OUR DAM

Brochure on Dam Development for Owners of Dams

SOUTH AFRICAN NATIONAL COMMITTEE ON LARGE DAMS

(SANCOLD)

2023

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GLOSSARY OF TERMS

Abutments:	Those parts of the valley against which the dam wall is constructed. The contacts between the abutments and the slope of an embankment dam are called the slope-abutment interfaces.
Dam:	Includes any existing or proposed structure which is capable of containing, storing or impounding water (including temporary impoundment or storage), whether that water contains any substance or not. Refer to the National Water Act, Act 36 of 1998 Section 117.
Ecological Water Requirements:	(EWR) The low and high flow requirements, combined to produce the final flow requirements, for a range of selected Ecological Classes. The EWR is not a fixed value but varies based on prevailing hydrological (flow) conditions for the river reach in question.
Foundation:	The foundation of a dam is the portion of the valley floor that underlies and supports the dam structure. This is also known as the solum.
Freeboard	The vertical distance between the crest of the wall/embankment (without camber but including parapet walls and wave barriers proud of the crest) and the reservoir water elevation. The more specific term “normal freeboard” is defined as the difference in elevation between the crest of the dam and the normal reservoir water level (Full Supply Level) as fixed by design requirements. (Refer to SANCOLD, 2011).
Full Supply Level (FSL)	Means the level at the dam where the reservoir is considered to be one hundred percent (100%) full under normal operating conditions (crest level of uncontrolled spillway). For a reservoir where the outflow is wholly or partly controlled by movable gates, siphons or by other means, it is the maximum level at the dam to which water may rise under normal operating conditions, exclusive of any provision for flood surcharge (DWS, 2012).
Non-Overspill Crest (NOC)	The part of the dam wall designed not to be overtopped. Usually this part consists of a roadway or walkway.
Outlet Structure:	Infrastructure allowing for the controlled release and conveyance of water from dam storage to the

	downstream river reach and/or water users. Releases may be made for a variety of purposes, including downstream water use, flood management, emergency drawdown requirements and the EWR.
Owner of a dam:	Person, institution or company that owns the structure, and includes the person in control of that dam. In South Africa, over 70% of the dams are owned and operated by the Department of Water and Sanitation.
Reservoir:	The reservoir is the body of water impounded by a dam.
Spillway:	Structure provided as part of the dam to safely discharge floods.

1. INTRODUCTION

This brochure is intended to alert the reader to elements of planning, design, construction and operation of dams, to provide information required for dam development and guidance to source material on key aspects.

It is not intended to be an all embracing report on state-of-the-art technology, but it is intended to report on designs and constructed works for the future benefit of society and the industry, which seeks compliance with performance standards in a cost-effective manner that ensure the safety of the public. Reconciling water availability and increasing water demands requires that decision making make provision for sustained agricultural, industrial, mining development and environmental considerations, in several regions of South Africa.

This document is focused more on the smaller and medium sized dams and is not intended to address pollution control dams (PCDs) and tailings storage facilities (TSFs), which are commonly required elements of mining practices. Although this document has much in common with pollution control dams especially with respect to the embankment features, the containment barriers and cost optimisation thereof are addressed in a separate SANCOLD brochure.

2. CHANGING PLANNING REQUIREMENTS

The planning process followed in response to a need may vary widely, depending on the purpose of the dam and what the need is. Planning requires an assessment or definition of the quantity and quality of water needed and an investigation into a range of options, which could fulfil the need. These options are then assessed for their environmental, financial and technical feasibility to inform a decision on the best practical option for implementation. With South Africa being a water scarce country there are limited feasible options for development, the first option preferably being to pursue demand management. Factors to be taken into consideration of technical feasibility include the availability of water at surface or from groundwater, sediment yield of the catchment or water resource, the re-use of water, the distance over which the supply is to be transported from storage to point of demand, the availability of suitable sites, the social and ecological environmental impacts and benefits, and the financial viability. Competent planning is a multidisciplinary approach that can be expensive and time consuming, but is warranted to ensure that the dam project can be implemented within the requirements and that the project is sustainable.

The development of water resources infrastructure reflects an increasing rate in consumptive use with time, and that only in recent decades has appreciation of water conservation with demand management and resource quality grown significantly. The process and practice followed in pursuit of authorisation for water resource infrastructure facilities have evolved significantly over the past five decades with changes in philosophy, technology and performance standards. The need for and process of change with time is reported below.

A brief overview **of water resources development legislation** and commensurate regulatory structures and objectives gives significant insight into the rate of change of development with time, with associated generation of waste or pollution and the significance attributed thereto.

Human settlements have been established near reliable water resources, usually our larger rivers, with the arrival of agriculturalists and during the iron age two millennia ago. While the oldest dams in the world are several thousand years old, the oldest known embankment dam was constructed on a wadi *(i.e. a low, dry valley)* along the Nile River in Egypt some 4 500 years ago (ICOLD Bulletin 143 (2013) *Historical Review on Ancient Dams*). The development of dam engineering as we know it in South Africa today commenced in 1800 with the next two dams constructed in 1830, and by 1900 there were some 32 dams in the country, built mostly for agriculture and some for domestic use. A brief history of water resources development in South Africa is included in **Appendix A**.

The development of water storage facilities over the past century has led to an increasing awareness of **soil erosio**n within catchments and the resultant sedimentation of dams. Reservoir sedimentation leads to a loss of storage capacity, damage to mechanical items, and upstream and downstream impacts.

Of the approximately 7 000 km^3 of storage in dams worldwide, approximately 3,000 km^3 is for **dead storage** and the remaining 4 000 km^3 is for live storage of which the majority (3 000 km^3) is for hydropower, and the remainder (1 000 km^3) is for irrigation, potable water, mining and industry (Msadala & Basson, 2009). In South Africa the total mean annual runoff is estimated at 49 km^3 *(i.e. 49 billion m^3)* and the total storage in large dams is estimated at 33 km^3 *(i.e. 33.4 billion m^3)*. The rate at which storage capacity in dams is lost to sedimentation was based on hydrographic surveys of selected reservoirs from time to time. An analysis of the reservoir sediment deposit data showed that almost 25% of the total number of reservoirs have lost between 10 and 30% of their original storage capacity (Msadala & Basson, 2009). That study has shown that the average loss due to sedimentation in South African reservoirs is 0.3% per annum whereas the rate for all the reservoirs in the world is rated at 0.8% per annum, but this varies widely.

The extent of **sediment deposition** in a reservoir, and in particular accumulation in the upper reaches, consequential increasing in flooding has been underestimated in the past (Rooseboom 2002). Rooseboom states that even with much improved modelling techniques available it is not possible to make exact long-term predictions, due to the complex nature of the processes involved. The consequences thereof, particularly with sediment accumulation above full supply level, include water trapped outside of the river system behind levees (Department of Water Affairs, 2009, *Welbedacht Report*), with socio-economic impacts associated with land acquisition and relocation out of sediment and flood impacted areas many years after initial reservoir development.

The **capacity of the country to meet its water requirements**, now and into the future, can be found in a detailed report *Integrated Water Resource Planning for South Africa – A Situation Analysis 2010* (Department of Water Affairs, 2010b). It states that water supply requires long-term planning, and strategies to source and supply water must be aligned to national development goals. Since publication of the National Water Resource Strategy in 2004, the Department of Water and Sanitation has undertaken strategic water resource assessments at water management area level, followed by supply and demand reconciliation studies for major river systems, metropolitan areas, growth centres, and smaller towns and villages across the country. This work is ongoing.

