CHAPTER SEVEN: INFLUENCE OF ENVIRONMENTAL IMPACTS ON TAILINGS IMPOUNDMENT DESIGN - DISCUSSION

Tailings impoundment configuration requires you not to respond to immediate emotional impulses without considering the big rational picture. Stakeholders are told, "This tailings impoundment may cause water and air pollution even with the best controls [immediate emotions], but without it the economy of the whole region will collapse [big picture]." In terms of the old dichotomy, what is being said is, "Don't base your decisions on romantic surface appeal without considering the classical underlying form."

Inspired by Robert Prisig (Pirsig, 1999:235)

7.1 Introduction

The total environmental and engineering aspect costs for different tailings impoundment cover types are integrated in Chapter 6. The costs for the two main impoundment stage categories are summarised in Table 75 and graphically represented in Figure 205.

Table 75: Simplified total environmental and engineering costs for different impoundment cover types. The costs are grouped into two categories namely development and operation cost, and closure and post-closure costs.

	Stage of tailings impoundment construction		
Total environmental and engineering cost	**Development[1] and operation cost[2] (R million)**	**Closure and post-closure cost[3] (R million)**	**Total (R million)**
No cover cost	**477 +**	**376 =**	**853**
Rock cladding cost	**477 +**	**405 =**	**882**
Grassed armouring	**477 +**	**271 =**	**748**
Diverse vegetation	**477 +**	**246 =**	**723**

[1] Development is the term used for the design and initial construction.

[2] Development and operation cost is the term used for all the engineering cost prior to closure.

[3] Closure and post-closure cost is the term used for the environmental and engineering costs during and after closure.

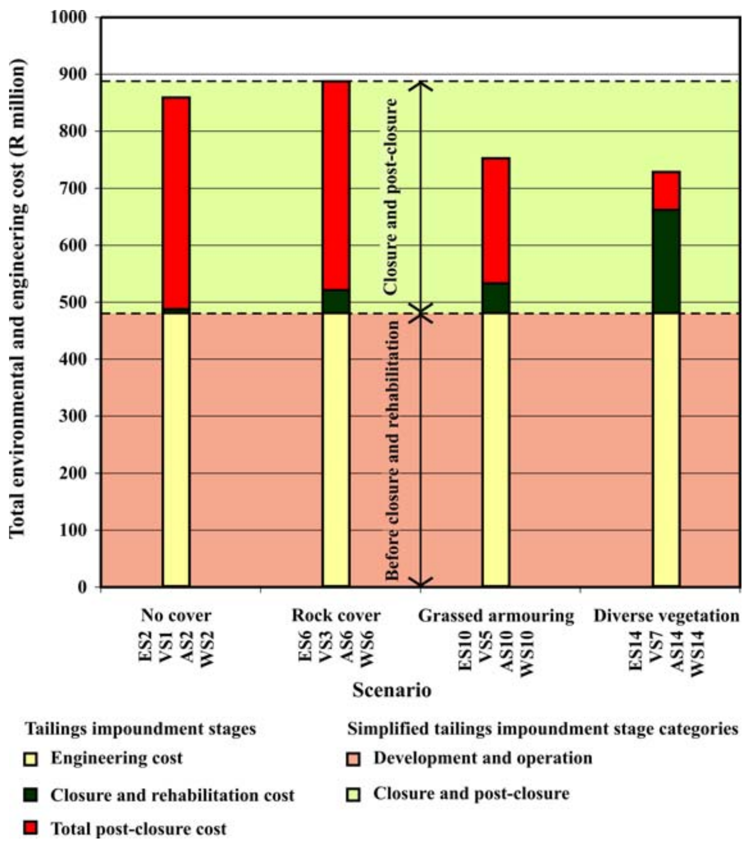


Figure 205: Simplified integrated environmental and engineering costs for different cover types.

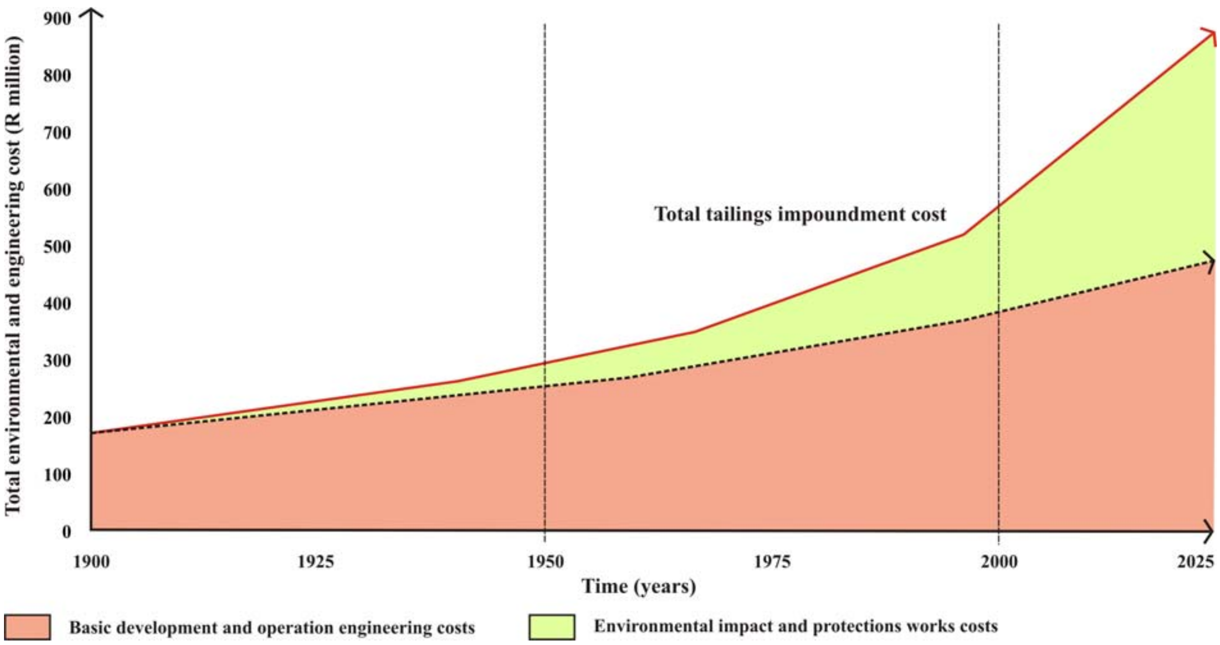


Figure 206: Schematic illustration of simplified environmental impact and basic engineering costs.

The total environmental and engineering costs for the cover types are:

- no cover (R850 million);
- rock cladding (R880 million);
- grassed armouring (R750 million); and
- diverse vegetation (R720 million).

The costs are grouped into the two categories to illustrate the potential change in total costs brought about by change in covers (Figure 205). The initial development and operation engineering costs are the same for the different covers since the volume, height and configuration of the impoundment remains constant.

By including the environmental costs in the cost estimation the closure and post-closure category costs are 45 % (No cover), 40 % (Rock cladding), 30 % (Grassed armouring), and 10 % (Diverse vegetation) of the total environmental and engineering costs.

