water & sanitation

Department:
Water and Sanitation
REPUBLIC OF SOUTH AFRICA

Guideline for Pollution Control Barrier System Design

In accordance with the NEMWA Regulations
2013 for Waste Disposal Facilities

3 September 2021

Prepared for the Department of Forestry, Fisheries and Environment by the Department of Water and Sanitation, Chief Directorate: Engineering Services in association with the DFFE Working Group 3 Panel of experts

Acknowledgements:
The DFFE gratefully acknowledges the contribution made by the compilers and panel of experts which lead to this guideline for the benefit of the Republic of South Africa.

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1. Introduction to Waste Disposal Facility Design

The general objective of landfill design is to provide a cost-effective, environmentally acceptable waste disposal facility.

More specific objectives include:

- **The mitigation of any adverse impacts identified in the Site Investigation and EIA.**
- **The prevention of leachate pollution of adjacent ground and surface water.**
- **The provision of sufficient cover material to ensure an environmentally and aesthetically acceptable operation for the type of waste.**

If the best available site, identified during the site selection process, is sub-optimal from an environmental or geohydrological point of view,the subsequent site design must compensate for these shortcomings by means of appropriate engineering. Where there is an environmental risk associated with the chosen site, the design must address mitigation of the impacts associated with sub-optimal site selection.

In the case of operating or closed landfill sites or waste disposal facilities, design upgrading or remedial design might well berequired. In such instances, the principles and requirements set out in the capping closure design guide of the DFFE are to be followed. http://sawic.environment.gov.za/documents/12494.docx

In both the above instances, i.e. a sub-optimal site or an operating site requiring remediation, the design must take the risks to the environment into account.

There are two stages of design:

Conceptual Design

The Conceptual Design addresses the principles of the intended design, but does not include detailed specifications. It includes all aspects of the design that will affect the successful operation and subsequent closure of the landfill in an environmentally acceptable manner.

Technical Design

The Technical Design is based on the Conceptual Design. Where necessary, it is also based on the results of tests on soils, construction materials and waste. The Technical Design includes detailed specifications of materials, measurements and procedures, as well as detailed drawings and a quantification of the anticipated performance for the site-specific design and construction quality assurance plan. In the case of all landfills for which liners are required, a technical design report must be submitted as part of the license application. The Technical Design, together with the associated bill of quantities, alsoforms the basis for contractual tendering and construction, and may therefore be required when commissioning a landfill.

The need to change from the philosophies of the Minimum Requirements which relied largely on attenuation to mitigate pollution dilution and dispersion, to pollution control by avoidance or minimization and containment became necessary with the advent of the Constitution of the Republic of South Africa with its Bill of Human Rights, and subsequent Acts of Parliament. The need for the change in approach to pollution control and waste management is further augmented by reflecting on the development of South Africa's water resources over time leading to a low volume of renewable water per person per annum, which reduces assimilative capacity of natural systems as the health of ecosystem services is reduced. A brief history reflecting the change is included in Appendix A.

2. Norms and Standards for Waste Containment Barrier Systems

The National Environmental Management Waste Act (NEMWA) Act 59 of 2008 paved the way for revising the prescriptive standards for attenuation barriers contained in the Minimum Requirements of 1994 and the 2nd Edition thereof in 1998. Although a significant delay occurred due to debate on whether the waste risk assessment should be based on total load (which had led to some abuse) or total concentration, the authority proposed a containment standard commensurate with waste risk which was subject to public participation for 4 years prior to implementation, including two government gazetted calls for comment. This containment standard was performance-based for Types 1, 2, and 3 waste, with Type 0 waste requiring treatment and Type 4 waste not requiring containment. It is this standard contained in the NEMWA Regulations of 23 August 2013 Regulation 636 3(1) and 3(2) as amended which this guideline seeks to address.

3. Site Selection, Investigation and Assessment

The site selection for a waste disposal facility may be influenced by the Environmental Impact Assessment which would take into consideration the source and nature of the waste, the site topography, geology, geohydrology, proximity of surface water courses and human habitation, and the socio-economic impacts of the development over the operational period.
For municipal solid waste (MSW) disposal facilities the Minimum Requirements for Waste Disposal by Landfill 2nd Edition (1998) (MR2) (1998)) provided guidance in chapters 3, 6 and 7 see:
sawic.environment.gov.za/documents/266.PDF
Guidance on geotechnical site investigation is readily available from the South African Institute of Civil Engineers (SAICE) geotechnical division which has compiled several codes of practice in conjunction with the South African Institute of Engineering Geologists (SAIEG) for use by the construction industry. These codes include both

geotechnical site investigation, the safety of persons working in small diameter shafts and test pits for geotechnical engineering purposes, and logging of profiles https://www.geotechnicaldivision.co.za/wp-content/uploads/2020/04/guidelines_for_profiling.pdf. Although these codes are not all embracing, they are based on accepted South African and International Engineering practice, and any deviation therefrom should be based on sound scientific and engineering motivation.

The designer should be particularly cautious if a site is underlain by dolomites; is undermined; is in close proximity of a fault or effect by similar geotechnical structures. Guidance on dolomitic areas and seismicity can be obtained from the Council of Geoscience: saieg.co.za/uploads/Publications/cgs_approach_november2007.pdf and https://www.geoscience.org.za/images/geohazard/seismicity.pdf respectively.

4 Conceptual Design

The following components, i.e. the waste type and commensurate class of barrier system for the site which may have an existing classification, volume of airspace required and service life of the waste disposal facility, are common pre-requisites for all landfill designs. They are therefore addressed under Conceptual Design.

4.1 Confirmation of waste type, commensurate class of containment barrier system and site classification

The NEMWA Regulations 2013 define the method by which waste is assessed resulting in a Type 0, 1, 2, 3, or 4 waste risk. Waste of Type 0 may not be disposed of on a waste disposal facility (WDF) and requires treatment. Types 1, 2, and 3 waste require contaminant containment barrier systems of Class A, B and C respectively, each comprising of a suite of components aimed at matching the containment risk with the waste risk. The Type 4 waste is considered to have a low pollution risk and hence not require containment.

Notwithstanding the waste risk assessment, the concept design should recognize the pollution risk arising from the material be it waste or product or other material for temporary or permanent storage. The waste leachate or pollutant may change in concentration with time leading to a higher risk and commensurate containment standard such as in the case of brine disposed of in evaporation ponds in which case the end of operational period material will have a higher concentration of pollutants as the water evaporates. So too should the design recognize the influence of activities on the waste or pollutant stream, such as the method of mining and ore processing on the leachate and resultant pollutant concentration.

It is important to note whether the site or in particular the cell onto which waste or pollutant material is to be disposed is accessible by humans. This is due to the nature of the waste risk assessment being based on thresholds that have the potential for human health impacts or ecosystem toxicology.

Furthermore, the 3-year transitional period for the NEMWA Regulations 2013 expired on 23 August 2016. Thus, while existing sites may have a permit or license defining the Class of site under the Minimum Requirements, new cells and expansions to existing cells are to comply with norms and standards of today.

4.2 Properties of waste

The physical properties of waste vary widely and need to be understood for the particular facility, as the nature of waste will influence both the basal contaminant containment barrier system and the closure of the waste disposal facility.

The strength parameters and compressibility are used to inform the stability analyses augmented by predictions of leachate level and settlement. The movement of contained material downslope or similar may induce additional tensile strains in the barrier system which reduce service life, and may simultaneously induce residual shear interface and internal strengths.

In hydraulically placed waste applications, the phreatic surface should be predicted for the entire life of facility using a full hydraulic and deposition model. The use of historic methods such as flow net estimation by assumed boundary conditions (Van Zyl and Haar, 1990) is only suitable for an initial concept but not a performance-based design.

Similarly, there is an abundance of literature available on waste material property strengths and their change with time, however, designers should be cautious in selecting such values which should be confirmed in the detail design phase. (See list of references and recommended reading; in particular GRI Report's #30 and #41 by Koerner et al; Legge and Bester, 2021; Dixon and Jones, 2003)

4.3 Size of waste stream

The rate of municipal solid waste generation and commensurate sizing of facilities is addressed in the MR 2 1998 section 3, referenced earlier.

For all waste disposal facilities, it may be appropriate to size a cell based on optimizing available airspace for disposal with the cost of the development (or return on investment.) This may lead to cells having a relatively short operational period of say 4 or 5 years prior to the development of an adjacent cell. Similarly, the height of waste should be optimized to gain available airspace for disposal and low cost per unit volume of disposal, while taking into consideration the effect of height and hence load on the containment barrier system performance.