The **adequate supply** of water for many areas can be sustained only if immediate actions are taken to stave off imminent shortages. The foremost action is the concerted implementation of water conservation and demand management measures. Additionally, the re-use of water offers an immediate and practical supply for cities and fast-growing towns, desalination of seawater offers security to coastal centres, and opportunities for groundwater development must be taken up. The remaining opportunities to build more dams should always be considered in the light of alternative options to supply the necessary water.

The challenge in reconciliation strategies is to ensure that the **demand curve never exceeds the supply curve**, illustrating available yield. A high growth trajectory is planned for as interventions can always be delayed in the event of lower growth, but it is often impossible to bring them forward to meet unexpected needs.

It is very clear from the reconciliation strategies that without active and immediate implementation of water conservation and demand management measures, almost all water supply systems run into deficit before new resource projects, with their long lead times, can be implemented. The water deficit countries are shown in Figure 2-1. **"South Africa cannot afford to waste any water, anywhere, at any time"** (DWA 2010) and (DWS, 2019). https://www.dws.gov.za/National Water and Sanitation Master Plan/DocumentsReports.aspx

The most important **feature of water conservation and demand management** is that it can be quickly and relatively cheaply implemented, with immediate results. Immediate savings of 10–15% can be targeted, with savings of more than 30% often achievable in the long-term. The reconciliation graphs accompanying all strategies show that supply targets will not be reached without serious measures and immediate investment in these measures.

Water re-use can be implemented quickly. The purification and recycling of treated waste water and other effluent will be essential in cities and larger towns. In the mining sector the re-use of water is already a regulatory requirement (DWS, 1999).

Groundwater is an under-used resource and its value often unrecognised, particularly in the case of smaller towns. It is thus critical to protect our groundwater resources from pollution, which renders the resource unsuitable for use or uneconomical due to the expense of purification.

Desalination applies to the removal of salt from seawater, and is also a critical part of the treatment of acid mine drainage and other polluted and saline water inland. Desalination has been adopted as an emergency source for coastal towns in drought-stricken areas, and is being considered as a source for coastal cities, and implemented for mine water treatment and urban supply on the Highveld.

The opportunity to build more dams is limited, with water delivered becoming increasingly expensive, especially given the long-distance transfers required. New dams must be weighed up in terms of impacts, economics and alternative options.

Catchment rehabilitation by way of Invasive Alien Plants (IAP) eradication may increase yield (Legge, 2019). Additionally, siltation management is required to reduce reservoir storage losses experienced due to dam siltation, and accumulation of sediment/silt in dam basins as a result of soil erosion.

Little additional water can be made available from conventional sources, and this water will be far more expensive.

Challenges in meeting future requirements include:

- The need for equity and for improved services from limited resources.
- Growth in water requirements where supplies are not readily available.
- Deterioration in water quality (acid mine drainage, salinity and untreated waste water).
- The development of sources and resources without destroying the environment.
- The implementation of the reserve.
- Climate change.
- Environmental requirements as explained in the next section.

Taking action in line with the reconciliation strategies put forward on the Department of Water and Sanitation website (http://www.dwa.gov.za) will ensure that water is available for sustained growth and development for the foreseeable future.

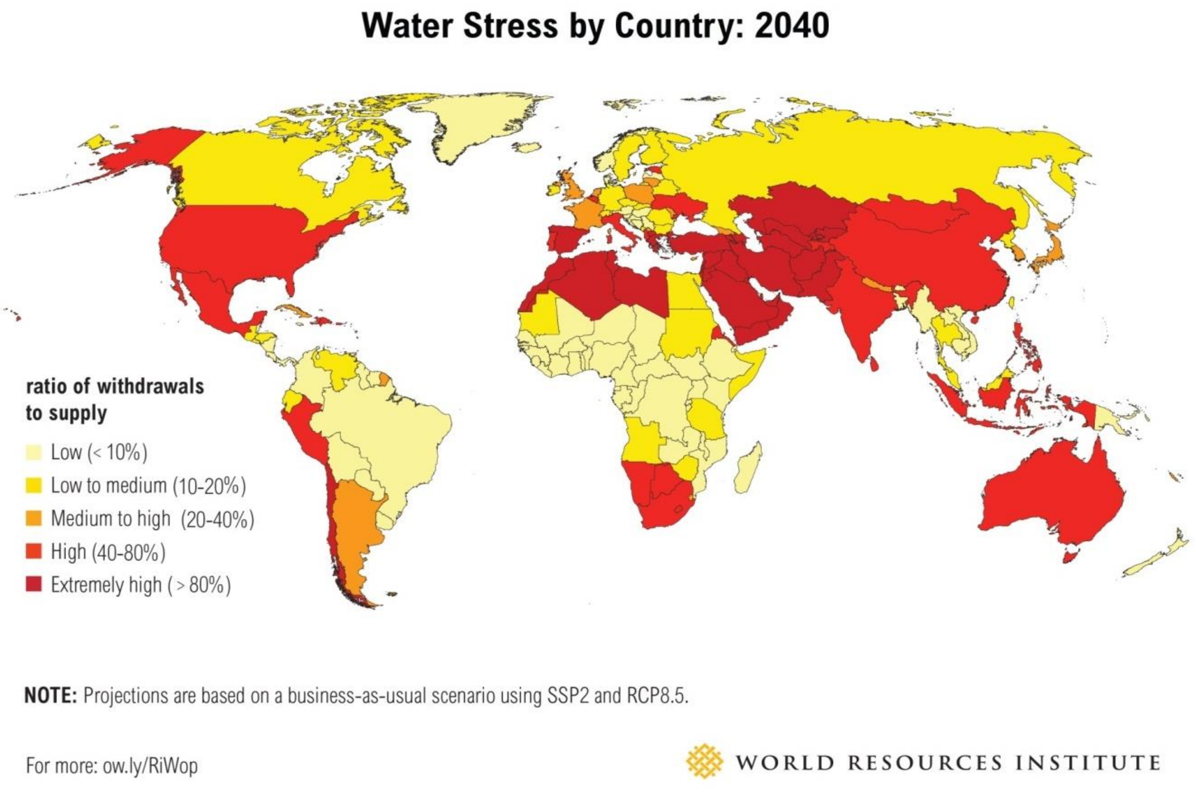

Figure 2-1: Water deficit regions for the world by 2040, as predicted by the World Resources Institute (2015)

3. DEVELOPING A DAM: LEGISLATION

3.1 Environmental Principles of Decision Making

The **National Environmental Management Act**, Act 107 of 1998, (NEMA 1998) defines the principles to be taken into consideration when considering actions which may significantly affect the environment. These principles are to be applied by all organs of state when making decisions which may affect the environment. Refer to Appendix B for a summary of Environmental Principles to be Applied by all Organs of State in South Africa (Extracted from the *National Environmental Management Act, Act 107 of 1998*).

