

The Influence of Environmental Impacts on Tailings Impoundment Design

CHAPTER EIGHT: CONCLUSIONS

"If we knew what it was we were doing, it would not be called research, would it?"

Albert Einstein (Quotations, 2007)

"We don't see things as they are. We see them as we are."

Anais Nin (Arden, 2003:123)

"The best time to begin is now. If you wish to leave something behind tomorrow, you must begin today."

Anton Rupert (Dommissie, 2005:413)

8.1 Decision-making system

"...a decision is a judgement and, as such, is rarely a choice between right and wrong but at best a choice between 'almost right' and 'almost wrong'."

Drucker (1967)

Decision making with regard to the configuration of tailings impoundments is multi-dimensional, multi-objective, and complex. The study describes a system whereby environmental impacts and engineering costs are rationally evaluated over the life of upstream deposited ring-dyke tailings impoundments. It demonstrates how a combination of models, techniques and approaches can be used to integrate various environmental and technical aspects to rationally inform decision-making with regard to the planning and design of tailings impoundments.

The following conclusions are drawn from the study with regard to tailings impoundment decision making:

- Decisions are unique in character, controlling variables and the preferred solution and must be specifically refined for each scheme.
- Site-specific information and decision-support tools such as databases, impact prediction models, and geographic information systems must be used to assist with making decisions.
- The system allows professional planners, specialists and researchers to draw on analytical and decision-support tools helping with, although not necessarily resolving, complex problems.

The system has the following characteristics:

- The system is simplistic, understandable, transparent and auditable.
- The system is supported by models and examines the influence of environmental impacts on engineering design.
- The system integrates key environmental aspects successfully with engineering configuration decisions.
- Environmental aspect zones of influence for visual perception and air quality, and sulphates calculated as mass flux are included in the system.
- Some of the models are easy to understand and use providing quick results (such as the use of Darcy flow equations) while others require in-depth specialist knowledge on the subject (such as the predictive air quality modelling).
- Although several factors influence the configuration of an impoundment, it can be said that the system and environmental aspect zones of influence provide sufficient structure to inform decisions having a bearing on impoundment design.
- The system is sufficiently robust to allow the addition of information and knowledge if and when it becomes available.

The system has the following advantages:

- The system integrates environmental impact costs and engineering costs.
- The system exploits joint capabilities of specialists and the generalist information.
- It provides spatial context to environmental aspects.
- It combines techniques, tools, methods, and computer models to facilitate effective and transparent decision making.

The following contributed to developing the system:

- Specialist understanding of the decision situation, opinions, and input were a major input to the overall design of the system.
- An understanding in sufficient detail and at the appropriate level of existing decision-making processes.

The system, models, and approach presented in this thesis can be used and acted on by decision makers tasked with the difficult and complex activity of tailings impoundment configuration. The successful outcome of using the proposed approach will be where consensus is reached amongst all stakeholders as to the acceptability of a scheme's configuration and its impact on the environment.

8.2 Engineering costs

The result from this part of the overall research programme is that a comprehensive engineering cost model for upstream spigotted ring-dike tailings impoundments is available which is sufficiently reliable not only to estimate the overall life-cycle cost but also check costs of for example modifying the overall embankment side slope, cover, and environmental protection measures.

The engineering cost model is conceptually straightforward and since it comprises linked spreadsheets using available computer software it is simple and flexible to operate.

The benefits to decision makers tasked with the management at different levels are primarily that:

- The model allows for different unit rates for different impoundments to be captured allowing correlation between sites and allows for differences in impoundment configuration, topography and location.
- Reliable predictive estimates can be made of future closure costs and that these estimates can be readily modified from time to time to deal with changed quantities, changes in specifications and escalating costs.
- The system also operates as a management tool in that any high cost item can be identified and examined to determine whether savings can be made by changing methods or specifications.

Although the system described is currently operating it must be noted that as with any system it is anticipated that use will indicate areas where improvements can be made. The simplicity and flexibility of the system ensures this.

