CHAPTER SIX: INTEGRATING ENVIRONMENTAL IMPACT COSTS WITH ENGINEERING COSTS

"God does not care about our mathematical difficulties. He integrates empirically."

Albert Einstein (Quotations, 2007)

6.1 Introduction

From the onset of the study the aim was to develop a rational and transparent system that can be used to quantify some of the key environmental aspects and also scale and weight the impacts so that the optimum long term design of a tailings impoundment can be achieved.

Planning a tailings impoundment site focuses on the engineering, biophysical, economic and social-cultural issues. It is often the economic and social factors, and not necessarily the practical matters, that hold the most sway when undertaking the planning and design of an impoundment. Although the main interest of the proponent is to meet certain financial targets. Despite the increased awareness of the importance of the environment, factors such as the fear of wasting money or not making enough money to please shareholders are likely to determine a proponent's final decision about a scheme more readily than environmental concerns. Proponents and regulators need to realize that economic disadvantage to individuals and society can result from failure to take proper account of all aspects of the environment.

Figure 169 (p. 276) and Figure 177 (p. 285) illustrate the combined engineering costs and environment aspect influences for a change in impoundment cover and change in embankment slope. Although altering the embankment slope of an impoundment influences engineering costs and change environmental aspect influences, it is not quite as dramatic as that resulting from changing impoundment covers. The change in slopes considered, which cover the full range of practical slopes, leads to a change in cost of about 6 % whereas the change in covers, which also encompass the full range of cover types, leads to a change in cost of about 30 %. Therefore the following section demonstrates the costing of impacts as a result of change in impoundment cover type.

Table 61 (p. 268) provides the unique codes for the scenarios modelled used to calculate the engineering costs and quantify the environmental effects. These scenarios are used to illustrate the influence of cover change for an impoundment with an overall embankment side slope of 1:3. Figure 169 (p. 276) presents the combined results and plots the environmental aspect influences and engineering costs for changes in tailings impoundment cover types.

Based on the assumption that depositing tailings is to take place; the specific planning problem can further be formulated as:

- the need to minimise costs, and
- the requirement to maintain a certain visual, water, air, and land use quality.

Visual and air quality deterioration and water pollution can lead to serious negative impacts on value of land, health, and services. The physical evidence is compelling.

The costing of these impacts is frequently ignored because it is:

- considered too difficult to establish direct cause-effect relationships; and
- not always feasible to place monetary values on effects.

Regardless, the following section in this thesis demonstrates how valuating environmental impacts can be used as a tool to facilitate decision making.

6.2 Valuating environmental impacts

Calculating the engineering as well as the environmental impact costs is an important part of the tailings impoundment planning process both in terms of actual cost to the proponent and the costs to society as a result of a scheme.

General conclusions reached by Georgiou, Whittington, Pearce and Moran (1997) are that economic valuation is:

- extremely useful in raising the profile of the environmental aspects of development projects;
- widespread in terms of its applications in developing countries; and
- generally successful in its application.

Costs to society can be incurred through for instance the:

- potential conflict in land use because of degradation to visual resources within the impoundment's visual zone of influence;
- increase in ill-health effects of people who live within the impoundment air quality zone of influence;
- mitigation or treatment cost incurred to treat polluted discharge to meet regulatory water quality standards;
- provision for new or additional infrastructure;
- extra work required to protect natural resources impacted on by the tailings impoundment; and
- loss of cultural resources with heritage value either as a direct result of the displacement caused by the physical footprint of the impoundment or as a result of the impoundment's sphere of influence.

The following section uses the ERGO Daggafontein site and practical examples to demonstrate this. The section on the valuation of impact change, Section 2.9.2 states that the following two key elements are required when valuating environmental impacts:

- measuring the environmental impacts; and
- placing monetary values on the measurements.