These environmental principles are applied when considering environmental authorisation applications for listed activities, as listed in Schedules 1 to 3 of the NEMA Regulations 2014 as amended in 2017. These Regulations provide both the procedure to be followed in obtaining an environmental authorisation and the activities for which either a basic or a full environmental impact assessment is required (NEMA Regulations 2014, R982, R983, R984 and R985).

https://www.dffe.gov.za/sites/default/files/legislations/nema_eia2014regulations_g38282_0.pdf

Note: The National Water Act (NWA) 1998 defines a dam and a dam with a safety risk as follows:

(a) "dam" includes any existing or proposed structure which is capable of containing, storing or impounding water (including temporary impoundment or storage), whether that water contains any substance or not; and

(b) "dam with safety risk' means any dam –
(i) which can contain, store or dam more than 50 000 cubic meters of water, whether that water contains any substance or not, and which has a wall of a vertical height of more than five metres, measured as the vertical difference between the lowest downstream ground elevation on the outside of the dam wall and the non-overspill crest level or the general top level of the dam wall;
(ii) belonging to a category of dams declared under section 118(2) to be dams with a safety risk; or
(iii) declared under section 118(3)(a) to be a dam with a safety risk";

Caution: This has led to confusion in the mining industry in particular where tailings storage facilities clearly have a wall height greater than 5 m and the permanent water storage volume below the penstock outlet level is less than 50 000 m^3 despite the temporary storage following rainstorms being significantly greater than 50 000 m^3 of water (especially for hillside developments), and the consequences of failure being significant (as referenced in Section 121 of the Act). A further manipulation of the definitions by industry is to design dams with a wall height restricted to less than 5 m despite significant exceedance of the 50 000 m^3 storage capacity threshold, which leads to numerous unnecessarily expensive facilities and the inefficient use of water, in particular in the mining sector where pollution control dams and return water dams are critical elements of the mining process and which require contaminant containment barrier systems. Such dam designs can be optimised to achieve the desired storage volume with the minimum of lined surface area below the full supply level so as to minimise capital cost of the lining system, instead of the pursuit of a dam wall height restriction to avoid registration of the PCD as a dam with a safety risk and consequential substantial increase in cost to the detriment of the owner. See SANCOLD brochures on *Tailings Storage Facilities* and on PCDs.

3.2 Principles of Water Resources Management

The central guiding principles of the **National Water Act,** Act 36 of 1998, are equity and sustainability in the protection, use, development, conservation, management and control of water resources. Chapter 1 of the Act provides interpretation and fundamental principles to be applied, whereas Chapter 4 guides responsible authorities in the exercise of their discretion when granting a licence and conditions attached thereto. Still further, Chapter 11 of the Act defines the roles and responsibilities of persons who own, develop or operate a dam with a safety risk. Of particular importance are the Dam Safety Regulations of 2012 which provide the requirements for dams as a function of their safety risk. https://www.gov.za/sites/default/files/gcis_document/201409/35062rg9689gon139.pdf

3.3 Regulatory Requirements

The Acts of Parliament referred to above make provision for a Minister of the Department of Water and Sanitation to issue regulations in respect of particular aspects of the Act. Persons interested or affected by dam engineering may be particularly interested in the following:

(a) The **National Environmental Management Act Regulations (**NEMA Regulations, R982, R983, R984 and R985) **of 2014** as amended in 2017. These regulations provide schedules or lists of activities which require environmental authorisation prior to the activity taking place and define the procedure to be followed in pursuit of such authorisation.
https://www.dffe.gov.za/sites/default/files/gazetted_notices/nema107of1998_amendments_environmentalimpactsassessmentsregulations_gnr326_0.pdf

(b) The **Water Use License Application and Appeal Regulations 2017** define the process to be followed in pursuit of a water use license. The construction of a dam usually requires a single integrated license for the uses defined as the storage of water; the impeding or diverting of water flow; and the alteration of the bed, banks or characteristics of a stream (as defined in the NWA Section 21). https://www.gov.za/sites/default/files/gcis_document/201703/40713rg10701gon267.pdf

(c) The **Dam Safety Regulations 2012** are pertinent and provide detail on how dam safety classification is achieved and the commensurate requirements of parties prior to commencement with construction and impoundment of water. https://www.gov.za/sites/default/files/gcis_document/201409/35062rg9689gon139.pdf The NWA defines a dam with a safety risk as "*any dam which can contain, store or dam more than 50 000 cubic metres of water, whether that water contains a substance or not, and which has a wall of a vertical height of more than five metres, measured as the vertical difference between the lowest downstream ground elevation on the outside of the dam wall and the non-overspill crest level or general top level of the dam wall*".

(d) The **National Water Act Mining Regulations of 1999 (GN 704)** addresses the use of waste material and location of facilities as well as the hydrological sizing of pollution control dams and the prevention of pollution. https://water.cer.org.za/wp-content/uploads/2018/01/GN-704.pdf

(e) The **National Environmental Waste Act Regulations of 23 August 2013** R634 and R635 which provide the method of assessment of pollution risk for particular materials and R636 which gives the norms and standards for containment barrier systems, with particular attention drawn to Regulation 3(2) thereof which defines the norms and standards to be addressed in a performance based design.

http://sawic.environment.gov.za/documents/2177.pdf

(f) The **Mineral and Petroleum Resources Development Act (Act 28 of 2022) Regulations (2004 as amended)** which provide clarity on sections of the Act such as Section 106 on permits and licensing, as well as financial provisions.

https://cer.org.za/wp-content/uploads/2014/02/Regualtions.pdf

(g) Furthermore, registered persons in terms of the Engineering Professions Act, Act 46 of 2000, are required to **abide by a code of conduct** as defined in Engineering Council of South Africa, Board Notice 41 of 2017, which requires designers and reviewers to *inter alia* take public interest and the environment into consideration, and form opinions based on fact.

The reader should note that there is significant cooperation between Organs of State in an attempt to reduce inefficiencies, as required by the Constitution of the Republic of South Africa, Act 36 of 1996, Section 41 (g) and (h). https://www.gov.za/sites/default/files/images/a108-96.pdf

4. DAM ENGINEERING

4.1 Purpose of Dams

The purpose of a dam is to impound (store) water, wastewater or liquid borne materials for any of several reasons, such as flood control, human water supply, irrigation, livestock water supply, energy generation, containment of mine tailings, recreation, or pollution control. https://damsafety.org/dams101#:~:text=The%20purpose%20of%20a%20dam,%2C%20recreation%2C%20or%20pollution%20control.

4.2 Site Selection

Dam site selection should take into consideration at least the following: hydrology, topography, construction materials availability, accessibility, foundation geotechnics and geology, seismicity, spillway requirements. These amongst other aspects should inform the decision on type of dam to be selected for the site. The extent of investigation for site selection is influenced by the need for a dam, its size and associated safety risk.

4.3 Types of Dams

In selecting the best feasible option, the type of dam chosen will be influenced by the foundation conditions and construction materials available at or near the proposed dam site and the acceptable risk of failure, along with social and economic factors. This may lead to a single type or combination of dam types such as mass concrete gravity dam; arch dams, earthfill embankment; rockfill embankment with earthfill core or upstream concrete face or rubble masonry dam. Other dam types which are not aimed at raw or potable water storage include flood attenuation dams; tailings storage dams (often referred to as TSFs) and PCDs. Examples of dams are shown in Figure 4-1.