8.3 Visual perception

A visual impact methodology that is objective and contains defensible measurements has been developed to assess the impact of ring-dyke tailings impoundments on the receiving environment. Visual perception thresholds are determined for various impoundment configurations. A panel of visual experts evaluated visualisations of the various configurations applying the nominal group technique (NGT) study method. Visual perception distances were determined for different covers and embankment slopes. Although there is variance in the perception distances when comparing embankment slopes for the same covers it appears that the overall embankment slope on an impoundment does not have a significant influence on the perception thereof. This is counter intuitive to what was originally thought.

Literature suggests that visual perception decreases over distance; however specific distances for tailings impoundments do not exist. It was required to develop a procedure to quantify visual influence and to test the effect of changing tailings impoundment configurations (mitigation measures). A procedure to determine visual perception threshold distances for tailings impoundments has been developed. The ERGO Daggafontein tailings impoundment was used for most of the modelling in this study as it is one of the largest upstream ring-dyke impoundments of its kind. It is also located within a flat terrain which assisted with taking unobscured panorama photographs. The study demonstrates a method to determine visual perception distance values and applies it to different impoundment configurations demonstrating the efficacy of mitigation.

The visual perception study uses computer manipulated panorama photographs to simulate hypothetical landform modifications (such as the different configurations depicting various scenarios) with high realism. Psychophysical concepts of visual threshold (awareness, detection and recognition) are adopted from literature, details of which are provided in Section 2.10. Visual attributes such as form, silhouette, colour and texture are designated as experimental variables (Figure 100, p. 191).

Visual perception distance threshold values are used to quantify visual perception zones of influences (ZVIs) which can now be used for landscape planning and management purposes. Although it is indicated that there are threshold distances between awareness, detection, and recognition it is unlikely that these distances will be absolute events.

The thresholds were obtained through controlled computer slide-viewing tests using simulated images with modified visual attributes such as overall side slope angle and cover. Analysis yielded average and specific thresholds of high apparent reliability. This is demonstrated by delineating the initial results in envelopes (Figure 130, p. 236) and using mean values to plot trendlines. The mean trendlines facilitate the interpretation, comparison, and communication of the results (Figure 132, p. 237).

Even though visual perception distances must ideally be determined on a case-by-case basis, the results from this specific part of the overall research can be used in first order assessments, especially during the conceptualisation stage of a scheme, to inform the level of visual impact assessment (VIA) required and setting the limits of additional ZVI studies. Cognisance should be taken that the visual perception distances are maybe on the conservative side as a result of the size of the tailings impoundment used to determine the distances.

Visual perception distance functions are communicated in a simple graphical form for various impoundment configurations. The results may in a sense be “obvious” or just what would be expected, that is that the level of perception would decrease with an increase in viewing distance. The observations are supported by numerical results determined by an experiment conducted rationally and transparently.

Simulated mitigation measures make a large difference to visual perception threshold distances and the overall ZVI. This quantitative information can be used to determine the visual impact of an impoundment. The enclosing ZVI could essentially sterilise the land for uses such as tourism and conservation as well as impact on the value of property. It is further postulated that the assessment of the change in land use within the ZVI discloses a monetary value of the visual impact.

VIA for tailings impoundments must be conducted differently than for example the assessment of linear developments such as transmission lines. The use of the test tailings impoundment in the study gave conservative results, that is larger threshold distances than what may have been expected. This is partly because ring-dyke impoundments are large-scale man-made landforms within the landscape and is distinguished from most other man-made elements due to sheer size, scale and in certain instances unnatural covers.

Visual perception threshold distances within the zone of visual influence (ZVI) can be obtained following the method described in this study. An important observation is the demonstration that different impoundment configurations (relating the overall embankment side slope and covers) have a significant influence on the viewing distances and hence influence the land surface area impacted

upon. Impoundments can be configured such that the perception thresholds within the ZVI can be manipulated. Although the research does not test the preference of people viewing a scheme, it does test the ability of viewers to become aware of, detect man-made landforms in the landscape and recognise tailings impoundments as a result of its configuration.

Specific conclusions on conducting visual impact analysis on tailings impoundments:

- VIA for tailings impoundments must be conducted differently from for example the assessment of linear developments such as transmission lines.
- The use of a regularly shaped man-made landform in the study gave conservative results, that is greater threshold distances as what was expected. This is in part because impoundments are large-scale man-made landforms within the landscape and also because it is distinguished from most other man-made elements due to sheer size and scale.