The measuring of the visual, air and water impacts are described in Chapter 3 and the results provided in Chapter 4. Placing monetary values on the measurements or valuation is now demonstrated. Two distinctive approaches to valuate impacts are described in detail in Section 2.9.2. Either objective valuation approaches (OVA) or subjective valuation approaches (SVA) can be used to cost impacts on the environment. Valuation of impacts can be difficult in instances such as the:

- valuation of changes in ecosystems;
- impact on sites of heritage importance; and
- loss of recreational benefits of game reserves.

It is possible although difficult to estimate the economic values of the impact of an impoundment on a nature reserve by using the travel cost approach or conducting contingent valuation studies.

Several impacts can also be related to a specific environmental aspect. For example, the increase in particulate concentrations in air can cause:

- ecological alterations especially when emissions include toxic elements;
- the reduction in visibility which in turn can have an adverse effect on transport safety;
- property values to change; and
- ill-health effects.

It is important to choose one or more of the effects in order to quantify and cost these. It is proposed that the:

- visual impact will be valuated by using property pricing and land value;
- air quality impact will be valuated by costing the increase in respiratory hospital admissions; and
- water quality impact will be valuated by using water treatment costs.

It is possible that, depending on the locality, that the construction of an impoundment will only be allowed if the proponent can demonstrate that the environmental impacts can be managed and in certain instances prevented. If an impact is entirely prevented, the cost of prevention can be taken into account when doing the economic and financial analysis of the scheme. If an impoundment is covered with rock at a cost of R40 million to eliminate air pollution, there is no impact on the air quality. On the other hand, if a grassed armouring is placed at a cost of R50 million, the cost of mitigation action is a direct and identifiable cost of the scheme, but the value of the residual impact on air quality, i.e. the possible increase in respiratory hospital admissions as a result from the increase in particulate concentrations, also needs to be included in the cost of the scheme.

The following environmental aspects are valuated in the next section as part of this study:

- visual perception;
- air quality; and
- water quality.

6.2.1 Visual

Valuating visual impacts typically make use of subjective valuation approaches (SVA) such as the hedonic valuation method of which the pricing theory holds that because people select a good for its characteristics, the value of the characteristics is reflected in the price of the good (Table 5, p. 67 and Figure 39, p. 69). The good in question is property, and the attribute of interest is aesthetics. A major problem with hedonic pricing arises from the extent to which the focus variable (in this case, aesthetics) can be correctly identified, accurately measured and reliably distinguished from related factors (Bateman, 1994, p. 31). The examination of property and land values will be used to calculate the cost of the tailings impoundment visual influence.

A desktop survey was undertaken to determine the way in which property prices and land values, especially that of residential property and land with the potential for game farming with a tourism component can be affected by its proximity to tailings impoundments. A process can be followed to elicit expert views of property valuator and estate agents as regards changes in property prices due to its locality within the different visual perception zones of influence. (It is recommended that this could be a topic for further research.) However, the premise is that land use and property values could differ depending on its locality relative to the tailings impoundment. Also, there can be incompatibilities between the post-closure tailings impoundment and the land use of the surrounding area.

Compatible and incompatible land uses for this study are proposed in Table 68. The impoundment configurations defined and used in the experimental work and modelling section will again be used and where, in the section on combing environmental impacts and engineering costs, the change was measured and described in visual detection and recognition zones of influence and expressed in surface area, the change will now be presented in monetary terms.

Table 68: Proposed compatible and incompatible land uses within the recognition and detection visual perception zones of influence.

		Visual perception zone	
Zoning	**Land use**	**Recognition**	**Detection**
Wilderness	**Wilderness**	Compatible	Compatible
Agriculture	**Grazing**	Compatible	Compatible
	Crop cultivation	Compatible	Compatible
Residential	**Low cost**	Compatible	Compatible
	Medium cost	Likely incompatibility	Compatible
	High cost	Incompatible	Likely incompatibility
Light industry	**Light industry**	Compatible	Compatible
Game farming	**Farming**	Compatible	Compatible
	Tourism	Incompatible	Likely incompatibility

Current and future land uses are discussed by comparing the ERGO Daggafontein study area's land use with the specific long-term impoundment configuration alternatives. Long-term post-deposition land use of an impoundment is likely to be completely different as the use and level of use on the site prior to the construction of the impoundment. The definition of level of land use is subjective. It is perhaps more appropriate to consider levels of post-deposition long-term uses to be that which are acceptable in terms of present and future planning initiatives and land use.