Figure 4-1: Examples of Dam Types

(a) Concrete face rock fill dam, (b) Concrete arch dam, (c) Concrete mass gravity dam, (d) Rubble Masonry Concrete dam, (e) Tailings Dams (f) Pollution Control Dam, (g) Earth embankment (composite) dam, (h) Flood Attenuation Dam

Figure 4-1 shows commonly found dam types encountered in raw water management systems. Further information on dam type selection can be found in the ICOLD Bulletin 183 *Preprint -Selection of Dam Type*.

4.4 Site Investigation

The purpose of the site investigation is to confirm information on topography, geology and the presence of fault zones. The investigation is largely required to identify the materials available on site such as clay, sand and rock and their volumes (preferably within the dam basin and wall area) along with anticipated foundation conditions. The results of this investigation significantly influence the dam type selection.

Guidance on the extent of the geotechnical investigation is provided by the South African Institution of Civil Engineering (SAICE) Geotechnical division and the South African Institute for Engineering and Environmental Geologists (SAIEG) in Site Investigation Code of Practice (2010) at https://www.geotechnicaldivision.co.za/wp-content/uploads/2020/03/SAICE_GeoDiv_SiCoP_Rev0.pdf . Further valuable information may be obtained from SANCOLD being The Design of Small Dams (Lecture Course - Stellenbosch 1997) and from the four volumes of *Engineering Geology of Southern Africa*, by A.B.A Brink.

4.5 Flood Hydrology

The estimation of design flood events, i.e., floods characterised by a specific magnitude-frequency relationship, at a particular site in a specific region is necessary for the planning, design and operation of hydraulic structures, e.g., culverts, bridges, spillways, etc. It is an established practice to design a facility for a certain flood event, commonly referred to as "Recommended Design Flood" (RDF) or "Design Flood", which informs the minimum design life of a structure. The design flood event is the probable flood event to be expected from a catchment following rainfall of estimated intensity and duration for a selected return period taking into account the hydrological characteristics of the catchment.

In many parts of South Africa, information is not available or smaller streams are not gauged to allow estimation of such floods for spillway design purposes. On larger dams and catchments, where it is more important that the spillway is correctly and properly dimensioned, it is of economic importance to study hydrology, climate, topography of the site and such related factors to arrive at reasonably accurate estimates of the peak flows. However, for smaller dams and catchments, unless this information is already available, the practitioners can hardly justify the cost of such an exercise and must resort to other means to safely estimate the design floods. In ungauged catchments, practitioners estimate design floods using either event-based deterministic and/or empirical methods, although, at-site and/or regional probabilistic methods or continuous simulation models could also be used to transfer design values from gauged to ungauged sites.

Event-based deterministic design flood estimation methods are most commonly used by practitioners in ungauged catchments. In the application of these event-based deterministic methods, it is acknowledged that both the spatial and temporal distribution of runoff, as well as the critical duration of rainfall, are influenced by the catchment response time. One such event-based deterministic method used in ungauged catchments is the Rational Method.

The Rational method, which is based on catchment area and assumed uniform rainfall intensity and runoff, is a useful tool for the estimation of peak flows from small catchments. The Rational Method is simple and most appropriate for catchments under 15 km^2 (it has been used successfully for larger catchments by more experienced users) and requires the design engineer to know the catchment area and the maximum daily rainfall to reproduce flood peaks. Other factors such as topography (especially the longest watercourse slope and catchment slope), the shape of the catchment, soil permeability and the vegetation cover, also require consideration. These characteristics will determine the catchment response to rainfall.

Where other structures already exist upstream of the proposed dam or new site in the catchment, ignore any flood reduction effects they may have as, the maximum probable flood will occur at the end of the rainy season when all storage areas, natural or otherwise, are at full capacity and they will, therefore, have little effect in enhancing the runoff and retaining flood water.

The Regional Maximum Flood (RMF) is an empirically established method that uses regional envelope curves to estimate the maximum probable flood that can be anticipated in a specific RMF region (Symbolized by K-values). The method further uses regional ratios derived from the recurrence interval flood peaks as a fraction of the RMF for estimating the recurrence interval of the latter. Also, it is used to calculate the Safety Evaluation Discharge (SED) in accordance with SANCOLD (1991) *Guidelines on Safety in Relation to Floods*. The SED is defined as the level pool peak discharge used to determine the sufficiency of a spillway system for a new or existing dam in the event of an extreme flood (SANCOLD, 1991). SEDs are calculated for various types of dams by scaling the determined RMF.

For further reading on the Rational Method, reference is made to the SANRAL Drainage Manual (2013) and for the Regional Maximum Flood determination to Kovacs (1988), whereas the method by (van der Spuy et al., 2023) is used by the DWS.

4.6 Spillway Sizing

The spillway of a dam is required to pass flood events safely. There are many spillway options available, each with its own attributes and risks. A spillway typically comprises of an approach channel, control structure, discharge carrier (transport/conveyance structure), energy dissipation structure and outflow channel. The control is generally classified as being gated or ungated, implying that the spillway is controlled by regulating devices such as gates or fuse elements. A description is provided in the table below.

Table 4-1: Spillway description

Component	Function	Example
Approach/entrance channel	Conveys water from the reservoir to control structure	Lined or unlined approach
Control structure	Regulates outflow from the reservoir	Ogee, labyrinth, PKW, etc.
Discharge carrier	Conveys flow from control section over, through or around the dam	Chute, channel, conduit, tunnel
Energy dissipation structure	Reduces energy and velocity of the flowing water/projects away from the dam	Stilling basin, roller bucket, etc.
Outflow channel	Conveys discharges to the natural stream downstream of the dam	Lined or unlined

The magnitude of the flood peak to be passed depend on the category of dam (size and hazard potential). The spillway system must accommodate the Design Flood without damage, while in the case of an Extreme Flood damage may be accepted, but the dam must not fail. An incoming flood could be attenuated in a reservoir and the discharge thought the spillway is normally of lower magnitude than the incoming peak. More details can be obtained from the SANCOLD *Guidelines on Safety in Relation to Floods (1991).*

The incorporation of flood attenuation dams in development of urban areas has become mandatory in several large metropolitan areas. No matter what the size of a flood attenuation dam, careful consideration needs to be given to the spillway size and type, including redundancy, so as to avoid blocking of the outlet orifices by debris. Such debris may take the form of refuse or animal shelters developed during dry periods, or vegetation and unnatural material displaced and transported by flood waters during and after storm events. These concerns may be especially valid for morning glory; syphon; gated; and similar closed conduit spillways, as well as for narrow spillways or wide spillways having piers or similar structures which could retain flotsam. Figure 4-2 shows different types of spillways.