4.4 Cover, airspace and site life for MSW waste disposal facilities

The potential volume or airspace of a site is calculated first by quantifying the volume of cover material available and then by applying a cover towaste ratio of between 1:4 and 1:6 by volume, to arrive at the total airspace. This means that for every 1m^3 of cover available, between 4 and 6m^3 of compacted waste can be disposed of.

Cover availability is thus a major factor determining the air space at a given MSW site, if it isto be operated in accordance with sanitary landfill principles.

The cover excavation design must therefore make provision for adequate cover material. This cover is for use both as daily cover in the operation and for final capping. Particular attention must be paid to providing sufficient material for capping the landfill, as this was a deficiency at many operating landfills and can have costly implications.

In assessing the quantity of available cover, careful attention must be given to the minimum requirement that there must always be an acceptable minimum physical separation between the waste body and the highest seasonal level of the ground water.

The available airspace can also be dictated by the shape of the final landform, which depends on the base area or ‘footprint’ of the landfill, the slopes ofthe sides and the maximum acceptable height as well as the safe rate of rise. There is therefore a balance between the cover availability and the physical airspace available.

The potential operating period of the site can be estimated by comparing the airspace utilization with the available airspace. Airspace utilization is based on the quantities of waste to be received, projected over the estimated period during which the site will operate. Various techniques for calculating landfill site life are included in Appendix 8.1 of the Minimum Requirements volume 2 for MSW facilities.

4.5 Site layout

The site layout must be designed with the landfill's closure and end-use closely in mind. The end-use, in particular, may decide the final shape or contours of the landfill, and this may influence the site layout and the Operating Plan. **For this reason, the environmental impact assessment and authorisation must be consulted to determine the intended end-use of the site.**

The site layout design will typically comprise of plans and sections, indicating existing, excavated and final contours. The following aspects would be addressed and in many instances would have to be indicated on plans:

Access

The requirements for road traffic access to the site andother necessary infrastructure must be assessed (see Sections 10.2 and 10.4 of MR 2 of 1998 volume 2). Access routes on a site shall be clearly demarcated to prevent the disposal of material on an area not intended for the purpose i.e. there shall be a clear demarcation of cells intended for different waste types and for liquids such as leachate and potentially polluted storm water or similar.

Access restrictions shall be clearly noted on drawings and operational plans unless human health is not at risk during operational phase reworking or recycling from the waste mass.

Surface hydrology and drainage design

Surface hydrology design will include surface drainage and storm water diversion drains, to meet the requirements of the National Water Act. This includes the separation of unpolluted from polluted surface water and the containment of polluted water on site in impoundments. Also, where leachate is generated, it must be contained separately from water which is only slightly polluted through contact with the waste.

The sizing of leachate collection dams or pollution control dams based on the type of waste, the operational procedure and climatic conditions is to provide adequate storage capacity without overtopping except in the case of mine waste for which the sizing shall result in overtopping not exceeding a frequency of 1: 50 years on average (and hence shall be based on a stochastic analyses using rainfall record data).

Containment

The regulations require a complete separation of Type 1, 2, and 3 waste from the environment which is achieved by containment barrier systems which comprise of both drains and liners which work in conjunction with each other.

A concept design of the barrier system for Classes A, B and C facilities is provided in the Norms and Standards R636 Regulation 3(1) which is made up of leachate collection drains and composite liners with additional leak detection drains and subsurface drains. A composite liner comprises of a geomembrane in direct contact with a compacted clay liner in which the CCL serves to reduce advection or seepage losses at a point of discontinuity in the geomembrane such as holes or tears and unsatisfactory geomembrane welds. For direct contact to be achieved, a confining stress is required. The superior performance of a composite liner in reducing total solute transport due to seepage and diffusion mechanisms of the total leachate load and volatile organic compounds respectively is a function of the material types and thicknesses. (See Foose et al 2001 and Rowe, 2012) Alternative materials of equivalent performance may be used as partial or total replacement of elements within a barrier system, however, their influence on the systems performance must be addressed in the technical design and performance quantification.

Leachate management systems and drains

Leachate management systems comprise of drains which are given effect by the underlying liner layer. They are required to drain under gravity usually augmented by drainage pipes to collector drains which discharge to sumps or pollution control dams and may include leachate treatment systems. It is thus good practice to have adequate slope for the drain to manage leachate removal and so limit hydraulic head on the liner, as well as to provide some self-cleaning of leachate collection pipes.

Above liner drainage is required to reduce hydraulic head on the containment system. This is usually achieved by means of a granular drainage layer of thickness and permeability, with collector pipe spacing selected to limit the above liner pressure head. This leachate collection system is protected by a filter system which may be granular or geosynthetic or a combination thereof. For MSW and similar waste the granular drain or leachate collection system has a typical grading of 38mm to 53mm nominal diameter so as to provide adequate throughflow rate or transmissivity in the presence of biological and chemical clogging around the stone drainage media. In monofil facilities where the waste material allows, the drain maybe of finer material or the waste itself may fulfill the drainage criteria desired.

Monitoring systems

Monitoring systems for surface and ground water pollution should be indicated (see also Section 13 of MR 2 (1998) volume 2). This will include the positions of both surface water sampling points and monitoring boreholes.

Gas management (see Section 8.4.5 of MR 2 of 1998 volume 2) and gas and air quality monitoring systems are required if, in the Site Investigation and the Risk Assessment, landfill gas migration and accumulation are found to represent a potential safety hazard or odor problem, or if an operating or closed site is situated within 250m of residential or other structures.

Gas monitoring systems could comprise gas monitoring boreholes or other monitoring devices approved by the authority. Their positions must be indicated on the layout plan.

Layout and development plans

The Layout and Development Plans should have a scale of 1:1 000 and a contour interval of 1m. They must show where the following aspects of the landfill operation will be situated, and/or how they will be staged:

- Infrastructure (including fences and buildings)
- Site access and drainage
- Excavation and stockpiling of cover (if relevant for the waste type)
- Screening berms and screening vegetation (tree belts)
- Cell construction sequence
- Deposition sequence and phases (including physical dimensions and timing for each phase).
- In the case of hazardous Type 1, 2 or 3 waste landfills, the laboratory, and treatment facilities.

Progressive Rehabilitation Plan

The Progressive Rehabilitation Plan should indicate when areas should reach their final level and how they will be progressively restored, by means of final cover or capping, topsoiling and vegetating. The type of vegetation envisaged should also be described.

Preliminary Closure Plan

A Preliminary Closure Plan, including an End-use Plan and possibly a Landscaping Plan, should be indicated.

Interested and Affected Persons (IAP) involvement

The Layout, Development and Progressive Rehabilitation Plans should take into consideration the needs of the IAPs. For example, the deposition sequence should ensure the least possible impact on the IAPs living close to the landfill.

When the Conceptual Design is complete, the design should be presented to and discussed with the IAPs, in order to inform them and to obtain any further input that might be forthcoming. Such input could include making opportunities for job creation during design implementation.

5. Testing of Soils, Construction Materials and Waste

Some *in situ* and laboratory testing of on-site soils and rock may have been done during the landfill site investigation (Section 6 of MR 2 1998), to assess the suitability of soils for cover, protection layers and linings. In the design stage, more specific testing may have to be performed, to enable the technical design of the landfill to be carried out.

5.1 Soil permeability

In situ permeability testing, using a double-ring infiltrometer or Guelph permeameter, may have to be performed on some, or all, of the following:

- The soil and/or rock immediately underlying the landfill. It may be necessary to seal the rings to the surface being tested.

- The unsaturated zone that will ultimately separate the waste from the ground water. This may require the testing of different soil strata.

Testing for compatibility of soils and leachate may also be necessary to assess the effect of leachate on permeability (see Section 8.4.3 and Appendix 8.2 of MR 2 of 1998). Such tests would be performed in a laboratory. The performance assessment should however take into account the difference in permeability measurements for the same soil when undertaken in a laboratory compared to infield, as the latter is often 1 to 2 orders of magnitude higher due to soil variability, discontinuities and the like (and as much as four orders of magnitude higher in highly active clays, having apparently low permeability).

5.2 Compaction properties

The compaction properties for any soil or modified soil proposed for use in lining or capping layers must be established according to the Standard Proctor Compaction Test. (The AASHTO compaction specifications were developed for pavement design pursuing rigid structures and are not suitable for clay liner specification which requires a pseudo-plastic soil structure)

5.3 Shear strength tests

Where appropriate, shear strength testing of soils must be performed to enable the overall stability and the permissible angle of cut slopes to be assessed. This is especially the case where extensive cut slopes or trench systems are envisaged.

Where excavated areas require lining, the side slopes should be such that it is possible to lay the required liner. Some geosynthetic materials have a low interfacial friction with soil, with other geosynthetic materials, as well as with waste. Any inclined surface covered by a liner incorporating a geomembrane must be investigated for possible interlayer slippage, taking cognizance of the peak and residual shear values and noting the critical interface between materials may vary depending on the normal load applied. This could be slippage of the geomembrane on its supporting claylayer, slippage between the geomembrane and a protective geotextile, or slippage of a soil protective layer overlying the geomembrane.