The land around the ERGO Daggafontein tailings impoundment is typically zoned for:

- agriculture;
- small holdings;
- residential; and
- light industrial.

Open space although indicated as agricultural land can be used for wildlife habitat and recreation. Using information on property transfers and applying recent house price indexes it is possible to calculate approximate 2006 prices for properties in the ERGO Daggafontein area (Table 69).

Table 69: Property values in the area of the ERGO Daggafontein tailings impoundment.

Erv no	Transaction date	Property value (R)	2006 value (R)	Property size (ha)	Value (R/ha)
Daggafontein Ext. 7A					
110	2005/03/29	250 000	305 279	0,74	413 490
158	2004/05/27	110 000	177 528	0,21	833 466
185	2005/12/20	120 000	146 534	0,18	798 986
				Average value	681 980
Daggafontein Ext. 1					
25	2004/08/16	220 000	355 056	0,12	2 927 093
42	2003/04/01	120 000	235 167	0,24	971 364
49	2004/02/06	275 000	538 925	0,14	3 816 748
62	2005/04/23	800 000	976 894	0,26	3 751 513
				Average value	2 866 679
Daggafontein Ext. 2					
441	1994/04/08	150 000	570 247	1,09	525 090
413	2002/02/28	92 000	211 846	0,30	714 732
344	2005/05/12	350 000	366 335	0,32	1 129 618
378	1995/08/24	109 000	398 442	0,20	1 944 568
360	1996/09/02	75 000	263 613	0,14	1 915 791
				Average value	1 245 960
Daggafontein Ext. 5					
610	1998/11/26	600 000	1 931 229	1,09	1 778 296
591	1996/09/12	100 000	351 484	0,30	1 185 843
535	1999/07/28	100 000	300 815	0,32	927 581
555	1998/10/20	170 000	547 182	0,20	2 670 482
570	1994/03/29	30 000	114 049	0,14	828 848
622	2002/08/19	1 200 000	2 763 214	0,50	5 526 429
				Average value	2 152 913
Daggafontein Ext. 7B					
194	1994/08/17	181 000	688 098	0,75	921 396
333	2006/06/03	161 000	161 000	0,40	398 022
212	2004/07/06	30 000	48 417	0,17	284 303
325	2005/10/13	1 400 000	2 259 449	7,14	316 472
313	2005/11/18	316 000	3 85 873	0,14	2 804 310
				Average value	944 901

The agricultural land use value for grazing is about R8 000/ha whereas land which is irrigated and used for crop cultivation can be as much as R42 000/ha. Small holdings sell for about R110 000/ha and residential property varies between R680 000 and R2,9 million/ha. Land used for light industry in the area sells for about R2,2 million/ha. Property values in Table 69 for the ERGO Daggafontein area is spatially represented in Figure 178.