Depending on the choice in cover (constructed during rehabilitation as part of the closure stage) a significant change in the closure and post-closure stage and the total environmental and engineering costs can be incurred. The environmental impact costs are therefore important in terms the overall costs for the construction of an impoundment. By choosing a diverse vegetation cover the costs can be reduced by R130 million when compared to leaving the impoundment in a state of disrepair (No cover). Similarly a grassed armouring cover can reduce the total costs by about R100 million when compared to not covering the impoundment.

Figure 206 (p. 316) illustrates the apportionment of environmental impact costs and basic engineering costs for the results presented in Figure 205 (p. 316). The figure is also used to illustrate the concept that the total tailings impoundment development cost is made up of two category costs namely the environmental protection costs and basic construction costs. These costs can now be quantified by using the costing system described in this thesis.

7.2 Decision-making system

Because decision making regarding the acceptability of the sustainable configuration of a tailings impoundment is a complex task it is important that approaches have to be developed and expanded in order to facilitate transparent decision making amongst the relevant stakeholders. Any given approach or method used to provide input into the decision-making process needs to keep a holistic perspective of sustainability during the key stages of development and must address biophysical, socio-cultural and economic aspects as well as specific related criteria to facilitate “holistic” judgment (Rademeyer et al., 2007).

The environmental and engineering costing system described is generic in nature and although developed for upstream ring-dyke metalliferous impoundments can be expanded to other types of waste disposal problems. Almost all decisions are unique in character, controlling variables and the preferred solution and ought to be specifically developed for other applications. The system although simplistic provides structure to important considerations and questions.

It is essential to understand the process by which environmental engineers derive at a decision, hence the requirement for a detailed methodology for making sense of the decision-making process. The configuration of a tailings impoundment is a multi-dimensional and -objective decision process using computer support to model some of the environmental aspect influence changes resulting from changes in impoundment configuration. The manipulation of data, retrieval and display of results has a remarkable impact on how decision makers reach consensus on outcomes. It was the intent of this study to exploit the available decision-making tools and models to facilitate innovative and effective decision making. It has been found that some of the tools are easy to use providing quick results while others require in-depth specialist knowledge. The system facilitates rational decision making and uses computer-based support tools and models to integrate environmental impact costs and engineering costs for various impoundment configurations.

This study provides decision makers with:

- a system to quantify and compare environmental impacts; and
- a demonstration of how models and tools can be used to provide environmental practitioners with support.

The system developed and described is useful and involves the following characteristics:

- large amounts of data are assessed to make conceptual use of it;
- it was necessary to quantify key environmental aspect impacts in order to arrive at a solution; and
- the approach can provide input into the DSS framework developed for the WRC (Rademeyer et al., 2007).

Important to note is that the process described allows decision makers such as specialists, professional planners and researchers to draw on analytical and decision-support tools helping with, although not resolving, complex decision problems. The approach does not make decisions but provides information that facilitates informed decision making.

7.3 Valuation of environmental impacts

Similar to the Multiple Accounts Analysis (MAA) method of analysis as discussed in Section 2.9.3 the approach presented in this thesis also relies on the assigning of values to impacts in order to evaluate the potential impact on the environment as a result of change in tailings impoundment configuration. MAA is typically used to compare alternatives with each other such as comparing alternative sites for a new tailings impoundment or to evaluate rehabilitation alternatives for a mine that needs to close. It is a tool and involves three basic steps:

- identify the impacts;
- quantify the impacts; and
- assess and compare the alternatives.

MAA is in essence a value-based analysis whereby numerical values to indicators are assigned using ranking and scaling techniques. Details of the method and framework are provided in Section 2.9.3. The assessment and comparison of the alternative configurations discussed in this thesis is done by valuating the impacts, i.e. assigning costs to the impacts. This is useful as it provides decision makers with a rational and transparent method to assess the costs of each alternative. The approach demonstrates how the impacts on visual perception, air quality, and water quality can be quantified and valuated.

The context of the three environmental aspects included in the environmental and engineering costing system is provided by Figure 38 (p. 65) which simplistically groups environmental aspects into socio-cultural, biophysical and economic elements. The configurations modelled were ranked by, for example, modelling the visual perception zones of influence for each alternative and presenting the information graphically on a comparative plot (Figure 164, p. 272).

The plots for all the environmental aspects modelled were overlaid and presented on a comparative plot (Figure 169, p. 276) which was used to compare the various configurations with each other. Philosophically this is no different than ranking and scaling the environmental aspects for each alternative. The weighting of each alternative takes place when the environmental aspects are valuated. The total cost of an alternative configuration is determined by the sum of the valuated environmental aspects. The configuration (slope or cover choice) is less favourable the higher the total environmental costs are.

The systems does not include all of the environmental aspects listed in Figure 38 (p. 65) as it was decided that it is more important to create a robust system which can be expanded with time by including other environmental aspects such as the impact on heritage, tourism, the living environment, and land capability and production.

Change in productivity and impact on land capability by the take of land (permanent loss of land) under the footprint of an impoundment may be important in certain instances such as where the land is used for the production of crops. The following example illustrates how such impact costs can be calculated and depending on the relative importance of the environmental cost can be incorporated into the overall system. The ERGO Daggafontein site is used to illustrate the potential loss in productivity as a result of the take of land.

Change in productivity

An impoundment can influence the productivity of other systems. The valuation can be straightforward if the change in production can be quantified and market prices are available. For example if the effect of increased dust fallout on the production of crops is known, the loss in yield could be calculated. The monetary value of the changed yield is attributable to the tailings impoundment and hence an economic cost of the project. The loss in production must have an assessable market value. Because the lower production is accompanied by lower costs of production, the change in net benefits yields the net impact of the externality. One of the objective valuation approaches (Table 5, p. 67 and Figure 39, p. 69) can be used to cost change in production and will be illustrated with an example.

The change in production approach can be used to assess the impact as a result of increased dust fallout and the loss of land. However, this economic impact is not illustrated. On the other hand, the loss in production as a result of permanent loss of land under the footprint of the tailings impoundment can be calculated. Depending on the post-closure impoundment configuration (Figure 64, p. 135) a permanent loss of land can be anticipated resulting in the production loss of crops such as maize, sorghum, soya bean and sunflower sorghum. The average yield per annum, price per tonne and potential production for these cash crops are provided in Table 76.

Table 76: Average yields and prices for cash crops (van Rooyen, 2006).

	Maize			**Sorghum**		
	Yield (t/ha)	**Average Safex price (R/t)**	**Potential yield (R/ha)**	**Yield (t/ha)**	**Average producer price (R/t)**	**Potential yield (R/ha)**
2003	3,06	1004	3072	2,80	1450	4060
2004	3,15	919	2895	2,90	900	2610
2005	3,85	682	2626	3,00	450	1350
2006	3,64	1190	4332	2,90	1010	2929
Average	3,43	949	3231	2,90	953	2737

	Soya bean			**Sunflower**		
	Yield (t/ha)	**Average Safex price (R/t)**	**Potential yield (R/ha)**	**Yield (t/ha)**	**Average producer price (R/t)**	**Potential yield (R/ha)**
2003	1,18	2250	2655	1,38	1974	2724
2004	1,61	1850	2979	1,23	2185	2688
2005	1,75	1497	2620	1,34	1828	2450
2006	1,74	1596	2777	1,28	2145	2746
Average	1,57	1798	2758	1,31	2033	2652

Between 300 ha and 400 ha, depending on the impoundment overall embankment slope, could be permanently lost under the footprint of the tailings impoundment. The ERGO Daggafontein impoundment is located on land which was previously used for grazing and the cultivation of crops. For the purpose of this illustration it is assumed that all of the land under the foot print of the impoundment is suitable for the cultivation of cash crops.