All types of interface incorporating geosynthetics can have very low angles of interface friction. Designs should be based on residual shear strengths of interfaces within the lining system, measured under saturated conditions. It is appropriate to determine the critical interface and shear strength parameters using large scale (300mm x 300mm) shear box apparatus having adequate displacement capability. Caution: **standard test methods are undertaken at near ambient temperature and under saturated conditions using water which do not necessarily represent the infield condition where elevated temperature and leachate chemistry may affect the geosynthetic material stiffness and resultant interface shear values. Furthermore, the rate of shearing should take into consideration the degree of saturation of the clay component and the influence of shearing rate on overestimating strength parameters.** Slopes mustbe graded to achieve a factor of safety against slippage of at least 1.3 and 1.5 post operation unless specified otherwise. This should also take into account the effects of pore pressure arising from an accumulation of liquid or leachate above the liner.

5.4 Geomembrane, geosynthetic clay liner and geotextile tests

Geomembrane liners (sometimes referred to as flexible membrane liners or FMLs) must comply with the requirements of SABS Specification 1526 (2015) as amended and SANS 10409 (2020) for HDPE geomembranes.

Where adequate data is not available, geomembranes, GCLs, composite liners and geotextiles (or geofabrics) will have to be tested for strength, interface friction, durability and compatibility with identified components of waste and leachate.

Depending on the details of the proposed waste disposal facility, the designer and/or regulator may call for additional performance criteria.

Because of potential clogging by biological slimesand chemical precipitation, geotextiles through which landfill leachates must seep, should be used with caution. Consideration should be given to covering such geotextile filters with a selected soil or waste layer to provide protection against degradation and fines contamination. Valuable guidance on filtration and drainage can be obtained from amongst others the ICOLD Bulletins on granular filters, geotextile filters, and tailings dam design. (See references list for ICOLD Bulletins)

Construction quality assurance (CQA) is to address all materials specified, irrespective of whether they are geosynthetic or natural or modified materials.

In general, the Geosynthetic Research Institute standard specifications in their latest amendment for geomembranes, geosynthetic clay liners, geotextiles as filters and geotextiles as cushion layers, and geodrains are acceptable.

5.5 Waste tests

Testing of waste may be performed to assess likelyleachate composition, field capacity, compressibility under load, compatibility with materials of construction used in the landfill, and compacted density. If necessary, shear strength tests must be performed on the waste to assess the overall stability of the landfill.

6. Technical Design

The Technical Design quantifies all necessary aspects of the Conceptual Design. It also gives predicted answers concerning the future performance of the landfill. Specifically, it takes into account the vulnerability of the environment to pollution.

Guidance on the stage of design to be put to the authorities for consideration is available from the Engineering Council of South Africa (ECSA) Board Notices on Conduct and on Stage of Design. https://www.ecsa.co.za/regulation/RegulationDocs/Code_of_Conduct.pdf and https://www.ecsa.co.za/regulation/RegulationDocs/Guideline_Fees_2016.pdf. The waste management license (and in some cases water use license) is based on inter alia the technical report signed by a registered professional engineer in the field of civil engineering, and the license or authorization shall be in place prior to the commencement of physical construction activities. The aspects of the design which follow are considered to require particular attention.

6.1 Design of upslope cut-off drain systems and contaminated drainage systems

The separation of clean and dirty water systems must be designed in accordance with the National Water Act (1998) and its regulations. Storm water drains must divert or contain the peak design storm of 50 year return period for the particular catchment area. The system must effectively separate unpolluted water, that has not come into contact with waste, from polluted water. The upslope cut-off drains must divert clean storm water around the site and into the natural drainage system. Notwithstanding the capacity of storm water diversion channels, the consequences of overtopping or failure of such systems on the integrity of the waste disposal facility must be taken into consideration.

Polluted water, on the other hand, must be collected in toe drains or interceptor channels, retained on the site in pollution control dams or similar facilities which have the same containment performance as the waste disposal facility. The management of leachate may be by controlled release to a functional wastewater treatment works, evaporation, reuse in process water, or treatment. (The use of leachate for dust suppression on lined areas may be considered if the design provides for such an activity in amongst other factors the water balance calculations and stability analysis, however, the consequences of leachate recirculation on air quality and barrier system degradation must be taken into account for putrescible and chemically active waste streams.)

The design of all such impoundments must also ensure a 0,5m freeboard in the event of a one in fifty year storm of 24 hour duration, unless prescribed otherwise in regulations.

6.2 Design of the separation between the waste body and the ground water

It is good practice that there always be an acceptable physical separation between the proposed waste body and the wet season high elevation of the ground water. This applies whether cover excavations take place on site or not.

The minimum permissible separation is 2m. This is to ensure that, particularly in rural areas, waste is not deposited into excavations where the unsaturated zone has been significantly reduced or where the water table has been breached. While this separation is likely to be acceptable in the case of clayey soils, a substantially thicker separation may be required in the case of more permeable, sandy soils.

It must be emphasized that the primary protection of the environment from the effects of a landfill is the result of careful siting (Section 4 of MR2 of 1998). However, cases may arise where siting of a landfill near an important aquifer is unavoidable. In such cases, the separation between the waste body and the ground water may require to be upgraded to provide additional protection. This may take the form of supplementing the thickness or upgrading the liner.

At this stage there is no set methodology for calculating the thickness of the separation between the waste body and the seasonal high elevation of the ground water. Consequently, there is frequently controversy and/or uncertainty associated with determining this minimum separation. The unsaturated vadose zone is however critical to mitigating impacts of limited pollutants which pass through the barrier system by means of diffusion and or seepage despite its site specific design and CQA plan for which a total solute transport assessment is to be provided. Furthermore, the position of an unsaturated zone provides for some protection against uplift forces on the liner system due to groundwater highs including perched water tables and soil void pressure development due to vacillating groundwater elevation.

Depending on site and ground water conditions, it may be necessary to address the problem of seepages from perched water tables and springs, entering the site. This can be achieved through sound drainage engineering.

6.3 Design of the lining system

The lining system is additional to the separation or unsaturated zone comprising soil or rock between the wet season high elevation of the groundwater and the landfill. Soil used for the construction of the liner may be excavated from the unsaturated zone. 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 25mm. The larger the particle size within the clay layer, the greater the influence on total tensile strain within the geomembrane. So to should it be noted that the coarser the soil grading, the higher the permeability and in particular the higher the interface transmissivity between geomembrane and compacted clay layer (CCL), which will affect the seepage assessment of the barrier system performance. Thus, the geotechnical investigation interpretation and selection of most suitable material for use in the upper layers of the CCL is critical for achieving cost effective containment barrier performance.

A lining layer, constructed of compacted soil of low permeability, must be so constructed that it permits no more than a specified maximum rate offlow of leachate to pass through its layers. Clay liners must be compacted to a minimum dry density of 98% Standard Proctor maximum dry density, at a water content of Proctor optimum to Proctor optimum +2%. Some variation in moisture content specification may be appropriate for soils which have a micaceous content, or are dispersive in nature, or which display significant activity due to an elevated Plasticity Index.

In addition, the following supplementaryinformation is required for design:

- Full particle size analysis (sieve and hydrometer tests).
- Double hydrometer test.
- Atterberg limits.
- Shear strength test results in terms of effective stresses on soil compacted at Proctor optimum water content to Proctor maximum dry density. Soils are to be either drained or undrained, with measured pore pressures on saturated soil.
- Permeability measurements in triaxial cells are also required on saturated soil, compacted as above.

The maximum outflow rates in the clay layers are measured in meters per year and should be 10^{-9}m/s for Class A and B facilities and 10^{-8}m/s for Class C facilities, however, the actual permeability of the soil is required in the seepage loss assessment for the particular cell design and construction quality assurance plan.

Because the liner will usually have to be designed at a time when only laboratory test data are available, the expected outflow rate will usually have to be based on permeability coefficients measured in the laboratory on specimens constituted in the laboratory.

These estimates must, however, be validated by field tests once the liner has been constructed. It must also be remembered that small-scale laboratory measurements could underestimate the permeability of a liner by as much as two orders ofmagnitude.