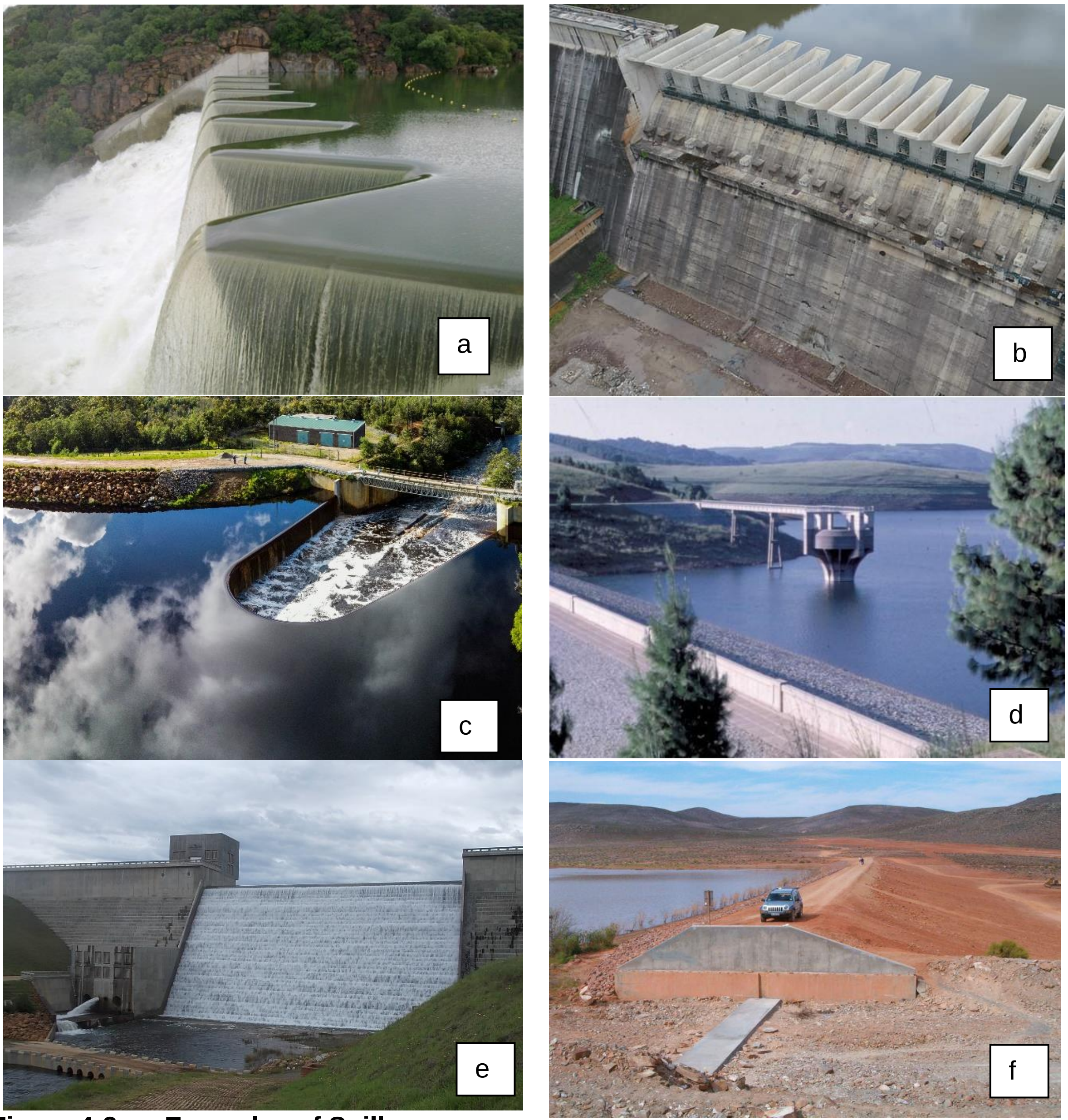

Figure 4-2: Examples of Spillways

Labyrinth spillway, (b) Piano key spillway, (c) Trough spillway, (d) Morning Glory spillway (e) Ogee gravity spillway, (f) Broad crested by-wash spillway

4.7 Outlet Works

The outlet works of a dam is required to make controlled downstream releases for the Reserve (i.e. the quantity and quality of water required for ecological functioning and basic human needs) and the intended use (domestic supply, irrigation, etc.). It is good practice to provide redundancy in the outlet system, specifically ensuring water supply can continue when maintenance activities occur. Bad planning or design at the beginning of the project significantly influences the lifecycle costing of this part of the dam.

The choice of upstream or downstream control will influence the extent of protection required of the conduits, and the nature and expense of access to the control valve(s). In several cases, a simple outlet system is implemented, which result in difficult maintenance afterwards. Divers may be required to carry out underwater maintenance, which is costly. A trade-off must be made during the design stage.

The use of downstream controls in embankment dams poses a risk of high-pressure leakage from the conduit induced by foundation or embankment settlement or materials ageing which in turn can lead to a delayed rapid failure through internal erosion or piping, and hence the use of downstream controls is restricted to small dams without a safety risk only.

Large dams typically have a dual (duplicate) outlet pipe system. Course and fine screens are provided upstream, to ensure debris does not damage the pipe lining or prevent the closure of valves. Staggered intakes, typically bellmouth shaped (for hydraulic performance) with selector valves immediately downstream, allows the best quality water with varying dam level to be released. A maintenance gate is typically provided upstream of the bellmouth intakes to facilitate maintenance to the selector valves and pipework. The horizontal pipes join vertical pipe stacks downstream, to convey water from the various levels to the horizontal bottom outlet. Flow control valves, typically sleeve valves, to regulate flow are provided on the downstream of the bottom outlet, with isolating valves immediately upstream to allow maintenance to the undertaken on the flow control valves. Smaller size ventilation and backfill pipes are also provided. Suitable hoists or cranes is required to facilitate removal of equipment for maintenance purposes. Sufficient working space is furthermore required.

Irrespective of the size of the dam, the outlet works should be designed and constructed to ensure **ease of maintenance**. Examples of outlet works are shown in Figure 4-3.

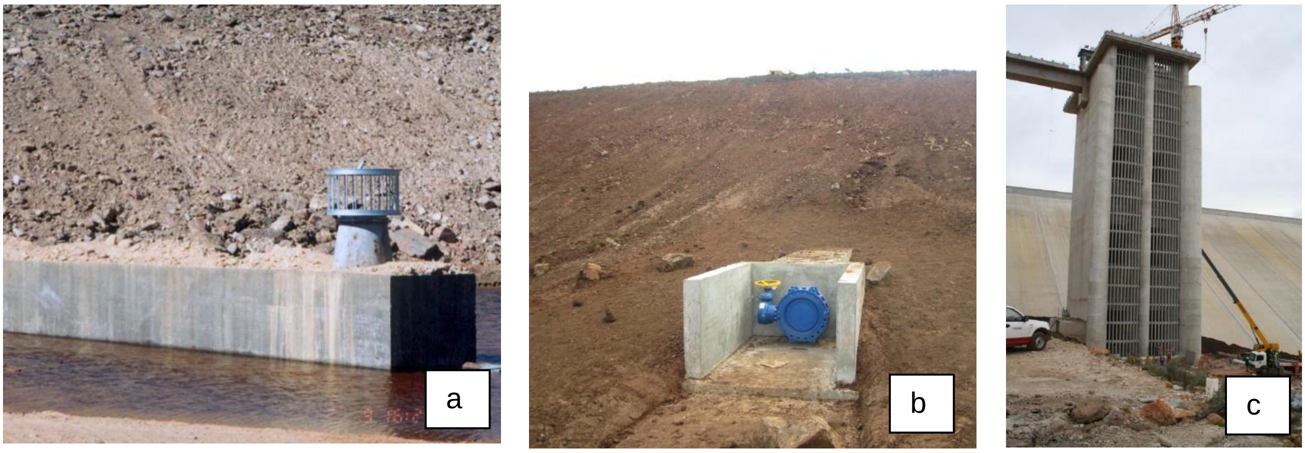

Figure 4-3: Examples of Outlet Works

(a)Examples of Upstream intake for farm dam, (b) Downstream Control of an Earth Embankment Dam, (c) Intake tower for large dam

4.8 Dam Walls and Embankment Dams

By following accepted engineering practice, the risk of dam failure is significantly reduced. The frequency of failure is independent of height of dam and thef type of dam (refer to ICOLD Bulletin 99, (1995) *Dam Failures – Statistical Analysis*) although the cause of failure may differ significantly and is usually a combination of factors.