Table 77: Potential loss in production due to the permanent loss of land under the impoundment.

		Potential loss in production (R/annum)			
Overall embankment slope (°)	**Footprint (ha)**	**Maize**	**Sorghum**	**Soya bean**	**Sunflower**
1:1,5	305	990 000	830 000	840 000	810 000
1:3	320	1 030 000	880 000	880 000	850 000
1:6	360	1 160 000	980 000	990 000	950 000
1:9	400	1 290 000	1 090 000	1 100 000	1 060 000

Figure 207 (p. 321) maps the land uses around the ERGO Daggafontein tailings impoundment. The main land uses consist of industry, residential, small holdings and agriculture. The agricultural land can be further sub-divided into cultivated lands, grazing, wilderness land, and wetlands and water bodies. Depending on the cash crop and if it is assumed that the area cultivated only yields one crop per annum, the potential loss in production loss could be between R2 600 and R3 300 per hectare.

The impoundment configuration with the steepest embankment slope (1:1,5) will result in a land loss of 304 ha and the flattest scenario (1:9) will require 396 ha. The difference in production loss can be as little as R800 000 and as much as R1,3 million per annum. The difference in the steepest and flattest embankment configuration for maize is almost R300 000 per annum which is close to a 30 % annual loss in production. The loss in productivity costs due the construction of the tailings impoundment can be used to help assess the costs and benefits of the impoundment in terms of the total mining costs and benefits as well as for the various impoundment configuration alternatives.

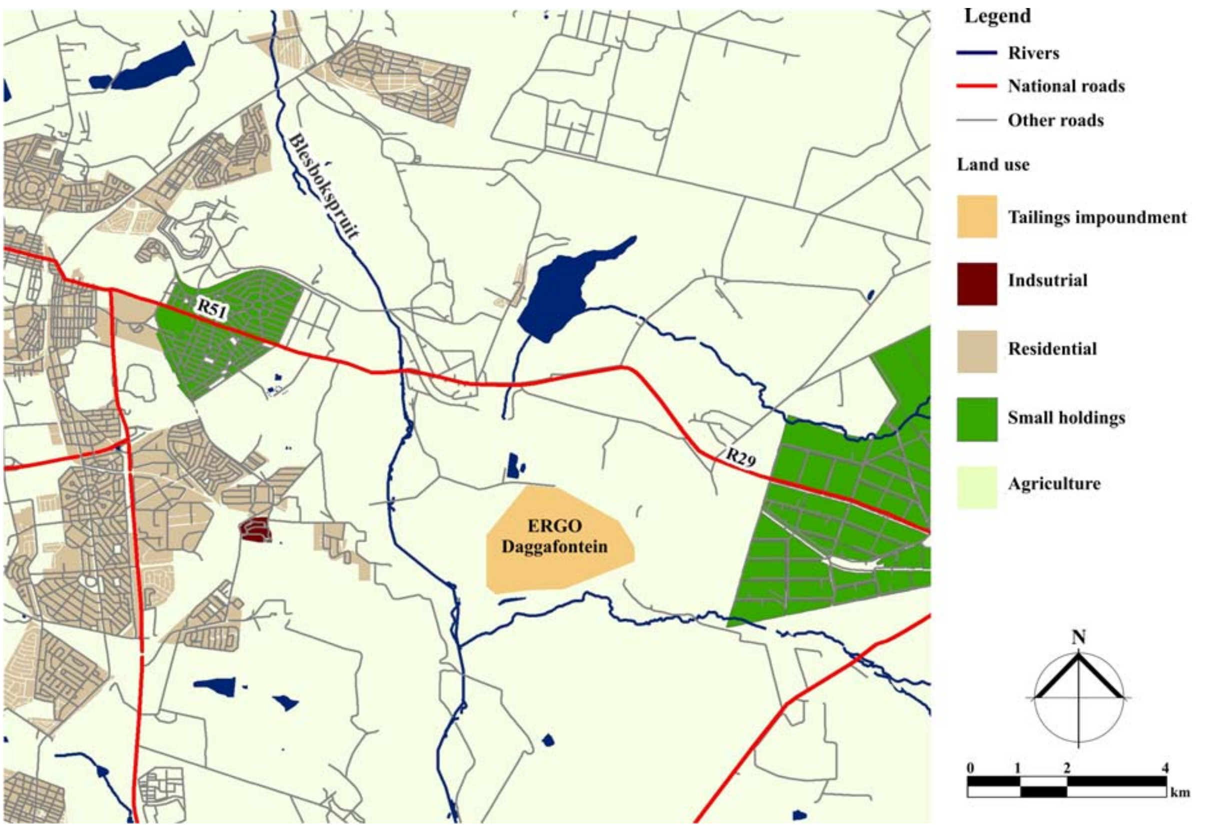


Figure 207: Regional land use map around the ERGO Daggafontein tailings impoundment.

7.4 Sphere of influence

Spatial representation of environmental impacts plays an important role when identifying potential conflicts in existing and future land use. Figure 208 (p. 322) illustrates how the environmental aspect zones of influence as well as the total environmental sphere of influence for tailings impoundments spatially represented once it has been determined.

Tailings impoundments in very few instances have any direct benefit to communities. The disposal of tailings is at the end of the chain in most mining developments and if the cost of the tailings disposal is too high it can jeopardise the viability of the operation. On the other hand, if the tailings impoundment is unsafe or it causes adverse environmental impacts after closure, there will also be a cost to society. The internalisation of the total environmental impact costs may also affect the viability of the mining operation and the construction of the tailings impoundment.

In some fortunate but rare instances, tailings impoundments have little or no effect on the environment. For example when an impoundment is constructed on naturally impervious foundations the effect on the water regime can be expected to be minimal as the source of water pollution is contained and will not impact on the groundwater regime. In such cases, the low quantity of seepage escaping the impoundment will have a negligible effect on the flow system. Where seepage cannot be contained and the discharge does not meet water quality criteria it may be sensible to place the impoundment sufficiently far from sensitive users by sensibly using buffer distances.