To validate the design, *in situ* permeability tests using double ring infiltrometers must be carried out on every compacted soil layer that forms part of a liner. The diameter of the inner ring of such an infiltrometer must be at least 600mm, while the diameter of the outer ring must be twice that of the inner ring. The infiltrometer must be covered and sealed with plastic sheeting to prevent the evaporation loss of moisture. **Caution: the use of Guelph meters to determine permeability in active or expansive clays may result in unreliable results.**

In the event of the geotechnical investigation or other constraint revealing inadequate suitable soil on site for use in the CCL of a composite liner within a barrier system, the use of geosynthetic clay liners or bentonite enriched soil liners (BESL) may be considered as a partial or total replacement of the CCL. In so doing the design should take into consideration the effect of both cations and salts in the base soil and in the leachate on the sodium bentonite used in the GCL or BESL. A rapid assessment of potential compatibility between leachate and bentonite may be achieved by undertaking a swell index (SI) test for the particular bentonite source (brand of GCL) or mine and comparing it to a swell index test in which the leachate replaces the deionized water of the test. **Caution: the SI test result can be manipulated by the addition of soda ash or polymers and hence the actual product to be used should be tested. Designers should also take into consideration the as yet unquantified durability of hydroscopic polymer additives and the effect of such polymers on stability and drainage media as the polymer leaches from the source GCL or BESL.**

The specification of the CCL receiving face prior to placement of the geomembrane should be in accordance with SANS 10409 (2020).

The geomembrane component of the competent liner should be specified as a high density polyethylene material in accordance with SANS 1526 (2015) as amended and SANS 10409 (2020) although project particular specifications may override standard specification criteria. The consequences of such deviations should however be taken into consideration, particularly with respect to service life determination and total solute seepage assessment of the barrier system performance, as well as the WDF stability.

The protection layer above the geomembrane is to provide both protection against construction and environmental damage, depending on the application as well as ballast. While research has shown fine grained soil protection layers to significantly reduce point load induced tensile strain development in a geomembrane, and to be superior to geotextile cushion layers under certain loading conditions, the designer needs to take into consideration the effect of further layer placement techniques when selecting the appropriate cover material and thickness. The use of geotextile cushion layers under limited normal stresses (typically less than 200 kPa) to limit geomembrane strain due to large aggregate stone of approximately 53mm diameter can be achieved depending on the CCL material selection and compaction, with evaluation by in situ or laboratory simulation tests. The actual site specific materials and loading conditions do however need to be tested and measured to confirm equivalent performance, failing which the barrier design layout may require amendments. **Caution: not all geosynthetic products are the same, and variations can occur from the same manufacturer having multiple factories located around the world, or even from the same factory.**

6.4 Design of leachate collection, leakage detection and leachate treatment systems

All waste disposal facilities have the potential to generate leachate, albeit sporadically, and therefore the base of the leachate collection system shall be sloped to a low point for collection and management. The leachate management system shall keep leachate isolated from the environment by means of collection, removal and treatment.

Leachate collection

Design of the leachate collection system is required to limit the pressure head above the liner, take into consideration the flow path, make provision for sumps (depending on the nature of leachate, and accommodate the leachate generation for the particular WDF.

Leachate collection is usually achieved using a (filter protected or filter compatible) granular drainage medium which is given effect by the efficiency of the under liner. For Class A, B and C barrier systems the under liner is a composite liner (of geomembrane plus clay component) or an alternative of equivalent performance.

The leachate collection system is a system of drains, bunds or trenches covered by the leachate collection layer. It is equipped with suitable drainsor collection pipes that direct the gravity flow of leachate or leakage to defined collection points orsumps, from which it can be collected for treatment.

Collected leachate must be treated to a quality standard that complies with the relevant legislation, before being released into the system.

Any drain, whether open or covered, that is used totransfer leachate from the leachate collection system to the leachate ponds or to the sewer must be properly lined. This should be achieved by means of pipe work or channels which are properly lined, with a 2mm thick geomembrane liner with joints welded to the same specification as the cell and protected from environmental damage.

Particular attention to detail is required at points of discontinuity in the liner system e.g. where leachate collection or drainage pipes penetrate it. The same or better containment standard is required to avoid leaks at these points of concentrated leachate flow. The make-off detail of geomembrane to pipe may be by means of a factory manufactured flange or a boot system. The selection of leachate decant system will depend on the type of leachate and may result in a design having no penetrations to the liner system and relying on an above liner sump and decant pipework with pumps. In all cases there should be some redundancy within the leachate collection system, taking into consideration the influence of biological clogging and chemical precipitate on the transmissive flow capacity within the leachate collection layer, and the influence of physical clogging or blocking.

In some circumstances, the waste itself may be free draining or used to contribute to leachate collection and drainage, as is often practiced in mine waste disposal facilities.

Filter design guidance is available in ICOLD Bulletins which address tailings dam or embankment dam developments, for both granular and geotextile filters. Similar guidance is available from domestic geotextile manufacturers https://kaytech.co.za/wp-content/uploads/2020/11/Geotextiles-as-Filters-brochure-BR-DRNG-0663-11_2015-1-

1.pdf .

Leak detection system (LDS)

The leakage detection system is designed to intercept any leachate that passes the barrier of the upper liner. This leakage is then directed to separate leakage collection sumps, where the quantity and quality can be monitored and from which accumulated leakage can be removed. This system is designed to fulfill the requirement for the 'early warning' monitoring of leachate. The design principles are similar to those of leachate collection system, bearing in mind that the LDS is often in an aerobic condition which may influence the formation of precipitate in some waste type instances.

The use of geosynthetic drainage systems can be considered in some circumstances provided the design confirms the filter and drainage capacity performance for the particular WDF physical and chemical loading conditions. The compressive creep collapse of geosynthetic drainage media for the load and service life is to be assessed along with confirmation of polymer and structural durability. Particular attention to detail is required where such thin drainage systems are to be joined or pass through bends, as the flow capacity is usually significantly reduced at these positions. The risk of physical, chemical, and biological clogging of drainage media having relatively small flow channels is to be addressed in the design. So too must the influence of geosynthetic drainage material on adjacent geomembranes be addressed, with respect to amongst others the influence on tensile strain development in the geomembrane, the effect of soil or geosynthetic intrusion into the flow paths of the geodrain, and the influence on stability due to the usually lower interface shear strength of such designs. **Caution: The Geosynthetic Research Institute publication on field investigations into geodrain performance is worth noting, (See referenced GRI Technical report #36, by Koerner and Koerner 2008) and hence the tendency to not use such materials in MSW leachate exposure conditions and similar.**

Leachate treatment system

The leachate treatment system will depend on the leachate composition and on the most appropriate method of treatment. This could be on-site chemical, physical or biological treatment, and/or off-site treatment where leachate is passed into a sewer or pipeline for treatment elsewhere.

This guideline on the design of barrier systems does not address leachate treatment, however, the containment of pollutants in leachate treatment systems is commensurate with the norms and standards. It is common practice to make use of above ground steel tanks or reinforced concrete structures designed to water retaining standards for the containment of contaminants in the early stages of treatment in particular. Design codes are available for concrete water retaining structures, such as BS 8007 and SANS 1200.

6.5 Design of leachate collection sumps and pollution control dams

The containment barrier system for leachate and other liquid retention systems shall have the same or better containment barrier performance as that of the solid WDF barrier system with which it is associated. (To mitigate the greater pressure head within the containment system).

Where intended, it is obvious that above liner leachate collection systems are not required, the facility should be designed with an adequate floor slope to drain during the operational life if necessary and at the end of the required service life. Even in raw water reservoirs, the minimum floor slope should be 1v:75h so as to allow for the escape of gas from beneath the liner, and so avoid the formation of “hippos” or “whales” in the lining system. The provision of ballast or protection layers above the geomembrane is essential if a composite liner performance is required. The thickness of the ballast layer would be informed by the confining stress required to achieve the desired seepage control and geomembrane protection from environmental conditions whereas the quality or strength of the ballast material will be informed by the anticipated loading conditions. It is thus common practice to make use of cement stabilized soil or concrete in a form that allows for trafficking by light machinery during sediment or sludge removal when required during the operation. Alternative layouts of the barrier system may be selected to reduce hydraulic gradient across the containment (secondary) liner or where the fluid to be contained would react with ballast material such as in the case of strong acids. Alternative materials such as reinforced concrete designed to water retaining standards may be preferable in some cases.

In the event of alternative barrier systems being designed, the seepage loss determination would be based on Bernoulli’s equation through geomembranes which are not part of composite liners systems, such as in double or triple geomembrane liner systems. In such cases, the design must ensure adequate flow capacity within the drainage system separating geomembranes to avoid above atmospheric pressure, especially at the decant points.

The design and operation needs to recognize the risk of unacceptable odors and hazardous vapors being present at such facilities and mitigate the risks associated therewith. So too should the assumptions of evaporation be validated due to the risk of oils and greases covering the surface of the liquid and so reducing evaporation rates.

At the end of life such containment facilities should be removed or closed.