The most common type of small dam in South Africa is the earth embankment dam at about 92% of dams, with small concrete dams being common for instream overflow structures. The publication by the United States Bureau of Reclamation *Design of Small Dams (1987)* as well as the *Design of Embankment Dam Structures*, a Master Degree Publication by Badenhorst (1988), is widely used to address materials selection; outlet sizing and spacing; spillway design; riprap and filter design; and similar. The complexity of planning and design should not be underestimated, especially for larger dams, and the responsible persons means of addressing uncertainties may rely heavily on state-of-the-art literature and extensive experience. The *Dam Safety Regulations (2012)* specify design aspects to be addressed for dams having a safety risk.

4.9 Drainage, Filters and Transitions (for Earth and Rockfill Dams)

A filter is incorporated in dam design as a means of allowing seepage water to pass from an area of high pressure to an area of low pressure in a safe manner without internal erosion of the earthfill of the embankment or the foundation taking place which could lead to piping through the earthfill and a rapid dam failure. Filter and drain layout and design is documented ion Badenhorst (1988).

Filter design is largely empirical and based on the Terzarghi criteria for non-cohesive granular material and the Sherrard criteria for fine grained cohesive base material. The use of geotextiles as filters or as adjuncts to filters may also be considered. While guidance is provided in ICOLD Bulletins https://www.icold-cigb.org/GB/publications/bulletins.asp, Bulletin 95 (1994*) Embankment dams – Granular filters and drains*, and ICOLD Bulletin 164 (2017) *Internal Erosion of Existing Dams, Levees and Dikes, and their Foundations*, as well as Bulletin 55 (1986) G*eotextiles as Filters and Transitions in Fill Dams and Embankment Dams*,.

4.10 Stability

The stability for the concrete structures for a concrete dam will be determined by the forces resisting sliding or overturning, along with the loading conditions, even if short term incidences such as during earthquakes or tremors occur. Kroon (1984) and United States Army Corps of Engineers. 2005 engineering manual on *Stability Analysis of Concrete Structures* provides details*.*

Embankment dams slope stability is also dependent on these factors but also on the shear resistance of the embankment material. The range of stability load cases to be considered as well as the corresponding acceptable factors of safety for embankment dams can be found in *United States Department of the Interior Bureau of Reclamation, 2011 – Embankment Design Standards no.13*, and Badenhorst (1988), amongst others. The applicability of the load cases is dependent on the dam type and acceptable risk associated with the dam being analysed. Software tools for seepage analyses and stability analyses are readily available.

Caution: The aspect of liquefaction occurring in materials susceptible to settlement when saturated is not addressed here but is critical to all tailings dams and soil platforms constructed under water. All tailings dam designers are urged to take note of the Global Industry Standard for Tailings Management (GISTM) published in 2020 and found at https://globaltailingsreview.org/wp-content/uploads/2020/08/global-industry-standard-on-tailings-management.pdf .

4.11 Reserve Releases

SANCOLD published the *Guideline for the Sizing of Dam Outlet Structures for Releasing Ecological Water Requirements from South African Dams* in 2022. The purpose of this Guideline is to provide dam designers in South Africa with a practical methodology for sizing the outlet structure of a dam to enable the implementation of Environmental Water Requirements (EWR) releases, while considering contributions from dam spills. The Guideline focuses on the quantity (volumetric) requirements of the EWR and, specifically, supporting the EWR by means of spills and releases through the dam outlet structure. The Guideline, however, does not address the process of determining the Reserve and associated EWR, water quality considerations in the design of the outlet structure to release water of certain quality or temperature, nor the release requirements for an emergency drawdown or other downstream water uses.

4.12 Operating Rules

Operating rules of dams assist in guiding affected stakeholders including dam operators with the operation of dams. In cases of water shortages, they assist with the restriction protocols to be applied in supplying water to the users. Flood operating rules, likewise, also guide in the safe operation of dams during the high rainfall seasons and floods, thus protecting downstream communities / users and the dam itself (the latter when the dam could be structurally susceptible to damage for example). By means of performing annual operating analyses for the dams, the Department of Water and Sanitation on an annual basis, determines operating rules to be employed for dams forming part of water supply schemes as informed by the water available in storage, water requirements, infrastructure challenges etc. This is mainly applicable to large schemes. Added benefits of operating rules include:

- Equitable water supply.
- Water supply to the users at their required assurance levels.
- Minimised operational costs.
- Reduction of water losses and yield maximisation.
- Facilitation of infrastructure maintenance.

4.13 Operation and Maintenance, including Dam Safety Inspections

In most cases dams are built for a specific purpose and therefore require regular monitoring and maintenance so that their safety and economic effectiveness can be assured.

4.13.1 Operation, Maintenance and Surveillance Manuals

An Operation, Maintenance and Surveillance (OMS) Manual describes the general operation, maintenance and surveillance procedures to be performed to ensure the safe use of the dam throughout its life. It defines the routine inspections which must be undertaken and the records thereof which must be kept. Inspections, maintenance and surveillance are considered essential for the successful operation of the dam.

4.13.2 Dam Safety Routine Inspections

Inspections are conducted to determine the status of a dam and its features relative to its structural and operational safety. These inspections are important in the early detection of deficiencies that could lead to major problems or even dam failure. Inspection consists of visual observations which are required to become aware of any change in the physical condition of the dam and the various components of the dam with respect to their function and safety.

Field or operating personnel normally conduct routine dam safety inspections. The primary focus is on the current condition of the dam and its features with reference to a particular/original inspection. The inspection also assists in identifying corrective actions and maintenance requirements. Routine dam safety inspections may be structured or unstructured. Structured routine inspections are conducted on a set schedule (e.g., weekly or monthly). Unstructured routine inspections are performed in conjunction with other routine tasks. For example, if a worker is at the toe of the dam to take a measurement from a weir, that worker may also inspect the entire toe and record any findings on a checklist or in a logbook.

Prior to instituting a dam safety inspection programme, it will be necessary to take certain preparatory steps in order to facilitate the inspections. For larger dams, inspections are undertaken on 5-yearly intervals by professional dam engineers or Approved Professional Persons (APPs). Owners of dams are responsible for the inspections and safe upkeep of their dams.

Caution on gas in manholes, galleries and low lying areas must be taken – noxious gases may collect in poorly ventilated low lying areas in particular and the use of a gas monitor is advisable to assess safety before entering such areas. It may be prudent to throw a lit match with caution into a manhole or similar to assess the presence of flammable gases such as methane.

4.13.3 Maintenance

Maintenance may be defined as the carrying out of all actions required to keep the structures fully operational and functional at all times. It also includes any action or remedial work required for safety, access, lighting, cleanliness for inspections, etc. There are two types of maintenance procedures, namely, corrective maintenance; and preventative maintenance.