The following observations are made regarding the Nominal Group Technique (NGT) study method:

- The expert NGT group was representative enough to ensure statistically robust sampling.
- The sample population was drawn from landscape architecture and environmental planning professional streams suggesting high homogeneity.
- The experimental results shows considerable consistency, i.e. the plotted result shows increasing impact with the increase of stimulus level and the decrease in distance from the tailings impoundment.
- Active participation of the experts is crucial. It can be said that the participant's feedback on the whole process have been positive and the process worked well.
- The opinions of the experts offered valued input and insights into the problem studied and assisted in flagging of important considerations and issues.

The following conclusions are drawn from the study with regard to the visual perception distances:

- Visual perception distance functions can be determined and communicated in a simple graphical form for various impoundment configurations.
- The visual perception distance study results (Figure 145, p. 247) show considerable consistency. The plotted result shows increasing impact with the increase of stimulus level and the decrease in distance from the tailings impoundment as had been expected.
- A significant observation is the demonstration that different impoundment configurations, i.e. covers and overall embankment side slopes, have a significant influence on the viewing distances and hence influence the land surface area impacted upon.
- The enclosing negative zone of visual influence (ZVI) could essentially sterilise the land for uses such as tourism and conservation as well as impact on the value of property.
- It is further postulated that the assessment of the change in land use within the ZVI could disclose a quantitative monetary value of the visual impact.
- It is evident from the experiment and consensus results that tailings impoundments can be configured such that the perception viewing distances within the ZVI can be manipulated.

8.4 Air quality

Air quality is of vital concern in many locations. Prior to the construction of a tailings impoundment an impact assessment must be undertaken indicating the effect of the tailings impoundment on air quality. It is important that the characteristics of the tailings impoundment be known prior to the prediction of the potential effect air quality. Even though an objective of constructing a tailings impoundment may be to limit impacts to human health, monitoring such effects are extremely difficult because of substantial uncertainties about the exposure of different populations groups to pollutants, their response to different levels of exposure, and the cumulative nature of damage.

Credible modelling of the air quality zones of influence requires significant effort and resources. Modelling emissions off tailings impoundments is complex and requires applying professional judgement. It must be emphasized that mathematical modelling of complex atmospheric processes involves uncertainty which can be made worse when data is lacking or unreliable. The modelled results in this study must therefore be used with care when applying it outside the context of this thesis and when using it in formal decision making. However, the approach presented and the results from the scenarios modelled in the air quality study are summarised and presented in such a way that it can be used to inform decision making especially during the development stage.

There is also uncertainty about the research on which the costing of respiratory hospital admissions is based. The approach to in this study uses respiratory hospital admissions to cost the likely impact that a tailings impoundment will have and is not all inclusive. Quantitative evidence is not available for every health effect suspected of being associated with air pollution. Also, non-health related effects such as materials damage, soiling, vegetation losses and visibility degradation is not included in the costing of the air quality impact. The omissions suggest that the results presented in this thesis are likely to underestimate the total effects of air pollution resulting from a tailings impoundment.

8.5 Water quality

Water quality impacts from tailings impoundments are important when considering the environmental impact associated with mining, both in terms of consequences and cost. Drainage from tailings impoundments is generally of poorer quality than ambient water quality. Deterioration may occur through salt mobilisation, excessive alkalinity, or more generally acidity.

An analytical model was developed that integrates the post-operation water pathways and impacts with the other environmental aspects modelled such as visual perception and air quality

The model has the following characteristics:

- It is simple and easy to use.
- The mass balance model calculates the post-operation steady-state impact on the receiving environment with an acceptable degree of accuracy. The results were compared to the results of a detailed numerical model in Section 4.5.1.
- The impact of the mass flux and not only concentrations must be considered on downstream concentrations.
- Due to net evaporation, mass that dilutes in a stream could concentrate in downstream dams and rivers.

