the information has been indicated, should be sufficient.

Residences, threatened development, together with entrance routes, should also be indicated.

D.1 Dam failure issues

Failures of pollution control dams can and do occur. It is important that the design and operation of pollution control dams take cognisance of this, due to the potentially significant impacts to people and the environment that such dam failures can have.

PCD failures constitute the following:

- Structural
- Seepage, and/or
- Excessive spillage.

The reasons for the above pollution control dam failures can be either:

- Insufficient storage capacity within the dam
- Poor construction
- Poor operation
- Control and instrumentation errors or failure
- Inadequate abstraction

Table 9 provides a summary of the causes of pollution control dam failures and the possible mitigation measures that should be put in place to avoid such failure.

Table 9: Dam failure causes and mitigation measures

Reason for failure	Causes	Pos
Insufficient storage capacity	• Incorrect hydrological calculations • Incorrect modelling during the design phase • Amendments to the dam and mine water balance during operations, contrary to the assumptions made in preparing the water balance during the design phase, e.g. lack of adequate abstraction and recycling of water or ability to use the recycled water • Lack of adequate maintenance of the dam during operations, e.g. sediment removal, cleaning of dam basin	suita
Poor operation	• Incorrect operations against the dam water balance • Failure in the leachate collection and management system • Mechanical and/or electrical failure • Operator error • Poor design	
Poor construction	• Inappropriate and/or inexperienced contractor team • Inadequate quality assurance programmes and quality control during construction	
Control and instrumentation	• Poor level control philosophy • Failure of the control systems on the dam	

The following discussion details some lessons learned from planning, design, construction, operation, maintenance and abandonment of dams. The most common pitfalls/mistakes/lessons/observations are be addressed as theses are deemed to be of most value to the prospective dam owner.

D.2 Some observations from good and poor planning

D.2.1 Plan the raising of a dam whilst planning/designing the new dam

With State or large municipal dams this aspect has been well addressed in South Africa, whilst in the case of private dams the situation is at the other end of the spectrum. It has been noted that many "farm" dams are raised some two (2) to four (4) years after completion because the

sible mitigation measures
Design checks Review/audit and sign-off of the dam design by a ably qualified person Regular updates to the dam and mine water balance to ensure that this adequately reflects the site conditions Regular maintenance and cleaning of pollution control dams
Regular review of the operations of the pollution control dam against the dam water balance Regular maintenance of the dam facilities Regular training for the dam operations personnel Awareness creation of the risks inherent in the operations and potential impacts of pollution control dams Suitably competent design team
Appoint suitably experienced contractor teams Employ suitably qualified site management personnel
Regular maintenance and testing of the control and instrumentation systems

owner has discovered the "real" value/benefit of water. Generally the outlet pipe is too small for the increased reservoir size, not only for water supply purposes but also to lower the reservoir level at an acceptable rate in [illegible]ergency.

In several cases dams have failed because they were raised by 3 m to 5 m on the assumption that the foundation of the original dam is satisfactory. Had proper investigations been done (i.e. reasonably deep "trial pits" with good soil profiling and sound evaluation) these dams would not have failed.

Notwithstanding the latter there are many clear cut cases where the foundation is particularly poor, and raising of a dam should not be considered at all. Unfortunately some economists, developers, inexperienced "professionals", as well as laymen, are not prepared to accept that there is a "limit". This is called the "ultimate limit state" (a term commonly used in structural engineering) which has been exceeded in some cases, and dams have failed.

D.2.2 Concrete gravity dams

It has been observed in many cases that sound planning has been adopted in South Africa with regard to the raising (or "staged construction") of concrete gravity dams. There has been a definite trend to construct these dams to the full "footprint" (as seen in plan) of the raised dam. Raising then entails the addition of mass concrete and perhaps some extension of the gravity section on the upper left and right bank, respectively. Foundation work is minimised and interaction between an existing loaded dam, and new concrete placed on an extended foundation (unloaded), is not an issue.