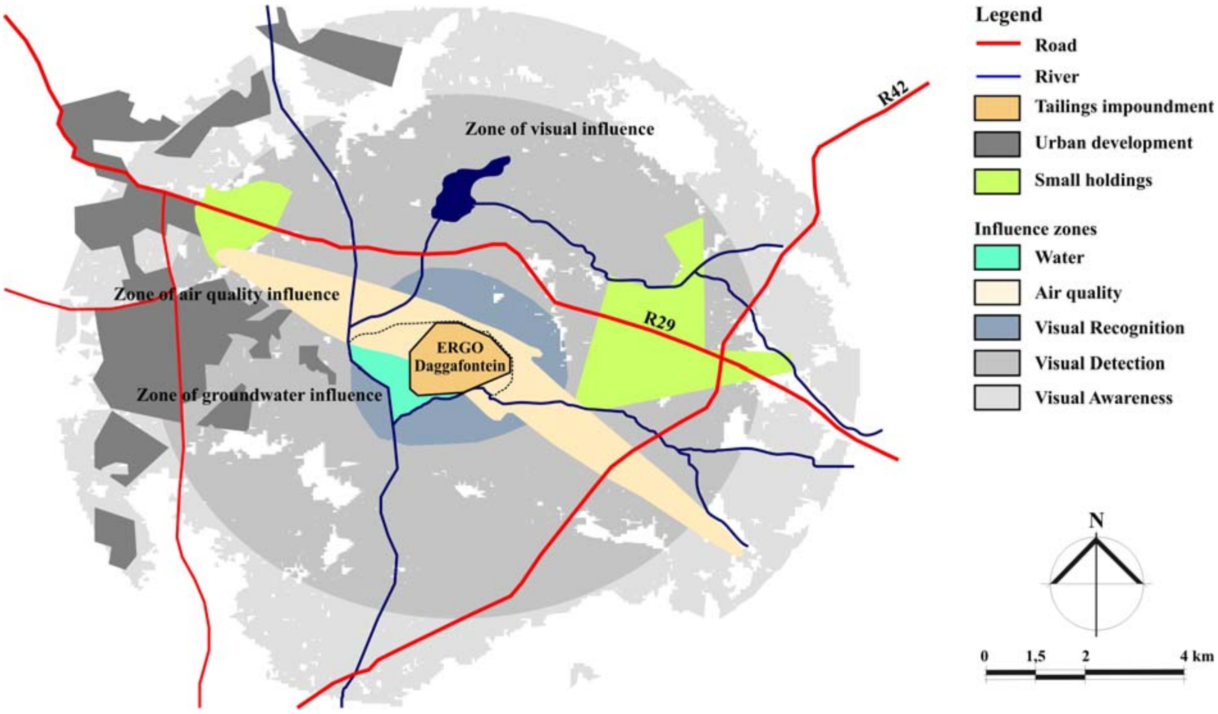


Figure 208: Total environmental sphere of influence modelled and spatially represented.

More intense involvement, such as suburban and urban development, with which higher land value is typically associated, usually requires drastic land disturbance. The rehabilitation steps to such end use are generally less expensive and involved. Most of the cost and effort is in the installation of new use. In contrast, to return a previously wilderness area to a near-wilderness state may require extensive rehabilitation efforts at high cost.

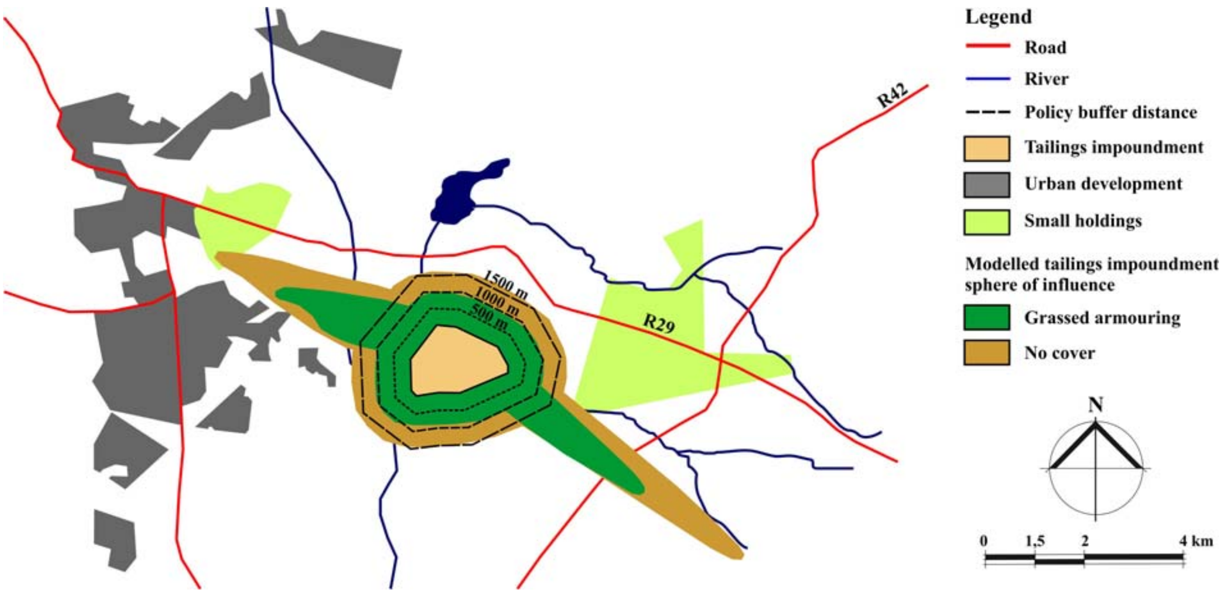


Figure 209: Comparing modelled zones of influence with typical policy buffer distances.

It may then be of economic advantage to plan an alternative future use at high-intensity level. The cost of rehabilitation as part of the mining process can be minimized. High intensity use ensures relief from long-term responsibility. In many cases such a goal is part of the preplanning process. However, the social value of a shopping centre or residential area in the middle of nowhere is questionable.

Delineation of alternative long-term uses requires compliance with socio-economic and public constraints as well as with goals of the mining company. In recognition of public welfare, regulatory authorities would be required to exercise strategic planning mechanisms with regard to laws, regulations, and planning and zoning.

Planning goals in determining acceptable future long-term alternatives must be developed by government regulatory authorities. In the most rigorous of cases, the alternatives may be extremely limited by zoning restrictions or future long-term land use plans for a region. In the least restrictive cases, virtually any alternative will usually have varying degrees of acceptability to stakeholders. From a practical viewpoint, the process defies specific detailing. The long-term post-closure use must be linked to the design, construction, operation and closure of the impoundment in space, time, and concept. Such linking is perhaps achieved by looking at alternative configurations during the concept design stage.

The construction of a tailings impoundment, because of its potential spatial and temporal boundaries, must be an integral part of the regional land use planning process. The ideal is that the planning process will result in an impoundment configuration that is compatible with existing and future uses within the tailings impoundment environmental sphere of influence. Deciding on a suitable site and impoundment configuration must be informed by strategic planning initiatives which take cognisance of short as well as long term zoning and land use into account. The essence of sustainable tailings impoundment configuration is about deciding on a final configuration which can support a preferred land use, how it will be constructed, and what it will cost to construct, operate, rehabilitate and manage the scheme in that particular locality.

7.5 Sustainable development

Despite its widespread popularity, the idea of sustainability is far from being clearly defined. Although the core of the vision seems simple such as a lasting and non-destructive way to live on Earth, the questions are and remain many. Probably the simplest widely used definition of sustainability is Brundtland's definition of meeting the needs of today's population without diminishing the ability of future populations to meet their needs. Sustainability in this sense could mean using resources without diminishing their future availability or quality. Even more simply, it requires living within our ecological means. Disposing of mining waste in such a manner that it impacts on the environment and diminishes future generations to use the land to meet their needs cannot be sustainable in the long term.