6.6 Gas management systems

Not all waste Types result in gas generation from the WDF. The production of gas resulting in odors and potentially explosive conditions is however associated with putrescible waste such as MSW, sewage sludge and abattoir waste as well as co-disposal facilities.

Many of the gas extraction facilities that have been designed and constructed to date in South Africa have been designed to extract gas by applying a suction to a system of perforated pipes within the landfill or beneath the cap. Such active gas extraction may significantly reduce the odor problem and the potential explosion hazard. If the collected gas is not used for energy or chemical feedstock, it should be flared off, taking into consideration the national environmental management air quality amendment act and associated legislation.

Passive gas management may, however, also be used to achieve cheaper gas management. This may include the construction of impervious migration barriers adjacent to the landfill and passive venting from boreholes and perforated pipes within the landfill. The resultant gas may beflared or passed through filters to remove odor.

If there is a need for gas management, the system and its design specifications must be approved by the authority, prior to construction.

6.7 Design of final cover or capping

The capping layer of a landfill serves the following purposes:

(i) It separates the waste body from the atmospheric environment. The cap is the only layer protecting and isolating the waste from the long-term effects of wind and water erosion, burrowing animals, etc.

(ii) It limits and controls the quantities of precipitation that enter the waste.

When considering the capping design with the corresponding liner design, it must be realised that the cap works in conjunction with the liner by limiting the long-term generation of leachate. The closure cap for a WDF should be shaped to maximize clean water runoff and minimize infiltration into the waste body, and significant cost savings can be effected for facilities having competent basal containment barrier systems. Guidance on closure capping design is provided in a document provided on the DFFE website. http://sawic.environment.gov.za/documents/12494.docx

6.8 Stability of slopes

The stability of a WDF development may vary during its life cycle from commencement of construction to post closure. The design needs to take cognizance of specified excavation activities and associated stability of such cut faces and slopes. So too must the stability of the waste body with its associated barrier system be determined over the life of the facility bearing in mind the variability in waste strength parameters (and in some cases the change in strength parameters with time).

Literature sources show a wide variation in waste material strength parameters. The operation may similarly result in different material concentrations in layers or zones of the WDF influencing the Factor of Safety (FoS). Literature also shows that about 40% of failures are due to excessive liquid within the waste body and that of the three failure mechanisms being; through the waste itself, along the barrier interface, or failure through the foundations, the majority are through the waste body. Failure is not unique to MSW or tailings facilities and includes rock dumps and similar having Type 4 waste foundation structures. See chronology of international mining failures: https://www.wise-uranium.org/mdaf.html

Interface shear strength parameters for various products and soils are available in literature, but designers are cautioned to use such parameters for concept development only and not performance-based design as required by SANS 1526 (2015) as amended in 2019 for HDPE geomembranes. Interface shear strength tests should make use of large-scale shear box facilities of the order of 300mm x 300mm and allow for adequate displacement to determine both the residual shear strength parameters and the critical interface within the barrier system, noting that the critical interface may vary depending on the normal load applied. The rate of displacement may further affect results and over-estimate strengths, particularly in the case of low permeability clays which have not been fully saturated. Designers are further cautioned to take into consideration the long-term effect of strain under elevated temperature or chemical exposure conditions when using short term laboratory tests undertaken at ambient temperature with water as a saturation fluid and thus not necessarily representing anticipated surface effects and degradation of texturing systems.

Computer based models are readily available for stability analyses based on methods such as those of Bishop, Janbu, Spencer, Morgenstern-Price amongst others all of which are dependent on the input parameters and option of method of failure selected e.g., circular or wedge failure or combinations thereof. In all cases, a realistic estimation of the phreatic head on the barrier system is required and in some cases, this may require the determination based on a full and combined seepage and stability analysis for the deposition method such as in tailings and ash facilities where the waste is conveyed and placed hydraulically. The seepage analysis reliability depends on calibration by means of piezometers, which should be installed in clusters (in plan view). The reliance on hand drawn flow nets may result in significant errors when compared to seepage analysis.

Particular caution should be exercised in the design of WDF facilities which include waste or foundations which contain a layer of material susceptible to contraction and resultant liquefaction failures.

The design of mine waste disposal facilities should comply with the Global Industry

Standard on Tailings Management, August 2020. https://globaltailingsreview.org/wp-content/uploads/2020/08/global-industry-standard_EN.pdf

6.9 Construction Quality Assurance

Construction quality assurance does not usurp nor replace construction quality control (and materials quality control), nor does it in any way override construction supervision by the design engineer. For guidance on construction quality assurance and an example CQA plan see the lead authority website: http://sawic.environment.gov.za/documents/12496.pdf and http://sawic.environment.gov.za/documents/12493.pdf As well as SANS 10409 (2020) on the selection and installation of geomembranes among other documents and standards.

6.10 Barrier System Performance Assessment (for service life and seepage losses)

For the Class of barrier system design and its CQA, the service life determination and total solute transport assessment should be undertaken. Service life is a function of the physical and chemical exposure conditions to which the geosynthetic material is subjected (being a specific resin and antioxidant package). Service life is addressed by limiting total tensile strain in the geomembrane to less than 3%, and the chemistry compatibility is addressed as per SANS 10409 (2020). While temperature is not anticipated to be the driver of degradation for many a facility, the tensile strain will be influenced by the design detail and applied load. Note that compaction of the foundation and the clay liner component will also influence point load induced strain. The strain can be determined by theoretical means such as that of Tognon et.al. (2003) based on plate bending theory; or by laboratory testing of the actual material such as was done by the Hornsey and Wishaw method; or by in-situ testing and measurement such as by the Chaperon et. al. (2020) method in South Africa which uses the same algorithm approach to the laser scan and interpretation.

While chemical compatibility of GMs is influenced by knowledge and experience, this can be confirmed for waste streams having long decay periods once leachate is available or by using a simulated leachate. The results will influence the capping closure design i.e. if the basal barrier system service life exceeds the waste polluting period only a rudimentary cap may be required for closure, whereas if the basal barrier is at risk of failing before the end of the polluting period then the cap may be a dry tomb or non-infiltration barrier design. Guidance on the approach to capping closure design is available on the DFFE website at http://sawic.environment.gov.za/documents/12494.docx.

The degradation of polymeric materials is significantly influenced by elevated temperatures. This degradation rate is not linear as temperature increases and thus average temperature cannot be used to assess the influence during materials handling, storage, construction, operation and post closure periods. Guidance is given on service life influence due to elevated temperature effects for a particular resin and stabiliser package of geomembrane in the Rankine lecture by RK Rowe, 2005. (https://civil.queensu.ca/Research/Geotechnical/R-Kerry-Rowe1/publications/documents/Geotechnique%20Rankine%20V55%20N9%20631-678%20Rowe%202005.pdf) and for various geosynthetic materials under exposed and covered conditions by the GRI White Paper #6. https://geosynthetic-institute.org/whitepapers.htm It should be noted that while this guide on temperature effects is available the chemical compatibility of a geomembrane and leachate is best determined by accelerated compatibility testing to assess the particular product's stress crack resistance, as seen in SANS 10409 (2020). Guidance on geomembrane service life assessment as a consequence of chemical compatibility is provided in literature, in which coupons are immersed in sample or simulated leachate and subsequently evaluated for performance reduction, based on loss in tensile stress properties or loss in antioxidant protection or onset of stress cracking. An approach to geomembrane selection is provided by Rowe et. al (2020). The reliance on standard and/or high-pressure oxidation induction time specifications alone does not ensure anti-oxidant protection under various leachate and strain conditions.

In respect of total solute seepage (excluding diffusion) the performance is significantly influenced by construction quality assurance – not only of the products installed but especially how they are installed and the associated wrinkles and holes etc. These influences are addressed in the CQA Plan to inform the calculation. Attention is drawn to the Casagrande lecture of 2012 and in particular the last equation under section 5 thereof for determining seepage losses through barrier systems. This reference is available on the web "Short- and Long-term leakage through composite liners" the 2012 Arthur Casagrande Lecture by R Kerry Rowe. https://www.geosynthetica.com/wp-content/uploads/2012-Rowe-Casagrande-CGJ-492-141-169-.pdf

7. Further Guidance

There is extensive guidance available on the internet and through capacity building activities of volunteer organisations such as the Institute of Waste Management South Africa (IWMSA) and the Geosynthetics Group of South Africa (GIGSA). For efficient processing of license applications reliant on design reports, still further advice can be obtained from Technical Advisory Notes from the Department Water and Sanitation which include:

- Standard of Design required for license consideration.
- Performance Standards for Water Uses including Pollution Control
- Cost effective design of barrier systems
- Construction Quality Assurance Plans

This guideline does not purport to be all embracing as some waste streams and site specific conditions may require unique detail design and hence the reliance on the registered professional engineer who certifies the design report and drawings in accordance with the NEMWA Regulations 2013 to undertake the design in accordance with the Engineering Professions Act, Act 46 of 2000, Code of Conduct for registered persons as given in Board Notice 41 of 2017 and related rules. https://ecsa.co.za .
This guide on contaminant containment barrier system design provides for a means for determining the performance quantitatively as required by the regulator, however, it does

not intend to influence the regulators decision making on acceptability of a particular design as the receiving environment conditions and implications need to be taken into consideration in accordance with the principles and procedures prescribed in legislation for which some guidance has been given elsewhere. https://doi:10.36487/ACG_rep/1910_0.02_Legge

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Prepared by:

Kelvin R Legge
Chief Engineer Integrated Development
DWS

Karl J. P. Bester
Chief Engineer: Dam Design
DWS

For DFFE Technical Working Group 3 of the Review of the Norms and Standards for Disposal of Waste to Landfill (2013), September 2021

APPENDIX 1: THE CHANGE IN WASTE DISPOSAL PHILOSOPHY WITH TIME

1. Changes in Philosophy with Time

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.