D.3 Some observations and lessons from the design **and construction of earthfill** dams

D.3.1 Earthfill embankment dams

Unfavourable incidents (or failures) as described in section 9 can be minimised, and with due care and attention mostly eliminated/prevented.

The possible failure mode that generally receives most attention at design stage is the slip failure. Although this can be a most dramatic failure, and possibly with serious consequences, it is not the most common incident in practice. It is probably given most concentration of effort because it lends itself to computation.

The strength parameters of the soils can be determined by laboratory testing of samples, a computer will calculate stresses on innumerable possible failure surfaces, and the designer can produce proof of factors of safety to meet laid down standards. All very neat and satisfying. But beware of a false sense of security. There is a host of potential errors in the method, regardless of the number of decimal points that appear on the computer printout.

The very small samples of soils tested may not be truly representative of the bulk of material incorporated in the dam embankment; the state of saturation and consolidation may not be the same as will pertain in the dam; assumed position of the phreatic surface and hence the pore water pressure at any point may not be the same as occurs in practice.

This is not to say that calculations of factors of safety against slip failure are completely redundant and should be omitted, but only that they should not be given undue prominence. The effort and expense of such calculations is probably not justified on dam embankments of less than 12 m height, provided that reasonable materials are chosen, with the selection based on parameters obtained from standard indicator tests such as grading, density and plasticity, and also having proved that the foundation is adequately strong. It is noteworthy that dam embankments all end up with similar design slopes, unless constructed of more unusual soils.

So if avoidance of slip failure is not to be regarded as the prime target of embankment design, one must find some other guidelines. It is seen that most of the failure modes are highly dependent on the seepage line and the position of the phreatic surface. If the saturation line breaks surface on the slope of the fill, and not at the toe of the dam there is the evident risk of piping or ravelling and the pore pressures in the embankment will substantially reduce the effective strength. It is therefore a design objective to prevent day lighting of the phreatic surface.

The solution then is to incorporate a properly designed chimney drain and blanket drain to intercept the phreatic surface, and safely discharge all seepage water, respectively (Kabell, 1994,12-13).

Compaction, moisture and density

Moisture content of soils placed in the embankment is not determined purely as an aid to compaction. In fact, with the heavy compaction equipment in common use, specified densities can generally be more readily obtained with moisture contents well below standard Proctor optimum.

Increased moisture contents during construction result in an improvement of the impermeability of a given soil, and also create a more plastic and flexible structure. This makes the embankment more tolerant of defections due to differential settlement or other causes, and reduces the risk of cracking.

The Dam Safety Office has observed that specified densities are easily achieved, and both contractors and some members of the civil engineering profession will quickly reveal this with pride when asked. However, upon further inquiry it is very common to be told that moisture content is “not quite up to standard”. There is a misconception that moisture content is of secondary importance if specified densities are regularly obtained. It must be emphasised that in earthfill dam design and construction both the specified densities and moisture contents must be obtained. An “either/or” situation is not acceptable. This is a very common and serious problem that has been observed throughout South Africa over the last decade.

Dispersive soils

Dams continue to fail in South Africa because no concerted effort is made to identify dispersive soils, or if identified, the embankment is not properly designed to address the problem, neither is the material correctly “treated”/handled during construction.

There is no “excuse” for these failures because there is a wealth of local experience and readily available literature on dispersive soils. Melvill and Mackellar (1980), Elges (1985), Gerber and Harmse (1987), Brink and Wagener (1990) are particularly good references to begin with.

Embankment materials, as well as the foundations, must be tested for dispersivity on every dam. Where dispersive soils are encountered the appropriate measures such as compaction at 3% wet of optimum to a minimum density of 98% standard Proctor, and protective filter systems and stabilisation where necessary, must be incorporated in the design (Elges, 1985).

It is strongly recommended that special care be taken with dispersive soils to avoid very expensive and disastrous incidents/failures.