There is strong evidence that constructing tailings impoundments without considering the long-term environmental impacts associated with the configuration (i.e. impoundment shape, embankment slope and cover) can significantly increase the overall tailings impoundment costs, and in some cases even prevents them from being used after closure.

Turning an undulating hillside into a constant percent slope undermines ecological function because it changes environmental form. Similarly, constructing a tailings impoundment with constant percent embankment slopes also undermines the ecological functioning of the landscape. For those who are concerned with sustainability, the relationship between natural form and ecological function needs to be carefully studied. Although real understanding of this relationship is still developing, it is quite clear that it is far more than a backward looking aesthetic.

Although no one really knows what a sustainable tailings impoundment landscape looks like, the following suggestions are made:

- The sustainable tailings impoundment landscape does not exclude human presence or engineering design.
- The sustainable tailings impoundment landscape does not waste energy or resources on trying to disguise human influence. Rather, it eliminates functional as well as visual influences that are destructive or disruptive.
- The sustainable tailings impoundment landscape follows natural and regional form whenever this can improve the ecological functioning of a built or rehabilitated landscape.

7.6 Rehabilitation

The rehabilitation of tailings impoundments:

- is expensive;
- uses energy; and
- requires labour and time.

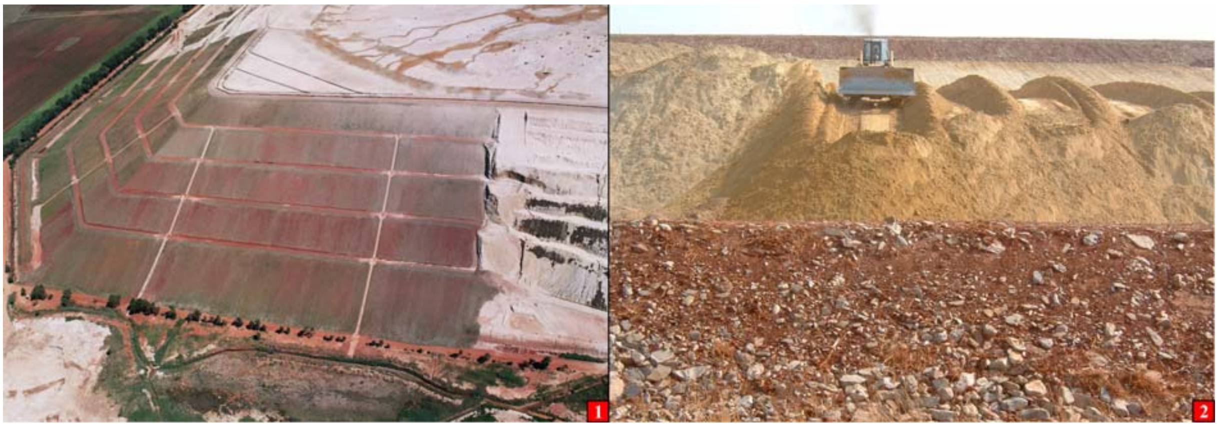
It appears to be cheaper to design, construct, and operate an impoundment with the envisaged final embankment configuration than it is to construct an impoundment with steep embankment slopes in the first place and later on flatten such mechanically.

Landform grading

Proper landform grading has been shown to decrease erosion and fits well with scientific theory about the geomorphologic evolution of natural slopes. It seems likely that properly designed embankment slopes will revegetate more quickly and cost-effectively especially if they offer a diversity of concave and convex, shaded and sunny, exposed and sheltered plant habitats. Implementing the stepped slope approach (Figure 210, p. 325) avoids some of the problems of conventional grading. Essentially stepped slopes are horizontal benches that are constructed as the slope is being graded, i.e. a modern version of the terraced slopes that has been used for centuries by traditional society practice agriculture on hillsides.

As water collects on each bench and begins to flow, it drops to the step below, dissipating its energy. Because it flows more slowly and puddles on each step, water falling on the slope has more time to infiltrate the soil, aiding plant establishment. Over time, the embankments of the step-ins do erode, but this only deposits loose soil on the benches below and serves as a rooting medium for seeds.

Step-in intervals can vary with their widths in proportion to an appropriate slope ratio. The steps are cut with a bulldozer when the excavation is made. The steps should be cut with the dozer travelling in alternate direction to prevent material from piling up at one end of the slope.



[1] Oblique view of a rehabilitated section at the ERGO Daggafontein tailings impoundment (photograph AngloGold Ashanti).

[2] View of mechanical reshaping at the ERGO Daggafontein tailings impoundment.

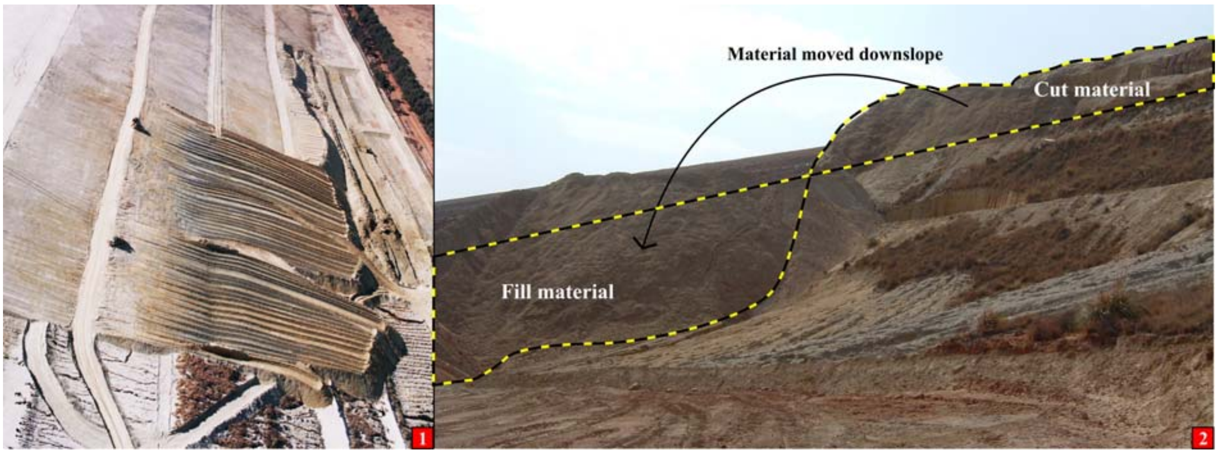
Figure 210: Creating stepped embankment slopes at the ERGO Daggafontein tailings impoundment using heavy machinery.

Grade subsoil not topsoil

If a final vegetative cover will be required and the tailings preclude in situ revegetation then it will be a prerequisite to subsoil and topsoil separately. Irrespective of the final impoundment configuration, it will be required to grade the impoundment and some instances the subsoil cover before placing the topsoil or growing medium. Topsoil is usually stockpiled and reapplied to graded or otherwise altered areas. The completed impoundment site will have a blanket of topsoil over the tailings or subsoil.

Balance cut and fill

Handling, moving and transporting soil is a costly exercise. It is for this reason that it is standard practice for large engineering projects to balance cut and fill on site and that soil need not be trucked in or carted off site. This concept can contribute to sustainability and should be considered in the design and construction stages of a project.



[1] Oblique view of the mechanical reshaping of the ERGO Daggafontein tailings impoundment (photograph courtesy of AngloGold Ashanti).