2. The 1800s

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 although the first masonry and gravity structures had come into being. Most developments were for agricultural water supply with only 8 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 F. E. 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 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 systematically surveying the colony.

- In the Transvaal, the Chief Engineer F. A. 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. 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 was insufficient for direct irrigation by extracting water from runoff river diversion works.

At Union in 1910, 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 F. A. 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 9 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 A. D. Lewis was called upon to investigate development of the lower Orange River that had formed the boundary between the South African Union and German South West Africa. 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 27th of 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 Great Depression from 1929 to 1939 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 from 1939 to 1945 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 to 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 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, that is 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. The primary objectives of which are: sustainable water resources management and poverty alleviation.

3. The democratic era inheritance and changes

Today South Africa is a relatively young developing country in which industry matured following a foundation in both agricultural expansion and mining practices in the hinterland. A century ago the results of early mining raised very limited concerns with respect to pollution as seen Table 1, and legislation was introduced in 1935 to assist with the management of water resources in the upper Vaal River catchment, one of the major rivers of the country and situated to the south of the gold mining reserves. Cities such as Johannesburg developed around these mining practices. For many years, pollution due to other sources such as municipal solid waste was not considered to be a serious threat to the water resources nor environment.

As recently as the 1970s a senior official within the regulatory system had stated publicly that landfill waste was not considered a source of pollution to be of concern. The practices for land filling were thus unregulated and municipal solid waste was disposed of in unlined abandoned quarries, random valley fills, and in any other suitable or accessible positions including as fill material to reclaim wetlands.

It was during the 1980s that an academic institution established a research program to look into whether landfills were indeed a source of pollution or not. This program looked at two existing facilities which had been operating for many decades, the one facility known as Waterval was a site serving the early gold mining city of Johannesburg. The other waste facility was situated at the other end of the country, just outside the city of Cape Town and known as Coastal Park. The investigation into these waste bodies included aspects of conventional geotechnical engineering such as drilling auger holes through the waste body and profiling the holes with depth, keeping a record of moisture content, extent of waste degradation, type of waste, extent of ash, and layering, along with the presence of free liquid. This investigation concluded that landfill is indeed a source of pollution and that the main drivers of leachate development were related to drainage of surface and surrounding water; the moisture of the waste being deposited including whether co-disposal was taking the place of liquids with solids; and the climatic water balance at the site. The research process had also included monitoring of groundwater with distance from the waste facility and it was noted that in the case of Coastal Park landfill, a pollution plume was moving off site at about 4 m/annum.

Table 1 Publications showing awareness of mining related pollution over the past decades (Liefferink 2012, Environmental Justice Forum)

1960	Final Report Interdepartmental Committee on Dolomitic Mine Water: Far West Rand, DWAF
1963	Council for Scientific and Industrial Research (CSIR) "Commentary on the Final Report of the Interim Departmental Committee on Dolomitic Mine Water: Far West Rand" 28/02/1963/10/02/1964
1995	Screening Surveys of Radioactivity in the Mooi River Catchment by the Institute of Water Quality Studies of the DWAF
1996	Scientists predict West Rand Decant in 2002 and suggested a solution in "An Integrated Strategic Water Management Plan for the Gauteng Gold Mines". The success of the proposed solution is dependent on the mines, water suppliers, water users and Government adopting an Integrated approach – with Government taking the lead role. The Western Utility Corporation developed an alleged technical and economical viable solution but at the time of writing, Government has not given approval to their initiative, Government alleges that the polluter cannot be allowed to profit from the pollution.
1999	Report, "Radioactivity Monitoring Programme in the Mooi River (Wonderfonteinspruit) Catchment". Institute for Water Quality Studies, DWAF, April. Mining activities are a major contributor to uranium and uranium series radionuclides within the catchment. Concentrations decrease downstream of the sources, indicating removal from the dissolved fraction by interaction with sediments.
2002	Publication of the "Radioactivity study as sediments in a dam on the Wonderfonteinspruit Catchment". Conducted by the Council for Geoscience and commissioned by DWAF (Wade et. al.) 2002 (WRC)
2002	Publication of the "Tier 1 Risk Assessment of selected Radionuclides in sediments of the "Mooi River Catchment". WRC Report 1095/1/02 by P. Wade. Radionuclides are concentrated by sediments downstream of their source. Sequential extractions show that these Radionuclides are distributed in multiple phases within the sediments and that they may be remobilised by environmentally by plausible chemical processes such as AMD.
2002	Coetzee et. al. of the Council of Geoscience reported on "Uranium and heavy metals in sediments in a dam on the farm Blauwbank." The study confirmed the findings of Wade et. al. and used further sequential extractions to characterise the sediments in a dam downstream of mining activities in the Carltonville area.
2005	Publication, WRC on "Impacts of gold mining activities on water availability and quality in the Wonderfonteinspruit River Catchment". Mining related impacts such as large scale land degradation associated with dewatering of domestic aquifers and widespread pollution of surface water and groundwater systems are discussed.
2005	Publication, Council for Geoscience, "Catchment contamination of wetlands by the Witwatersrand gold mines processes and the economic potential of gold in wetlands" by H Coetzee et. al, Report number 2005- 0106. For more than a century the mines of the Witwatersrand have discharged contaminated water into the streams and rivers of the area, which led to a formation of a system of large wetlands. Concerns have been raised about their ability to cope with the pollutant loads flowing into wetlands.
2006	Publication of "An Assessment of Sources, Pathways, Mechanisms and Risks of current and potential future pollution of water and sediments in gold mining areas of the "Wonderfonteinspruit Catchment". Report WRC, H Coetzee et. al. Council for Geoscience, 2004, Report number 1214/1/06

4 Development of initial waste management philosophy

This research led to the belief or philosophy that it was only necessary to contain the most hazardous of waste material, whereas for small sites or low risk point sources of pollution the groundwater regime could employ the philosophy of attenuation for protection. During the early 1990s the regulatory body responsible for water resource protection developed a suite of guidelines which became the accepted standard against which the permitting of landfills took place. These standards were based on the philosophy that mitigation can be achieved by containment for the most severe pollution source and attenuation for the low significance pollution sources, with a range of standards between these two extremes as shown in Figure 1(a). Classification of waste was thus addressed by toxicity and concentration, leading to classification of waste as either hazardous or general. The size of a site was taken into consideration based on the rate of waste disposal leading to a second parameter of large, medium, small or communal facilities. To give effect to the research result which identified available water as a critical factor, it was accepted that a third factor would be water balance at the particular site, with the leachate producing facilities conceptualised as being those situated at positions where, for the wettest six months of a year, the rainfall would exceed evaporation as shown in Figure 1 (b). Sites are thus classified with a third parameter as either water surplus or water deficit.