Alluvial boulder/gravel with a sand/silt/clay matrix

Recently three (3) very long embankments varying in height from 8 m to 13 m were constructed on alluvial deposits where there was a limited amount of suitable core material. Alluvial boulder/cobble/gravel with a sand/silt/clay matrix was used for the outer zones of the embankments and segregated when placed, and was difficult to compact. In the case of the first two dams the contractors “treated” the fill as though it were “normal” earthfill, whilst the lessons/experience gained could be passed on for the benefit of the third dam.

“Difficult” alluvial material as described above should be basically treated as though it were a type of properly “moisture” conditioned rock fill (not sluiced). The material should be carefully selected, spread and mixed, with very strict control of layer thickness. A study of the literature shows that a minimum of 4 passes of a 10 ton vibratory roller should be sufficient.

It is recommended that a minimum number of passes is specified in the bill of quantities, with an “extra-over” item rate on the number of passes to give the compaction required. The latter will depend on moisture content of the material, how well the material is spread and mixed, and layer thickness.

This was established at the Greater Ceres Dam (currently under construction) where a trial section of rock fill embankment was tested with 3, 4, 5, 6, 7 and 8 passes using a smooth drum vibratory roller. On the surface of the test section (a rectangle in plan) spray paint marks were placed at strategic points, then leveled before and after the requisite number of passes. When settlement had “stabilised”, it was deemed that the minimum number of passes required would be a “number” that yielded “minimal or insignificant” change in settlement.

It should be noted that where there is uncertainty as to whether a “difficult material” will behave as rockfill or earthfill during construction, both a smooth drum roller and a sheep foot (or pad foot) roller might have to be used initially to find out which gives the best results.

It is essential that a very firm stand be taken at the beginning of a project where a contractor is required to handle “difficult” material/fill as described in this section. If the first two hundred meters of an embankment is not correct, or there are problems with “methodology”, then the work must be stopped. It is much easier to rectify the first four (4) layers of 200 m of embankment instead of the “bulk” of 1.2 km at a later stage.

D.4 Lessons and problems in **connection with outlet works**

D.4.1 Size of outlet pipe

In many instances the size of the outlet pipe is too small. When problems are experienced with a “flaw”/crack in the pipe and concrete surround, a sleeve is inserted in the pipe and the annulus grouted. Failure of outlet pipes is very common in South Africa and it has reached such notable “proportions” that designers should consider using steel pipes or using larger pipes to ensure that outlet capacity is not reduced when a pipe is “sleeved”.

D.4.2 Concrete surround and steel reinforcing

The number of failures is so common that there is no doubt that concrete surrounds for outlet pipes are insufficiently reinforced. Designers are encouraged to design for bending as well as direct tension induced by “lateral spreading” of the embankment, rather than to provide only nominal longitudinal steel and stirrups. A special research project should be launched to investigate the failure of outlet pipes and their surrounds, with the aim of providing good design guidelines.

D.4.3 Pressure tests on outlet pipes

In many cases this is not done either because of lack of experience or because it is too much trouble. The Dam Safety Office is aware of at least five (5) cases where outlet pipes/surrounds appear to have been damaged during construction, failed the water pressure tests, and have had to be “sleeved” before the dam has been completed.

D.4.4 Intake structures/boxes/screens for outlet pipes

On a number of occasions the Dam Safety Office has visited dams where the intake structure/box/screen for the outlet pipe has been placed incorrectly i.e. too low, in relation to the surrounding “floor” of the reservoir basin, and in a localized depression.

With time debris collects at the inlet, or the steep side slopes of a localized hole creep and collapse against the intake structure partially (or totally) blocking it. Particular care should be taken by dam designers to position the lowest intake of the outlet works for a dam at the correct level i.e. not “too low”. Even if an intake is installed 1.5 in “too high” there will generally be an insignificant loss of storage capacity. This will invariably involve a design change when the foundation of the structure has been constructed, and the “average” ground level in the vicinity confirmed, however, this extra effort is a good long term “investment”.