8.6 Environmental impact valuation

The economic valuation of tailings impoundment environmental impacts and integrating such with the engineering costs are extremely useful in raising the profile of the environmental aspects relating to upstream deposited ring-dyke tailings impoundments. Using the methodology described in this thesis may not guarantee an acceptable outcome but is likely to facilitate choice between developing an impoundment or conserving the land. Also, the alternative land uses of the scenarios are compared through the valuation of environmental change. This assists to identify the most critical aspects determining the sustainability of the proposed tailings impoundment end land use. When conflicts are unavoidable, quantitative decision-support systems and models allow optimisation among competing management objectives. Such decision-support systems and models need not be complex. Rather, it was found that systems and tools of varying complexity are essential for successful decision making.

Closure objectives which form part of the required environmental management plan must inter alia identify key objectives, define future land use objectives and provide proposed closure costs. It is the latter which transforms laudable aims into reality and with the increasing stringency of regulations and standards, the necessity for reliable closure cost estimates has become paramount.

The engineering life-cycle costs are fairly insensitive to overall embankment slope angle (Figure 172, p. 280) and it is therefore advised that the preferred final embankment slope must be determined prior to construction. As upstream spigotted ring-dyke tailings impoundments uses hydraulically placed tailings to construct the outer embankment and occurs simultaneously to the disposing of the remaining fines. There is therefore little or no economic incentive for over steep slopes if only considering the cost of placing the tailings. It is imperative that an embankment slope angle has to satisfy safety constraints and achieve economic design.

The lowest environmental and engineering cost option may not necessarily be the best, preferred or most acceptable option when constructing a tailings impoundment.

The following quote introduces the thesis and set the scene for everything which followed. It is maybe appropriate to reflect on what Vick (1983:129) said a quarter of a century ago...

"In the past, selecting a preferred alternative *tailings* disposal method or tailings impoundment site was a relatively simple procedure. *Engineering* cost estimates could be generated for each option, and the lowest cost option would ordinarily be the hands-down winner. More recently, however, environmental considerations have gained increasing importance, and perhaps nowhere else in mining operations are these environmental issues of more significance than in tailings disposal and *tailings impoundment configuration*. Environmental factors are often of equal or greater importance than economic issues in tailings disposal planning and *design*..."

"At present [1983] tailings disposal alternatives having different combination of economic and environmental attributes are often compared and selected on an informal ad hoc basis. Since few formal guidelines exist conducting the evaluation procedure, disposal decisions made by mining companies are sometimes viewed by regulatory agencies as lacking objectivity, and similar evaluation of alternatives by regulatory agencies may appear arbitrary to the mining company. At the core of the conflict is often the way in which alternatives are evaluated and selected."

(Italics indicate own words)

The overall aim of this research was to develop a rational system and present a structured approach to evaluate change in tailings impoundment slope and cover. It has not only been demonstrated that it is possible to combine environmental impacts with engineering costs but it is also possible to value environmental impacts which allow the environmental impact costs to be integrated with engineering costs in a system. This system is useful for rational decision making.

8.7 Recommendations

A system and approach to integrate environmental planning with engineering design is presented in this thesis and has been developed to the point where it can be used to guide decision making. It must however be refined further by including some of the other environmental aspects and calibrating some of the predictive models used.

To achieve this it will be necessary to pursue the following:

- Ongoing research is necessary to calibrate and refine predictive models.
- Compare the visual perception results presented in this study to impoundments in different environmental settings and expand the results and findings accordingly. This can be done by applying the method developed in this research to other mining regions within the South African landscape such as impoundments located in the Northern Province, Mpumalanga and the North-West Province.
- Monitor air quality and seepage at existing tailings impoundments to verify predictions and calibrate the models used in this study.
- Review procedures and develop methodologies for best practice tailings impoundment rehabilitation especially in South Africa where upstream deposited ring-dyke impoundments are still being constructed.
- Test and demonstrate the system developed in this study on the design of new tailings impoundments. Since new and promising technologies and approaches that could play a role in minimizing environmental resource degradation caused by tailings impoundments will be developed subsequent to this study it is important to start with demonstrating the system. The system can be used as the basis for further research or could be used as a reference by industry.

'Writing a *thesis* is an adventure: to begin with it is a toy and an amusement, and then it becomes a mistress, and then it becomes a tyrant, and then the last phase is that just as you are about to be reconciled to your servitude, you kill the monster and fling him out to the public.'

(Italics indicate own words)

Winston Churchill