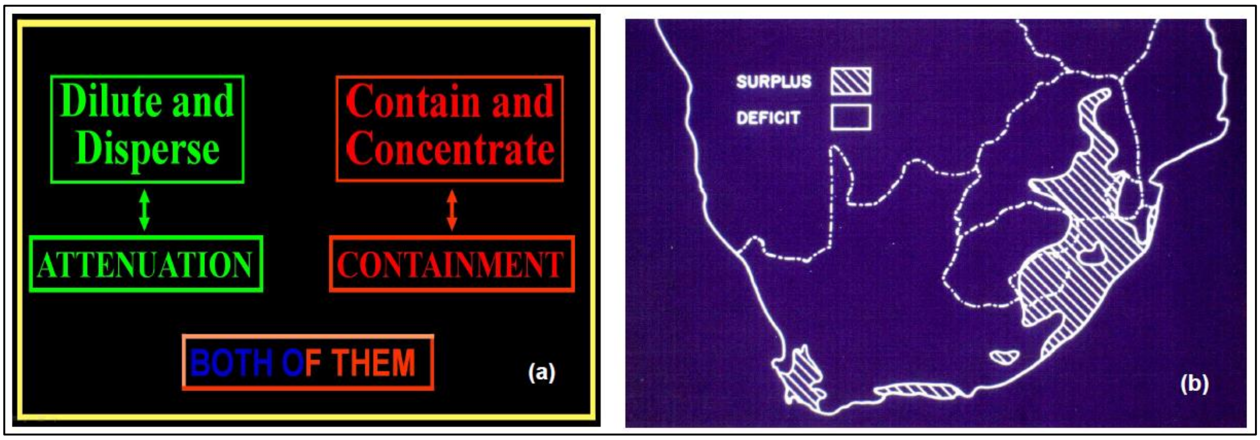


Figure 1 The 1990s' philosophy on pollution generation and range of mitigation (Ball 2002): (a) The extreme philosophies of dilution and dispersion relying on attenuation through a range of standards to containment; (b) The concept of water balance showing water surplus and water deficit areas based on precipitation and evaporation only

The classification of sites as hazardous or general; large medium or small; and water surplus or water deficit then led designers to minimum requirements for containment barriers beneath such facilities. It is recognised that these containment barriers did not pursue containment to the extent that was reasonably achievable, but allowed for some dilution and dispersion. Thus only hazardous waste facilities in recent years generally employed a double liner system of which at least the primary liner was a composite liner made up of both a geomembrane and a compacted clay liner, and this compacted clay liner being made up of multiple layers with a total thickness of at least 600 mm. In all cases where double liners were specified as a minimum requirement, they were separated by a leak detection system. So too was it a minimum requirement for all containment barrier systems incorporating a geomembrane that there should be a protection layer between geomembrane and the overlaying leachate collection system. For the general waste facilities clay only barriers were employed with thickness in proportion to size classification, and leachate collection systems required only for those sites situated in a positive water balance area.

This range of documents gave waste facility owners guidance beyond design and construction, and included operation and monitoring of performance. The minimum requirements were used extensively at a time when the country was going through significant change in legislation and a growing environmental awareness with recognition of the limits to natural resources. Thus while these documents were employed for over a decade leading into significant law reform, the regulators and professional societies involved in waste management used the opportunity to ascertain the suitability of the philosophy and the requirements.

There were several lessons to be learnt from applying these requirements or standards in the local framework. It was recognised early on in their application that even in the driest of regions, falling well within the water deficit classification, leachate was indeed produced within the waste body and was as a result a source of pollution as seen in Figure 2(a). Similarly, it became quite apparent that the waste stream to landfall varied with time and position, and this had an influence on the performance of leachate collection systems in the water surplus areas. These leachate collection systems were found to block readily as seen in Figure 2(b), as they were not protected by filter systems defined within the standards and thus not employed by the owner or designer. So too was significant experience gained in the use of geomembranes as liner materials.

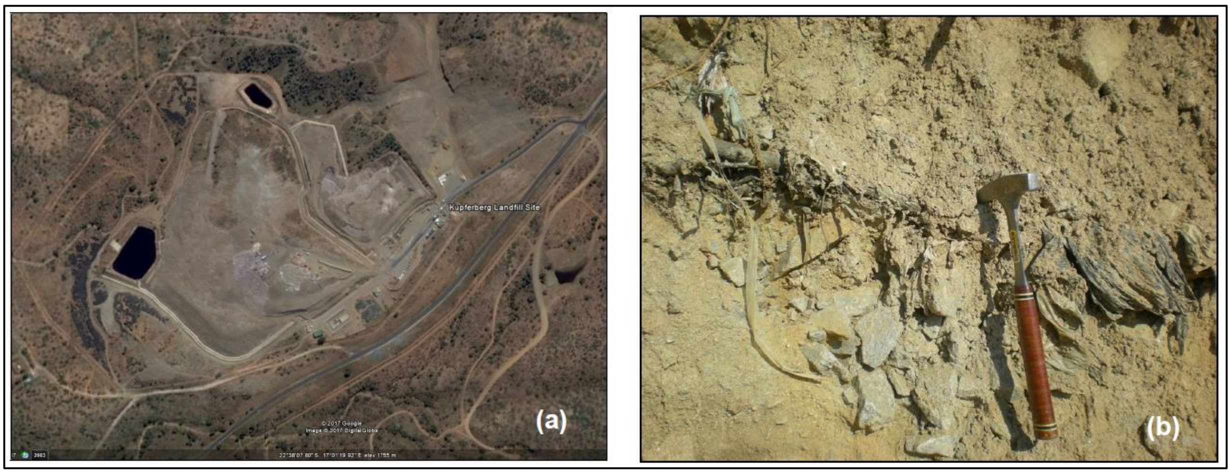


Figure 2 Experiences from applying the Minimum Requirements for waste disposal (DWAF, 1998) philosophy: (a) Excessive leachate is generated even in a desert environment (Google Earth image of Kupferberg, Namibia (Alphabet Inc. 2019)); (b) Aggregate leachate collection systems clog readily if not protected by a filter (Shamrock and Msiza 2015)

The use of geomembranes in South Africa had historically been for applications where water containment was required, often associated with inter basin transfers, or delivery of raw water over significant distance from its source and hence competent storage was required for this valuable asset.

5 Development of modern philosophy

The new-found international relations with the world allowed South Africa to exchange technology with countries willing to do so, and the advent of the Internet facilitated an even greater rate of sharing of knowledge and experience.

The new legal framework placed environmental protection and human rights high on the legislative agenda. The Constitution of the Republic of South Africa, 1992 and 1996, Bill of Human Rights demanded a rethink of waste management and pollution control measures. A hierarchy of waste management strategies emerged with a priority to address the rapidly deteriorating limited water resources as seen in Figure 3. It is widely known that with the long history of mining practices in certain parts of the country, that salts are a significant problem in the groundwater and river systems (Brink et al 2009). The assimilative capacity of many watercourses and rivers was exceeded bringing about the de-oxygenation and anaerobic conditions with associated loss of biota. Many human lives and the health of communities or persons who made use of runoff river water supplies were placed at risk.

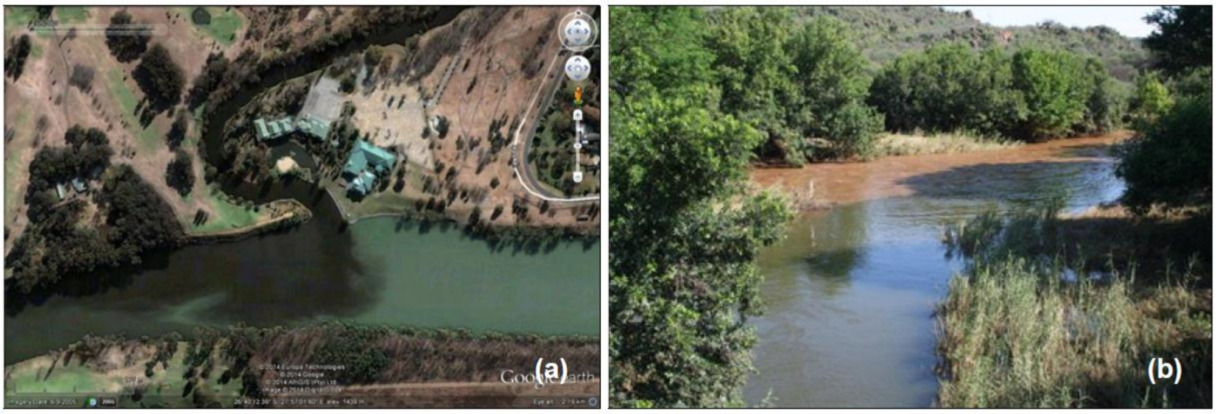


Figure 3 Visual evidence of waste and mining pollution in rivers. (a) The confluence of the Vaal and Klip Rivers (Google Earth Image of confluence the Vaal and Klip River); (b) The confluence of the Steelpoort and Klip River (photo courtesy RB Martin)

This attention to the significance of South Africa's water resources was escalated largely by the World Commission on Dams South African Initiative, which recognised the scarcity of water in this region of the world. Similarly, the dependence of poor persons on natural resources drew attention to the water quality of river systems which was further emphasised by acceptance of international treaties and the importance of biodiversity and wetlands in the remediation of water resources impacts.

Despite the privilege of a domestic geomembrane manufacturer and several lining installation contractors, as well as a local geotextile manufacturer with several suppliers, the investigations and performance assessment of geosynthetic products was undertaken by academic institutions to a large extent, and to a lesser extent by the regulator itself. With the limited resources available for research, the use of international literature, access to material producers from around the world, and cooperative studies were pursued.