D.5 Examples of failures

D.5.1 Abandonment of a dam after inadequate maintenance

A safety assessment of a high-hazard earth dam in 1987 revealed the spillway capacity to be 300 m^3/s, compared with a regional maximum food (RMF) of 1,400 m^3/s. The embankment was overgrown with large trees and the outlet pipe was blocked. The crest width was only 1.5 m in places, and the slope stability was well below acceptable standards. In the dam safety inspection report it was recommended that the dam be upgraded, the full supply level lowered, or the dam abandoned. The owner chose the latter solution, because it was more cost effective, and an alternative source of water was readily available.

The embankment was breached under controlled conditions, and precautions were taken to ensure public safety. The breach was designed to pass large floods so that the remaining structure (without further operational action, maintenance or inspection) would hold no danger to human life or property.

D.5.2 Safety of a post-tensioned dam

A 30 m high composite dam was constructed in 1942, and raised by 7 m in 1960 using 200 t post-stressed cables, anchored through the original structure into the sound foundation rock. A safety assessment in 1988 revealed that no reliance could be placed on the post tensioned cables. With no contribution from them, the dam could have failed by sliding, with loads imposed by a 1:100 year return period food; this could have caused the loss of thousands of lives. Further investigations were carried out and it was decided to make the dam safe by demolishing the raised spillway section. The time-dependent integrity of non-re-stressible cables in very old dams is an issue with many unknown factors in the context of dam safety, and they should be monitored by means of a well designed and maintained “geodetic system”. At least two (2) dams exist (32 m and 51 m high, respectively) where the period 1988 - 1997 (i.e. a “decade”) has been “lost”. Valuable deflection trends could have been observed and recorded over this period, but the time cannot be bought back.

D.5.3 Overtopping following ignored directive

Sometimes failure occurs when safety assessments and improvements are not done at an appropriate time. A dam safety inspection directive issued in February 1987 met with resistance and was ignored by the owners of the 21 m high Tierpoort Dam. One year later the earth embankment was overtopped by 300 mm and failed. The incoming flood of 4,000 m^3/s was reduced to 1,700 m^3/s because of basin absorption, but the maximum capacity of the spillway was only 830 m^3/s. Within two hours the 132 m long embankment had been completely washed away, according to reliable eyewitnesses, and the dam break flood peak was subsequently estimated to have been 6,400 m^3/s. The dam was reconstructed and completed in 1990.

D.5.4 Failure of the Wally Holmes Dam **after “token” compliance with the** regulations (1992)

The owner of a 17 m high dam being constructed complied with the legislation until two months after a permit to construct had been issued. To cut costs he neglected to have compaction tests done, and insisted that visits to site by the approved professional engineer be minimized. It was also specified that the owner should contact the engineer at strategic stages during placement of sand and chimney drains. This instruction was ignored. When the engineer visited the site again the dam was nearly complete, and there were indications that some of the filters and drains had been omitted, and density tests had not been carried out.

Heavy rain fell in the catchment area, and when the dam had filled to a depth of 10 m, the embankment started piping in two places. Fifty (50) people downstream of the dam were evacuated because the dam was in danger of imminent failure. Pipes in the embankment developed to between 2.5 m and 3.0 m in diameter on the upstream and downstream faces of the embankment respectively. The dam failed. Fortunately there was no loss of life, but a downstream weir silted up, resulting in economic loss to its owner. The cause of failure was poor quality control, and piping was located at the elevation where approved professional engineer “involvement” ceased.

D.5.5 Dam safety and neighbouring states

The failure of the 38 m high Zoeknog Dam by piping during first filling in January 1993 is another example of what can happen if appropriate control is not exercised. At the time of construction, no dam safety legislation was in force in that part of South Africa. The investigation into the cause of failure revealed several shortcomings which would normally have been identified and alleviated during the review process required according to RSA dam safety legislation. In dam safety, as with water resources planning, it is important to remember that water knows no boundaries, and countries should promote the adoption of appropriate dam safety legislation across common borders.