[2] Schematic showing the concept of cut and fill on the ERGO Daggafontein tailings impoundment side slope.

Figure 211: Stepped sloped grading balancing cut and fill.

Vegetating tailings impoundments

The lack of trees and shrubs severely limits the tailings impoundment's potential for creating wildlife habitats and not to mention visual variety. Woody vegetation provides perching sites for birds which in turn disperse seeds, helping to plant other areas with pioneer woody species. This planting strategy is called "habitat islands." Although the overall aim of planting woody species on tailings impoundments is to reduce wind and water erosion, planting of indigenous woody species such as *Rhus lancea*, *Rhus pendulina* and *Combretum erythrophyllum* in situ in the tailings also contributes to the reduction in rehabilitation costs. Isabel Weiersbye of the School of Animal, Plant and Environmental Science at the Witswatersrand University is the programme leader of the initiative to use indigenous species, inoculated with growth-promoting mycorrhizae, during the rehabilitation on tailings impoundments (Figure 212). The advantage of this approach is that significant cost savings are possible in that suitable soils required for sustaining vegetation do not have to be imported and that very little additional amelioration of the in situ tailings is required. The woody vegetation produces organic material from fine roots and leaves which contribute to the increase of the anthropogenic soil organic content which in turn encourages increased microbial activity.

[1,2] Photographs of woody vegetation trials on tailings impoundment in the Welkom gold mining region.

Figure 212: Woody vegetation planted in situ on tailings impoundments.

The initial trials on the project have shown that woody and semi-woody species can be established in situ with minimal amelioration and no irrigation. The mycorrhizae serve to make the plants tolerant to the droughty, low nutrient, and heavy metal content conditions of the tailings (Knoll, 2004:24).

Tailings impoundment landscapes

Tailings impoundments are structurally unique in the built environment. In extreme cases they are sealed on all sides to isolate the mine residue from the environment, preventing pollution, and acting as huge containers within the landscape which must not be punctured. Tailings impoundments, as they close, present remarkable opportunities for the development of new open space. If the slopes and cover are properly designed a park can be created which presents blank slates for what might be called high value consumer landscapes such as golf courses, wildlife reserves, and community parks built on rehabilitated land. Developing tailings impoundments relieves the pressure to develop greenfields sites for these uses.

1 and 2 The McLeod High tailings impoundment was reshaped to create an environmentally stable sculptural landscape (photographs courtesy of Martha Swartz Partners).

Figure 213: Integrating tailings impoundment design with long-term regional land development objectives.

7.7 Integrated environmental planning and design

The outcome of the research is a comprehensive model of the life cycle of tailings impoundments from conceptual planning through to closure allowing operations within the cycle to be evaluated in terms of their direct engineering costs and their environmental impacts. This enables, at the planning stage, comparison in a rational and consistent way of, for example, the direct costs and other impacts of alternative end uses; the influences of different covers and the influences of different embankment slope angles. It is also possible to compare the opposing strategies of either minimising construction and operation costs – whilst adhering to environmental controls – and accepting larger end rehabilitation costs, or, alternatively having more costly construction and operation but lesser closure and post-closure costs to achieve the planned sustainable end use, which will be compatible with the aesthetical, economical, environmental and social requirements of the area in which the facility is located.

The principles and much of the detail of the proposed methodology can equally apply to coal and other non-metalliferous tailings impoundments. At this stage, however, because of the dramatic growth in metalliferous mining the system was first developed for the platinum and gold industries using upstream deposited ring-dyke impoundments for containing mine residue.

The engineering cost model was developed and calibrated which can be used as a standardised system for cost estimation for tailings impoundments. This model was supplemented by the environmental impact evaluation modelling to form the comprehensive model which was the ultimate aim of the overall research.

It is believed that the development of the proposed system will, because of its rationality, enable effective long term planning decisions to be made which will satisfy the requirements of the ethos of sustainable development; hence, the system could form the basis through which regulating authorities will in future assess the acceptability of planning proposals for tailings impoundments.

Society has advanced to the point where all our engineering endeavours should be viewed against the criteria of sustainability. Responsible industry shares this view and the question is not whether we should strive for it, but how best can it be achieved. It is the contention of this study that one means of advancing this in the mining field is to undertake the paradigm shift of considering tailings impoundment as an integrated system from planning to sustainable closure. The research project developed models for such a system in which costs and impacts can be rationally assessed so that the system can be optimised. In addition, it is my opinion that a rational system can positively inform legislation on tailings impoundment closure.

The result of integrating environmental planning with the engineering design can best be illustrated in a concept tailings impoundment rehabilitation plan aimed at creating a sustainable and regenerative landform (Figure 214) and also by comparing its profile with that of a typical impoundment (Figure 215 and Figure 216). Four slope configurations (1:3, 1:4, 1:6 and <1:6) in combination with three surface covers (T – tailings in situ, R – Rock cladding, A – Armouring i.e. topsoil and rock mix) are applied to the tailings impoundment and indicated in the legend of Figure 214. The combination of different slope geometries and surface cover follows a rational and analytic process considering factors such as slope aspect, flora and fauna specie distribution as well as macro- and micro climatic conditions, specific to the site location.