6 Monitoring of minimum requirement-based facilities

A further consideration of these shortcomings of the Minimum Requirements was realised as the regulator pursued monitoring of existing facilities and, in particular, those facilities incorporating a geomembrane liner. The requirement that hazardous waste facilities and large leachate producing facilities monitor the performance of the primary liner through the use of a leak detection system was fatally flawed due to the prescriptive means. This leak detection system is given effect by a secondary liner which in all cases except for the hazardous waste lagoon, is a compacted clay liner only, and typically of the same material as within the primary liner but even thinner (usually only two layers). It was thus clear that the apparent reporting of suitable containment by the primary liner systems was in fact not a true reflection of the primary liner performance, but rather a failure of the secondary liner to report leakage exceeding the expected threshold. This was deemed a fatal flaw of the minimum requirements, and in particular for the most important waste streams being those which receive the toxic and larger volumes of waste.

Although the Minimum Requirements 1998 applied to waste management, the mining regulations under the National Water Act came into being in 1999 with greater emphasis on enforcement in 2006. The monitoring of drainage systems to three coal residue deposit facilities in Mpumalanga during the period 2007 to 2011 gave greater insight into liner performance. Although sites 1 and 2 were adjacent to each other and Site 3 some 50 km away, the drainage systems of finger and toe drains above the Site 1 compacted clay only liner compared to the composite 1.5 mm thick linear low density polyethylene (LLDPE) geomembrane and 450 mm thick compacted clay liner (CCL) of Site 2 showed the latter reported approximately 118% more leachate per month in drain flows on average (over different lengths of monitoring periods). A comparison between Site 1 and the distant Site 3 of similar composite liners showed a higher drain flow of the order of 400%. However, by comparing the 2011 season results only, so as to remove climate and rainfall as a variable, the drainage flow increased by about 270% above a composite liner compared to a clay only liner. (Acknowledgement to Jones and Wagener Consulting Engineers). Drain flow should not be confused with seepage losses through liners. The difference in the volume of retained polluted water is emphasised for appreciating water conservation as well as pollution control.

7 Importation of technology and renewable water

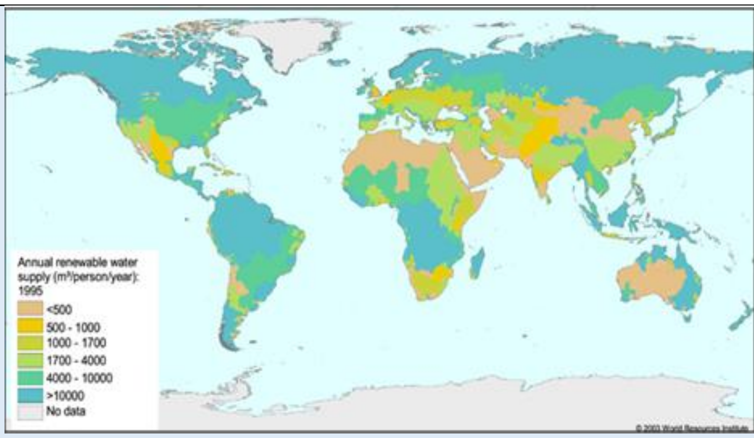
Regulations employed in foreign countries were considered for their suitability to the South African landscape. In particular, the countries of Australia, Canada, Germany, and the USA, along with the supporting technology, were studied.

An analysis of international standards led the regulator to believe that South Africa had one of the lowest standards of containment for waste amongst those countries in the world, which did regulate waste containment barriers systems at that time. The worldwide survey (Koerner and Koerner, 2007) confirmed that the world standard for waste containment, irrespective of whether the waste was hazardous or general, was the employment of a composite (geomembrane plus compacted clay in intimate contact) liner within a barrier system, whereas South Africa was to a large extent relying on clay only liners for partial containment and in many cases relying on rudimentary drainage layers and clay only liners for controlling the rate at which pollution took place.

Although it was tempting to adopt a standard from another country which had experience in modern containment standards for barriers systems, the South African situation of a large industrial and developed economy in a water scarce environment had to be taken into consideration. The water availability per capita per annum (shown in Table 2) needed consideration to reflect the acceptable assimilative capacity of our ecosystems within watercourses.

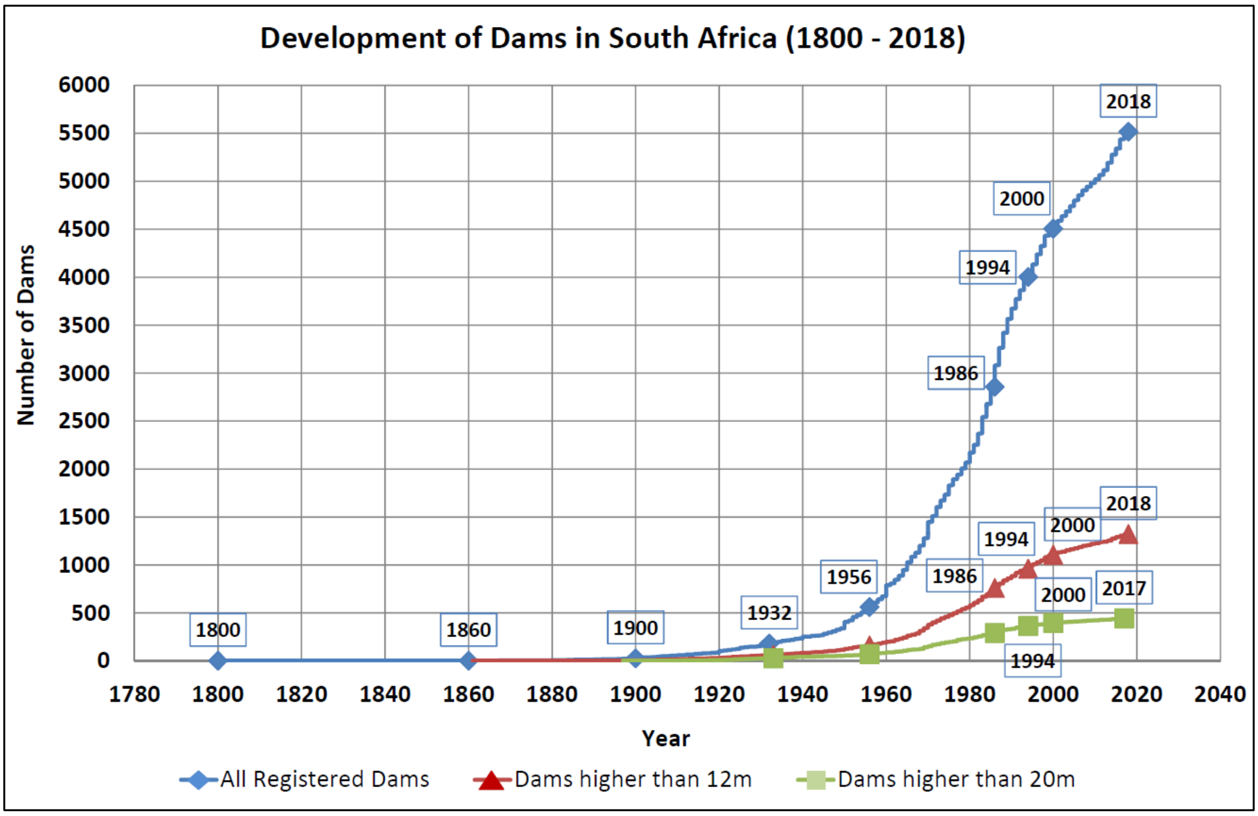
Table 2 Estimated renewable water available in cubic meters per person per annum for selected country/region as at 1995, extracted from global image (World Resources Institute 2003)

Country/ region	Annual renewable water supply (m^3/person/year)
Australia	2,000–4,000
Canada	>10,000
Germany	1,000–1,700
Scandinavia	500–4,000
South Africa	800
USA	4,000–10,000



The small volume of water available per person per annum in South Africa reflects the importance of maintaining aquatic ecosystems in a healthy functioning condition. It became quite apparent that the historic philosophy of the past 20 years which allowed for dilution and dispersion relying on attenuation was not acceptable.

This situation was further aggravated by the limited water quantity for dilution and realisation that future large dam developments for water supply to agriculture, mining and industry are exceedingly expensive, as reflected in the change to rate of development shown in Figure 4.



Development of Dams in South Africa (1800 - 2018)
Number of Dams
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1780
1800
1820
1840
1860
1880
1900
1920
1940
1960
1980
2000
2020
2040
Year
1800
1860
1900
1932
1956
1986
1994
2000
2018
1986
1994
2000
2018
2000
2017
1994
All Registered Dams
Dams higher than 12m
Dams higher than 20m