D.5.6 Romans River Dam near Wolseley (piping failure)

H = 4.9 m V = 89 000 m^3 Earthfill dam

This dam failed by piping on first filling in 1993 at the junction/interface between old earthfill and new earthfill which was used to make a larger “U”-shaped embankment (in plan) from two existing embankments. Water from the pipe (±1.2 m in diameter) washed away ballast and embankment fill on the Cape Town to Johannesburg railway line leaving the rails “suspended”. This occurred at night just after a train had passed! The repaired dam has since been declared a dam with a safety risk. There was no “engineer involvement” for the design and construction of the modification of this embankment.

This case study clearly illustrates that special care is required at earth “interfaces” which may not be that obvious to the inexperienced dam engineer or layman.

D.5.7 Watergang Dam near Stellenbosch

H = l4 m V=110,000m^3 Earthfill darn

This was a classic “circular” slip failure of the downstream face of the embankment (constructed 1964/1965) coupled with severing of the outlet pipe (25 July 1993). An emergency channel was excavated on the left flank to lower reservoir level by 5 m and a diver closed the outlet pipe on the upstream side to prevent saturation and total failure of the embankment.

Police, traffic police, fire brigade and the local authority participated in a “civil defence” role with respect to safety at the main road, ±500 m downstream of the dam. This involved day/night surveillance over a 72 hour period.

Subsequent investigation revealed that problems had been previously experienced by the owner of the dam where there was a “flaw” a short distance away from the “ultimate” position of the “fracture” of the pipe. The pipe was a 225 mm diameter asbestos cement pipe encased in concrete with very nominal steel reinforcing. Failure of the dam is attributed to a very weak foundation and the build up of high pore water pressure. The outlet pipe (with its surround) appears to have failed in “direct” tension during the circular slip of the embankment coupled with “lateral spreading” of the embankment itself.

Interestingly enough there was no differential displacement at the “break” in the concrete pipe (i.e. nearly perfectly “aligned”), whilst the two annular faces were some 100 mm to 200 mm apart. This is the first time that the DSO has seen an outlet pipe fail in direct tension. The lesson to be learnt from this incident is that it is unwise (also poor design practice) to use an asbestos cement pipe with a concrete surround unless it is located on a solid rock foundation.

D.5.8 Kruin Dam near Grabouw (piping failure due to a cracked outlet pipe)

H = 16 m V = ± 225,000 m^3 Earthfill dam

On 18 July 1994 at approximately 17:00 this dam, which was some 60% full, failed by piping causing an estimated dam break flood of 350 m^3/s. The manager of the farm Spioenkop on which the dam is located was an eyewitness to the failure and said that “first there was just a small hole, almost as if a mole had burrowed through the wall. Then it just grew.” The media referred to the failure as a “triple dam burst” where “a powerful torrent of water coursed through two other dams before engulfing 15 houses far below.”

Approximately 60 people were evacuated with no loss of life. The residents were reluctant to leave their houses because it had not rained from some two (2) weeks and it was “beyond comprehension” that a flood could be on its way. Had the failure occurred one (1) hour later it would have been dark and there would have been many fatalities. Damage to houses, buildings, machinery, personal belongings and orchards was approximately R 2.5 million (excluding the cost of the three dams which failed). Particulars of the two dams downstream of Kruin Dam which were damaged are given below:

Middle Dam H = ± 8 m V = ±40000 m^3
B = 3 m x 4.5 m*

Stoor Dam H = ± 9 m V = ±90000m^3
B = 3 m x 7.0 m*

* B = Size of breach = depth x width, respectively.

Kruin Dam was constructed some 15 years ago and failed due to one or a combination of the contributory factors listed below.

- Poor design (if any)
- Inadequate foundation preparation
- Material properties (dispersive soils)
- Seepage around and along the outlet pipe
- The 150 mm diameter asbestos cement outlet pipe was not encased in concrete neither did it have a sound foundation. The pipe could have cracked and water flowed along the outside causing piping, subsequently leading to the embankment being breached.

The dam was not registered and the Department was not aware of its existence because, being on top of a very high hill (totally surrounded by very tall trees), the dam was not "visible" thus not likely to be identified during normal "dealings" with a farmer/water consumer. The owner of the dam stated that he had not registered his dam because he was under the impression that only dams with capacities greater than 227,305 m^3 had to be registered.