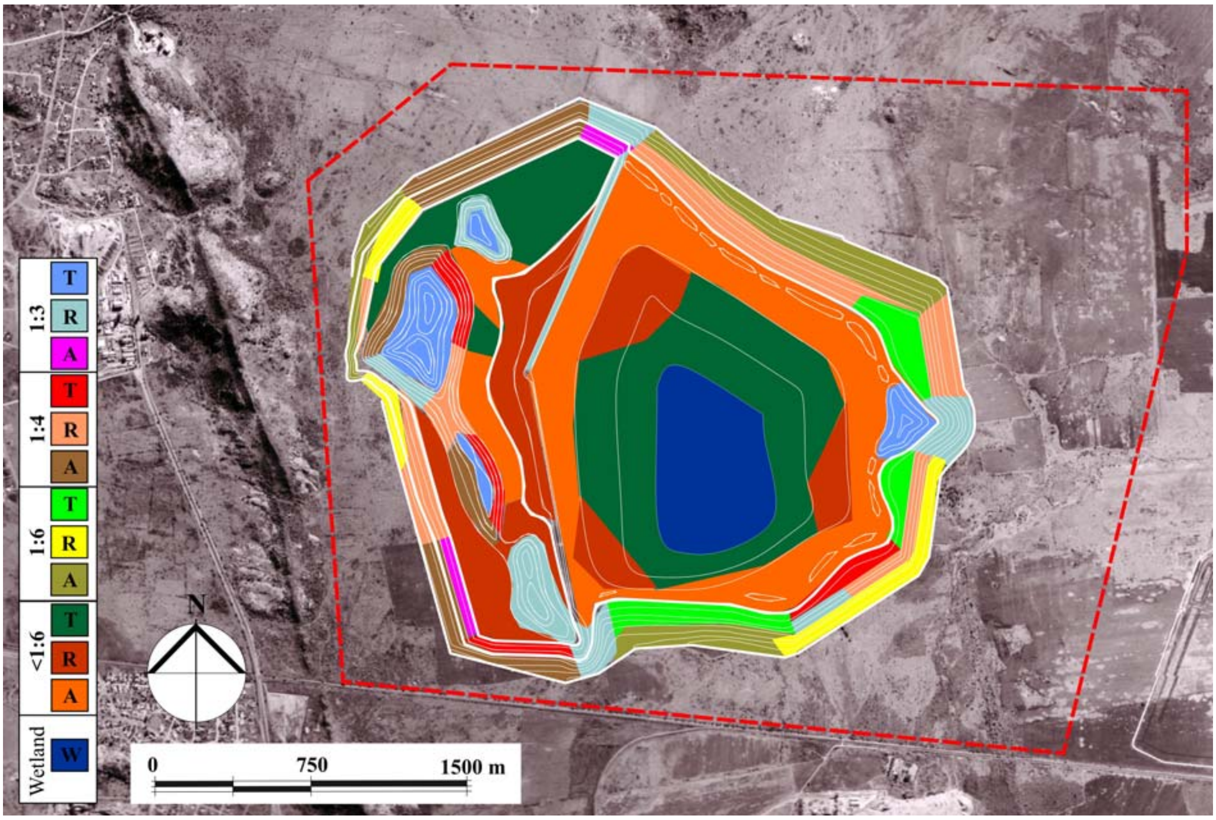


Figure 214: Hypothetical regenerative impoundment landform (Rademeyer and van den Berg, 2005).

Figure 215: Typical tailings impoundment profile (van den Berg, 2004).

Figure 216: Tailings impoundment profile that is sensitive towards the natural landscape (van den Berg, 2004).

The hypothetical outcome satisfies the design brief through applying surface stabilising practices in combination with landform design principles. Habitat creation is a function of the context in that it is guided by local ecological systems and vegetation distributions. It is believed that these two aspects will result in an aesthetically pleasing landform, unlike the unsightly mine residue deposits that are so common in the South African landscape.

Configuration of tailings impoundments necessarily includes rehabilitation with the aim of eliminating or reducing adverse environmental impacts and creating a new landform that conform to the principles of sustainable development and something that will be acceptable in the long-term. The process is driven primarily by legislation which ensures that the mine owner must comply with the intention of achieving those end conditions, which are defined in broad terms by guidelines, hence the need to rationally define the end conditions.

Two measures can encourage rational decision making and better planning:

- development of regional landscape plans requiring injection of ideals into the planning process;
- modification of single-objective impoundment schemes to improve the contextual relationship with the landscape. This can be seen as impact mitigation in environmental assessment terms.

Tailings impoundment schemes should be modified in order to produce multi-objective project designs. Design modifications can prevent negative environmental impacts and promote positive environmental impacts. Although it is a legal requirement to assess the impacts of a scheme on the biophysical, socio-cultural and economic environment, insufficient attention is paid to the impacts on the surrounding land use.

Envisaging the final tailings impoundment during the initial planning stage may result in a differently designed facility. This could result in lower final rehabilitation costs possibly at the expense of higher initial costs. High decommissioning and closure costs can easily negate short-term benefits of disposal strategies which do not facilitate easy rehabilitation. Important to note is that it is perfectly feasible to do the afore-mentioned and lastly, to rationally inform the approach it goes without saying that costs would have to be considered. The cost of doing something and the cost of not doing something in terms of sustainable impoundment landform planning and design would have to be compared and it might well be that it is in fact cheaper to do the right thing from the start…

The approach presented in this thesis does not replace sound application of knowledge and judgement but is simply a systematic rational application of these. Any approach should remain easy to facilitate reaching consensus. It is a tool intended to help with transparent decision-making between regulatory authorities, proponents and consultants. Although decision-making for the sustainable design, operation and closure of tailings impoundments is not an easy task the approach and results presented in this thesis can already be used to aid decision-making. The application of the findings although simple in concept, will require some experience to ensure its effective use.

The following conclusions are made with regard to the configuration of tailings impoundments:

- A holistic planning approach is necessary to understand the impact of tailings impoundments on the environment.
- Post-closure land use of an impoundment is a function of the final landform's ability to sustain an end use acceptable to all stakeholders.

- The final landform and use must be informed by both present and future land planning initiatives within the impoundment sphere of influence. The potential conflict between land uses in the sphere of influence will require management.
- Conflict in land use as a result of a tailings impoundment can be controlled by changing its design.
- Failure to incorporate the final configuration and anticipated end land use from the start will result in an impoundment that is difficult and expensive to rehabilitate during the closure stage.
- Embankment slope and impoundment cover are two of the key aspects that constrain post-closure use of an impoundment.
- Access onto an impoundment is a function of the embankment configuration. Steep embankments slopes support less uses than flatter slopes. The flat impoundment top does not have the same constraints than steep embankments.
- Rehabilitation during the closure stage comprises two significant engineering cost items, namely bulk earthworks required to mechanically flatten slopes and reshape an impoundment, and the construction of a suitable cover in support of the post-closure land use.
- It is cheaper to construct an impoundment with its final embankment side slope configuration during the operation stage through the hydraulic deposition of tailings than it is to mechanically flatten the slopes during the closure stage.
- Flattening side slopes increases the tailings impoundment footprint which could, depending on the final choice in cover, result in an increased environmental sphere of influence.
- Final cover, more so than embankment slope, controls the extent of the environmental sphere of influence.
- Environmental impact prediction, evaluation, planning, and implementation must be conducted at meaningful temporal and spatial boundaries. Long enough periods must be allowed for to assess the cumulative impacts during the post-closure stage of a scheme. The latter must be based on the sphere of influence even if political boundaries are crossed.
- The match between site characteristics, environmental attributes, planned end land use, and selected management technologies must result in an impoundment configuration that is acceptable to stakeholders. Mismatches of the afore-mentioned can result in significant environmental impacts and require continued external inputs to maintain the closed impoundment.

The following practices are recommended for tailings impoundment design:
- Involve a multi-disciplinary team to assist with the identification of alternative technologies, site selection, concept design and final design.
- The final embankment slope must be determined prior to construction and deposited during the operation stage.
- If a soil will be required during rehabilitation as a growing medium, then the soils should be stripped and stockpiled separately for use during rehabilitation.
- It is preferable that plant species which are drought tolerant and can grow directly in tailings should be identified and used where possible. This will negate the need to import and cover the tailings impoundment with a suitable growing medium. Further research is required in this regard.

7.8 Meeting legislative requirements

The continued expansion of metals mining to meet global demand will result in an increased need to dispose of mining waste. However, legislation regarding new mining project is such that details need to be provided by proponents as to how environmental impacts will be managed and how the areas disturbed by mining activities will be rehabilitated. The South African government has launched an integrated Phepafatso strategy. Phepafatso means that you must clean up in Tswana and it is expected that this approach will change environmental practices in South Africa.

New environmental EIA regulations came into effect during July 2006 with one of its objectives to streamline decision making with regard to the environmental assessment process. Mining projects are currently excluded from this new process and will continue to be regulated by the Department of Minerals and Energy (DME) until further notice. This however does not change the fact that there is a need to rationally inform decision making when considering tailings impoundments.

The long-term risk to the environment from tailings impoundments include:

- the potential for failure resulting in the flow of slurry; and
- the impact on environmental aspects such as visual perception, air quality, and water quality.