Corrective maintenance (or breakdown maintenance) is the rectification of a defect or fault after it occurs. This type of maintenance usually applies to items where defects cannot reliably be predicted or anticipated, e.g. small rockfalls on cut slopes, etc.

Preventative maintenance conversely aims to prevent such defects or breakdowns from occurring and is actioned by replacing or repairing elements or components at predetermined intervals before they fail or become defective. The replacement or repair intervals are usually determined by building up a historical record which enables predictions to be made. It is strongly recommended that the maintenance staff introduce a system of preventative maintenance as soon as possible as this system greatly reduces downtime, increases safety and in the long term is more economical than corrective maintenance.

While each structure is unique, items such as vegetative maintenance should be undertaken at regular intervals. These could include mowing or brush removal, and no burning. Soil loss must be prevented by undertaking appropriate maintenance practices. Control of pests and vermin is also typically included.

4.13.4 Emergency Preparedness Plan (EPP)

The EPP is a requirement of the Dam Safety Regulations 2023 and is a formal document that identifies potential emergency conditions at a dam and list actions to be followed to minimise loss of life, damage to property and adverse effects on resource quality. It must include a flow chart of names and contact details of persons to be contacted in the event of an emergency. This includes, where applicable, the district, municipal, or designated disaster management authority or office or, alternatively, the provincial disaster management office.

4.14 Abandonment of Dams

Decommissioning means taking steps to ensure that the remaining structure will, without any further operational action, maintenance, inspection or safety evaluation, hold no danger or potential danger to human life or property, have no significant adverse impact on resource quality, or significant detrimental effect on the environment.

The term dam decommissioning refers to the full removal of the dam and its associated structures as well as partial removal or lowering the height of the dam.

If a dam is found to be unsafe, usually after an inspection, the owner of the dam is offered the option of repairing the dam to meet current standards or abandoning the permits for the dam and removing it from the river. The decommissioning of a dam does trigger activities requiring environmental authorisation before commencement therewith.

Further guidance on the decommissioning of dams can be found in ICOLD Bulletin 160 *Dam Decommissioning Guideline* (2019).

5. WHO CAN HELP

The Department of Water and Sanitation manages the water resources of the Republic of South Africa in accordance with the *National Water Act, Act 36 of 1998*. The regulations of dams having a safety risk as defined in Chapter 12 of the Act, is undertaken by the **Dam Safety Office** (DSO). For further details see http://www.dws.gov.za/DSO/About.aspx. This links gives further information about the dam safety office, the legislative documents, and in particular the forms to be completed for amongst others the application for registration of a dam, classification of a dam, an Approved Professional Person (APP) for certain tasks, a license to construct or a license to impound water in various categories of a dam, vital information for emergency preparedness plan (EPP) and more. The website includes contacts for the dam safety office by region and for managers.

Further information on dam engineering can be obtained from the South African Commission on Large Dams (SANCOLD) http://sancold.org.za or the SANCOLD secretary – secretary@sancold.org.za .

The International Commission on Large Dams (ICOLD) http://www.icold-cigb.org is a valuable source of generally accepted practice on a variety of aspects of dam engineering published as Bulletins.

In the event of an emergency: contact the owner of the dam who is to activate the Emergency Preparedness Plan (EPP).

The EPP is a requirement of the Dam Safety Regulations 2012 and is to include a notification flow chart of names and contact details of persons to be contacted in the event of an emergency. This includes where applicable the district, municipal, or designated disaster management authority or office or alternatively the provincial disaster management office.

In conclusion, the planning, design and construction of dams has evolved with time to become a well-established engineering practice when led by a competent person in compliance with norms and standards as reflected above. The deviation from these generally accepted practices of dam engineering usually leads to more expensive structures and structures having a higher risk of failure and negative social and environmental impacts.

6. ACKNOWLEDGEMENTS

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APPENDIX A: A Brief History of Water Resources Development in South Africa (Reference Legge, KR, 2019) https://doi.org/10.36487/ACG_rep/1910_0.02_Legge

A brief overview of water resources development legislation and commensurate regulatory structures and objectives gives significant insight into the rate of change of development with time, with associated generation of waste or pollution and significance attributed thereto.

Taking ourselves back in time to the 1800s we would have known of the history that had brought us to that time – a fairly sparsely populated country which had seen several colonial powers and regional wars come and go. The Portuguese, the Dutch and the British, amongst others, had visited the country. The first dam was constructed in 1800 as an earth embankment structure situated in the Northern Cape. In 1860 two further similar dams were constructed in the Eastern Cape and Gauteng provinces. By the turn of the century a total of 30 dams had been constructed, the highest of which was an 18 m earth embankment dam although the first masonry and gravity structures had come into being. Most developments were for agricultural water supply with only eight dams being for municipal water use. In the late 1800s, the former provinces of Natal and the Cape were under British rule, while the Transvaal and Orange Free State were Boer Republics.

The establishment of a hydraulics division in 1875 under the Commissioner of Public Works in the Cape Colony marked the birth of a very important Department of State. This department's work varied widely and was of the highest technical order, which was indispensable to the development of all sectors of the economy at that time. The first hydraulic engineer was John G Gamble who was an extremely competent engineer. The son of the famous Andrew Geddes Bain, known as Thomas Charles John Bain followed him in 1885.

In 1903, following the changes brought about by the two South African wars, arrangements were made to second two irrigation engineers (Messrs Kanthack and Hurley) from the Indian Irrigation Service to each of the colonies of the Cape and the Transvaal. These two engineers played a major role in moulding the early water policies and development in South Africa.

During the period 1902 up to the Union in 1910, water matters were dealt with in the four colonies; Cape, Transvaal, Natal and the Orange Free State, as follows:

- In the Cape, the Irrigation Department was mainly a technical department attached to the Public Works Department with FE Kanthack as the director, which had only scanty funds and a small staff component to undertake responsibilities. It was, however, due to the Cape Irrigation Act of 1906 (Juta 1907) that some extraordinary progress was made by a policy of assisting irrigation development through irrigation boards which included irrigation farmers who were required to allocate and distribute water in their districts. However, the lack of staff and funds severely hampered the essential task of collecting hydrographic data and systematic surveying of the colony.
- In the Transvaal, the chief engineer FA Hurley headed the Irrigation Department which fell under the administration and control of the Secretary for Lands. The Transvaal concentrated on investigation of major projects, most of which proved to be too expensive to implement.
- In the Orange Free State, irrigation matters were dealt with by the director of public works; and
- In Natal, irrigation matters fell under the Surveyor General and for all practical purposes, no irrigation work was undertaken.

The Union Irrigation Department formally came into being by the establishment of a new Act, Act no. 8 of 1912, known as the Irrigation and Conservation of Water Act (Union of South Africa 1940). The objectives of this Act were to consolidate and amend the laws enforced in the Union relating to the use of water in public streams for domestic, irrigation and industrial use and to provide facilities/infrastructure for the irrigation of land and use of water. This Act was destined to encourage the construction of storage works where the river flow during the low flow season were insufficient for direct irrigation by extracting water from runoff river diversion works.