D.5.9 A.N. Other Dam (1)

H = 11.5 m V = 120,000 m^3 Earthfill dam

This dam was raised from 8.0 m to 11.5 m and the work completed in May 1993. A "slip" occurred on 8 September 1994 on the downstream face of the embankment at a point where the outlet pipe was extended (i.e. where the new pipe joins the old pipe). When the owner of the dam reported the incident he said that the outlet pipe had quite likely cracked. When questioned by the Dam Safety Office about reinforcing steel in the concrete surround he indicated that only steel supports were used to keep the pipe clear of the pipe trench during concreting. No steel reinforcing was physically included in the pipe surround.

On further investigation it was found that there was an agreement between owner and engineer that the latter would do the design (including drawings and specifications) whilst the farmer would construct/extend the outlet pipe. Obviously the owner did not read the drawings properly, and naturally there was no engineer "involvement" prior to concreting of the pipe surround. Such "arrangements" are not acceptable and engineers should be totally involved in all aspects of the engineering of the dam.

D.5.10 A.N. Other Dam (2)

H = 14 m V = 209,000 m^3 Earthfill dam

This dam was completed in about 1965 and the embankment sustained a severe downstream toe slip of limited area/extent early in 1985 along a ±30 m length in the river bed. The maximum "vertical" displacement was ± 4 m and ground heave ahead of the embankment toe indicated a deep seated location for the failure horizon within the foundation. After promulgation of the dam safety legislation on 25 July 1986, and when the overall dam safety program had gained momentum in South Africa, it was decided that nothing would be achieved by "formal inspection" of the dam because this could be done as part of the repair / "betterments" of the dam.

A sand toe drain was installed, the embankment repaired with an acceptable downstream slope for that particular material, and the works completed in the last quarter of 1991. In November 1991 a 10 mm wide crack approximately the same length as the "top" of the original slip length (parallel to the crest of the embankment) was observed. This crack widened to 200 mm in March 1992 and several months later developed to a classic circular slip failure with a "vertical displacement" of approximately 1.7 m. During the latter process the toe of the embankment/immediate downstream zone of the embankment heaved (bulged "upwards") above normal ground level by at least 1 m.

In depth investigations revealed a very soft "impermeable" clay layer of alluvial origin (40 m wide and ± 4 m thick) along the course of the original stream bed. This deposit, overlain by 1 m of black root impregnated, sandy alluvium, and overlies a residual Malmesbury soil (silty clay and gravelly clay) comprising highly weathered siltstone and greywacke, had never been previously "identified"! It was also established that the lowest point of the critical/ failure slip circle plane was 5 m below natural ground level and limited to the contact between the alluvium and residual Malmesbury soil. Some back calculations yielded factors of safety of between 0,96 and 0,98 for a range of slip circles. Further investigations revealed that the failure of the dam was basically caused by a failure of the foundation itself which had been subjected to high pore-water pressures. The latter was confirmed by 11 months of monitoring by piezometers where it was found that the underlying residual soils showed the greatest (and quickest) response to changes in water level in the reservoir. Analysis showed that (depending on realistic possible c' and O' values selected) the order of magnitude of pore-water pressure to achieve instability (or F = 1) varied between 60% and 87% of full supply level "depth" of water.

The "slip" has continued to creep downstream and the entire "failure environs" is monitored by regular observations taken from some twenty (20) standpipe piezometers. The outlet pipe also cracked and it has been accepted that seepage from the pipe has further saturated and weakened the foundation. A "liner" was installed in the outlet pipe and the annulus grouted. The embankment is operated at a "safe" operational level of some 3 in below full supply level. Repair will take the form of a dam with a lower full supply level and "drainage measures" or, a stabilising berm, at the downstream face/toe of the embankment and separated from it by a suitably designed chimney drain and blanket drain. The lesson from this case study, that may not be that obvious, is that even with small embankments particular care must be taken with identification/profiling of foundation materials with their associated strengths/weaknesses with emphasis on "drainage considerations".