The risks are site specific and depend on:

- the nature of the material impounded;
- the configuration of the tailings impoundment; and
- how the impoundment will be rehabilitated.

In some instances the sphere of influence could result in restrictions on future land use which places an obligation on both the proponent and the local planning authorities. It is therefore important that planning authorities considering tailings impoundment applications ensure that:

- the environmental sphere of influence is determined;
- the final impoundment configuration must be finalised prior to construction;
- the proposed impoundment land use will be compatible with regional plans;
- future land use conflicts are anticipated and identified as part of the initial planning and site selection; and
- rehabilitation and long-term environmental costs are estimated to ensure that adequate funding is available.

7.9 Summary

South Africa has a diverse and unique geology and despite occupying only 1 % of earth's land surface, it produces most of the world's chromium, diamonds, gold, manganese, platinum group metals, and vanadium. Mining of South Africa's mineral resources has given rise to hundreds of mine residue deposits (MRDs) which cover large tracts of land. Tailings is a significant part at most precious metals mining operations and the disposal of tailings can result in unintended but unfortunate impacts on the environment.

Tailings disposal facilities are complex. The design of a facility can include a composite liner (soil, geosynthetic clay liner, and a geomembrane), a leachate collection system consisting of piping and gravel and geocomposite drain layers, a final cover capping system (soil, geosynthetic clay liner, and a geomembrane), and surface and subsurface drainage systems in the cover soils. The cover and liner can be designed to minimize water infiltration and oxygen penetration into the tailings, and discharge of contaminants from the facility into the groundwater. It is however important that whatever the tailings disposal facility configuration entail, that the design must provide for the protection of the environment.

The term sphere of influence is used in this study to describe the three-dimensional tailings impoundment impact zone on the environment. This sphere is the spatial overlay or sum of the different environmental aspect zones of influence. It is useful in the quantification and valuation of environmental impacts related to tailings impoundments. Measured key criteria must meet agreed numeric standards within the sphere of influence.

It is required by South African law to define future land use objectives prior to the commissioning of any mining activity. This, although not necessarily explicitly stated, implies that the future land use of tailings impoundments, an integral and inseparable part of mining, must be determined during the development stage of a mine and not as an afterthought during decommissioning and closure of the impoundment.
The main reason for actively pursuing a pro-active rather than reactive planning approach lies in the constraints imposed by reactive rehabilitation and having to remedy post-closure environmental impacts.

Man has since the beginning of time expressed himself in the landscape constructing man-made landforms. This study demonstrates how environmental aspects can influence engineering design. The study integrates elements to satisfy not only engineering but also environmental, social and economic criteria.

The following environmental aspects have been successfully modelled and integrated with engineering costs in this study:

- visual perception zone of influence;
- air quality zone of influence; and
- water quality calculated as the sulphate mass flux.

The starting premise of this thesis is that most of the difficulty decision makers have with the configuration of tailings impoundments comes from maybe too much emphasis on the bits and pieces and not enough on the synthesis of key elements. This study presents an innovative approach to integrating environmental impacts with engineering costs.

The system examines and describes key issues relating to the configuration of tailings impoundments and can be used to answer critical questions such as:

`Is it better to flatten tailings embankment side slopes?`

and

`Which cover is likely to be most acceptable?`

Although many factors influence the configuration of tailings impoundments it is believed that the system is robust enough to be useful for comparing the change in slope and cover.

Predictive simulation models are used to quantify environmental impacts as measured data is not available for all the scenarios described in this study. To develop comprehensive data sets for alternative impoundment configurations is costly and takes time. Predictive modelling has the advantages of being less expensive and quicker than obtaining long-term monitoring data for alternative impoundment configurations. The disadvantages are those associated with most predictive models namely uncertainty and errors in model structure, parameter estimation, and model output. A range of available predictive models of varying complexity was used in this study. It was found that the importance of the consequence of the environmental impact directs the appropriate choice in model.

An acceptable post-closure impoundment configuration can only be achieved where engineering costs, environmental concerns, land use conflicts, and stakeholder desires are in balance. The difficult bit is that what is considered acceptable today may be different in a couple of years because of changing values, knowledge base, or political factors.
This thesis describes the valuation of different impoundment configurations to evaluate the acceptability of tailings impoundment configurations. The most appropriate or acceptable alternative design depends on the specific site characteristics, the type of tailings and how it is stored, and the potential long-term environmental impact costs. A rational and informed decision can only be made if all these factors are accounted for. The goal will therefore be to improve the quality of the technical information used to select an impoundment configuration which is not only cost effective but meets regulatory standards.

The future application of the approach will require that the results are interpreted, weighted, and made precise for each site specific case. In one case, the impact on air quality may be the overwhelming consideration and in another, it may be the preservation of a groundwater resource or the creation of a post-closure landform that will blend in with the existing landscape. But the environmental issues addressed in this thesis are general enough to be useful in evaluating schemes and at least as a start rationally inform the drawing up of objectives during tailings impoundment conceptualisation.

The South African Constitution provides people the right to an environment that is not harmful to health or well-being, and that is protected for the benefit of present and future generations. These rights are to be ensured through measures that prevent pollution and ecological degradation. The basis of the polluter pays principle is firmly entrenched in legislation and requires that the costs of environmental impact should be borne by those responsible for the impact (DWAF, 2006). The National Water Act No. 36 of 1998 (NWA, 1998) specifically refers to the polluter pays principle as an economic mechanism for achieving effective and efficient water use.

Legislation requires that when an activity results in an environmental impact, the party in control of the activity has to pay:

- the direct costs of the impact;
- the cost to remedy the impact; or
- compensate society for the impact incurred.

This study presents a system to determine such costs.

Section 38(1)(d) of the Mineral and Petroleum Resources Development Act No. 28 of 2002 (MPRDA, 2002) stipulates that a tailings impoundment must be rehabilitated to a predetermined state with a land use which conforms to the generally accepted principle of sustainable development. Integrating closure plans and designs with regional land use programmes will result in a post-closure tailings impoundment land use that is not in conflict with future regional land uses. To prevent future land use conflicts and defer unnecessary costs it is imperative that tailings impoundment environmental impacts are integrated during the conceptualisation and design stages with engineering life-cycle costs. Similar to the NWA (1998), it also states in Section 38(1)(e) that the holder is responsible for any environmental damage, pollution or ecological degradation inside and outside its boundaries.

The system developed and the approach described in this study can assist to determine the financial implications of such requirements and can provide input into rational decision making when considering rehabilitation alternatives. The system also provides costs for rehabilitation during closure as well as cost for residual environmental impacts. The determination of these costs is a requirement of the MPRDA (2002).

Proponents are required to contribute towards a rehabilitation fund so that external costs are internalized based on the economic polluter pays principle. The fundamental underlying principle for the minerals industry may be that the permission to mine, process and deposit tailings should not be given unless it can be demonstrated that the post-mining tailings impoundment landscape will at least be stable, non-polluting and useful.

The study emphasises the importance of planning the after-use of a tailings impoundment prior to approvals is given for the construction thereof. Among other things a conceptual closure plan should be submitted at the feasibility stage which includes detailed information on the final tailings impoundment configuration and associated rehabilitation. It can be concluded that a better tailings impoundment after use can be achieved at a lower cost if adequate planning takes place.