At Union, considerable reorganisation and rationalisation took place. The way forward then took the form of active involvement of groups of irrigators with a policy of systematic research and investigation taken from the Transvaal model. Thus, Kanthack became the first director of irrigation and FA Hurley the assistant director under the union. The organisation was established to administer and implement the provisions of the Act, focusing on decentralisation. Decentralisation took the form of a circle engineer who was responsible for everything within his circle. Head office essentially controlled and reviewed the activities that took place in the nine circles. The period 1912 to 1914 was largely taken up by reorganisation, establishing circle boundaries etc., and this period was immediately followed by the first World War which brought about new challenges as many staff members enlisted for service and the prolonged drought was broken by unprecedented rain in 1916.

So it was in the following years that dams like Hartbeespoort Dam, Lake Mentz, Tygerpoort, Kamanassie, Grassridge and Lake Arthur were built.

Cooperative governance was investigated as AD Lewis was called upon to investigate the development of the lower Orange River that had formed the boundary between the South African Union and South West Africa (which was under Germany rule). Lewis left Cape Town on 20 November 1912 by horse and cart. Only two of the four horses drawing his cart made it to Pella on the 27 November due to the tough going. Thereafter, he left the horses and cart behind and made his way by foot carrying all necessities with him. Two weeks later he had covered the 400 km down river to the Orange River mouth, making notes of every physical feature and irrigation potential. By 30 December 1912, Lewis had completed a report on the irrigation potential of the lower Orange River.

The onset of the Depression in 1929 (which lasted until about 1934) brought about actions to relieve unemployment in various districts, and projects such as the Pongola Irrigation Scheme were started in 1932. Due to the increase in hardships for the unemployed and the consequences of the drought, the Department of Labour requested that the Department of Irrigation fast track further schemes and the Vaal–Harts and the Loskop irrigation schemes were started.

Further changes were brought about with the Vaal River Development Scheme Act, Act 38 of 1934 which had the notable feature of the tendency towards state ownership of water.

At the end of the 1930s, the department had a large staff component and many resources associated with the rapid growth in construction. The outbreak of the Second World War brought about changes yet again with the director of the Department of Irrigation being seconded to the Technical Committee of Defence on War Supplies, while a large number of officers took military rank in the Works Directorate, and many other staff members became the core of four companies for the Mobile Field Force. Over 50% of the department's technical staff was released for military service.

The year 1945 brought a radical change in thinking on water management. During the past half century, the department's emphasis had been on supplying water to irrigators who had used much of the water rather extravagantly. The ever-growing needs of expanding mines and industry, as well as domestic use and the acceptance of the fact that the water resources were limited, required a complete change in water legislation. Thus the functions of the department were expected to change. As a first step, pro rata tariffs for irrigators were introduced as far as possible, rather than the flat rate based on land schedules. The Minister was also empowered to grant subsidies to municipalities for the construction of municipal water supply schemes. The next step towards meeting the growing demands was to establish separate planning and research divisions in 1949.

On 7 April 1950, the Governor General appointed a water law inquiry commission to investigate and report on matters related to the existing laws and their required amendments in order to provide for the utilisation of water resources, to the best advantage of the people. The result was that parliament in 1956 passed an Act that repealed the 1912 Act and heralded a new era in water resources in South Africa. The new Water Act, Act 54 of 1956 (Union of SA 1956) specifically provided that there shall be no private ownership of public water, i.e. in a natural stream of water whether visible or not which flows over two or more original properties in a defined channel and which is capable of common use. This Act also placed water use for agriculture, industry and urban demands more or less on an equal footing. Riparian rights were retained where the state did not control the water, to the extent that riparian owners were entitled to a fair share of the normal flow of a public stream. This Act also gave the Minister absolute control over water in dolomitic areas and subterranean water controlled areas. The host of new responsibilities placed on the department lead to the establishment of additional divisions and sections such as the Division of Water Utilisation with its subdivisions of agricultural water and industrial water; the separation of the design and planning functions; the creation of a hydrological division, and the formation of a section to deal with the administration of permits for the abstraction of water etc.

In 1962, the Prime Minister announced in parliament the development of the Orange Fish River project. This yielded another change from the norm of planning, designing and constructing in-house by the introduction of the use of consulting engineers and contractors, for the design and construction of certain components of the work such as the main dam and tunnel. In 1966, the State President appointed a 15-member commission to investigate all matters pertaining to water and this commission found a need for investment in scientific research. The hydrological research centre at Roodeplaat Dam was approved in 1969–1970 and opened in 1972. A number of regional committees were also established to advise the Minister of Water Affairs on matters including interactions with neighbouring states.

The 1970s were characterised by multi-purpose dam development projects. By the 1980s, the storage infrastructure development rate had slowed and the department had been referred to by some members of cabinet as a junior department. In 1992 an interim government came into being as preparation for the first democratic election of the country in which all South Africans of age participated. This brought about a process of development of principles for water resources management and a new legislation – the National Water Act, Act 36 of 1998

(Republic of South Africa 1998b). The primary objectives of which are: sustainable water resources management and poverty alleviation.

APPENDIX B: A Summary of Environmental Principles to be Applied by all Organs of State in South Africa (Extracted from the National Environmental Management Act, Act 107 of 1998).

These principles are:

- Consistency: the principles apply throughout the Republic of South Africa (RSA) and to all organs of state (2.1).
- Equitably: environmental management must put people at the forefront of concern and serve their needs equitably (2.2).
- Sustainability: development must be socially, culturally and environmentally acceptable (2.3).
- Impact avoidance: impacts on biodiversity, pollution, landscape, resource depletion, people's rights and waste generation must be avoided, and where unavoidable be minimised and mitigated recognising a risk averse and cautious approach. (2.4a) best practical environmental option (2.4b).
- Environmental justice: an adverse impact shall not disadvantage other persons, especially the previously disadvantaged and vulnerable (2.4c).
- Equitable access: all persons shall have fair access to resources, even if special measures are to be taken to facilitate previously disadvantaged persons (2.4d).
- Responsibility: responsibility must be maintained throughout the activity life cycle (2.4e).
- Participation: processes must be inclusive and provide for capacity building where necessary (2.4f).
- Inclusive decision-making: decisions must recognise person's interests, needs, values and all knowledge of interested and affected parties (I&Aps) (2.4g).
- Environmental Education: Community wellbeing and empowerment must be encouraged through knowledge sharing (2.4h).
- Complete consideration: decisions must reflect consideration, assessment and integration of disadvantages and advantages (2.4i).
- Right of refusal: workers may refuse to do dangerous work and should be informed of dangers (2.4j).
- Transparency: access to information must be in accordance with the law (2.4k).
- Harmonious policies: there must be intergovernmental coordination and harmonisation on policies and actions (2.4l).
- Conflict resolution: actual or potential conflicts between organs of state should be resolved procedurally (2.4m).
- Global interests: global and international responsibilities are to be discharged in the national interest (2.4n).
- Public trust: environment beneficial use must serve public interest and be protected for common heritage (2.4o).
- Polluter pays: costs of remediation and of preventing, controlling or minimising further pollution and health impacts must be paid by those responsible for harm (2.4p).

- Recognition of women and youth: the vital role of women and youth must be recognised and promoted (2.4q).
- Ecosystems require special attention: specific attention shall be given to stressed, vulnerable, highly dynamic and sensitive ecosystems (2.4r).

https://www.dffe.gov.za/sites/default/files/gazetted_notices/nema107of1998_amendments_environmentalimpactsassessmentsregulations_gnr326_0.pdf