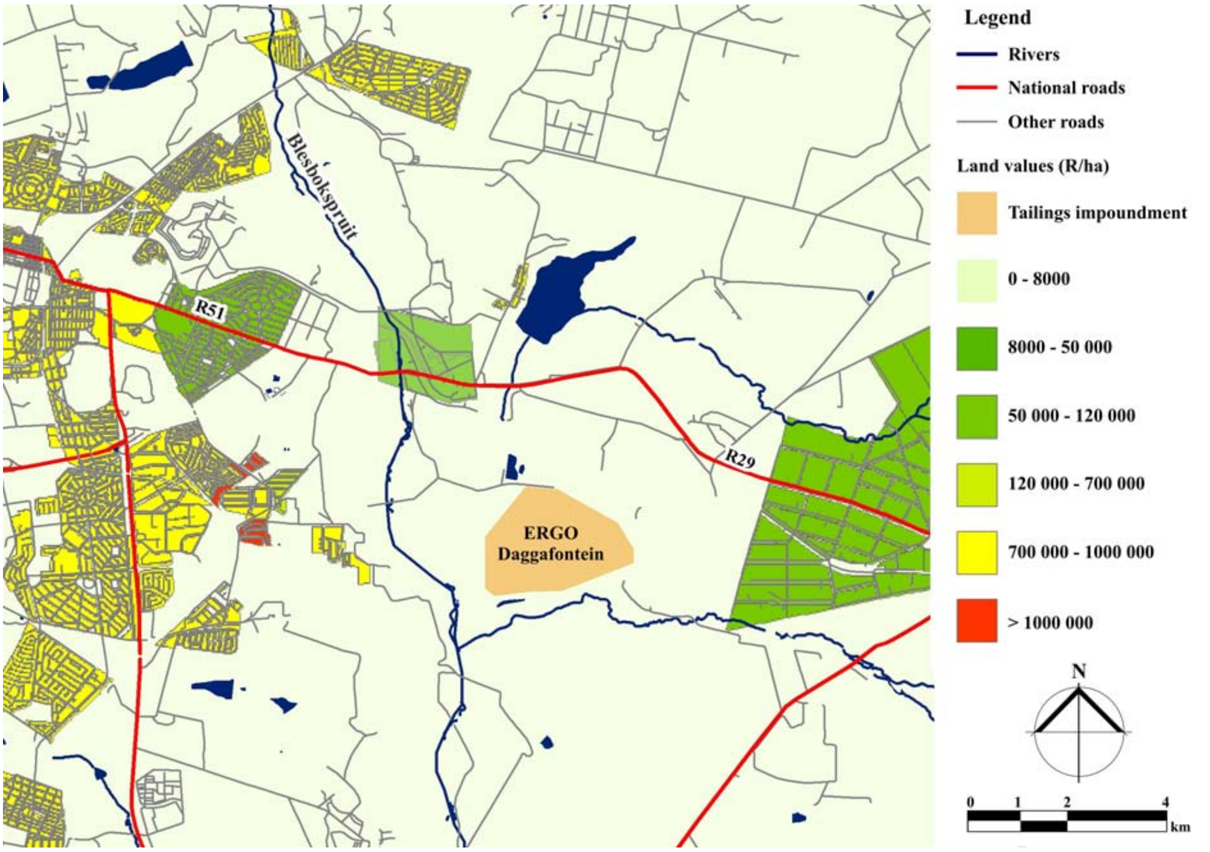

Figure 178: Land value map (R/ha) around the ERGO Daggafontein tailings impoundment.

It may be possible to decide on a post-closure impoundment configuration and use that are least in conflict with these surrounding uses. Simplistically there are five general levels of use that can be committed to for future use.

These are, in ascending order of level of involvement:

- wilderness;
- limited agriculture or recreation with little development, such as grazing and game farming;
- developed agriculture such as the cultivation of crops;
- residential, light commercial and light industry; and
- residential, heavy commercial and heavy industry.

Visual perception zone of influence for scenarios VS1, VS3, VS5 and VS7 are included in Appendix A4. If the recognition and detection zones are superimposed on the land value map (Figure 178) and applying the land values (Table 70) a bar chart can be used to compare the existing value of land within the area of influence (Figure 179).

Table 70: Land values used in the quantification of land use incompatibilities.

Zoning	Land use	Land value (R/ha)
Wilderness	**Wilderness**	8 000
Agriculture	**Grazing**	8 000
	Crop cultivation	42 000
Residential	**Low cost**	680 000
	Medium cost	1 430 000
	High cost	2 870 000
Light industry	**Light industry**	2 150 000
Game farming	**Farming**	25 000
	Tourism	120 000

The existing total value of land in the recognition visual perception zone of influence for the cover types modelled are approximately R17,5 million (VS1), R21 million (VS2), R8,7 million (VS5) and R1,3 million (VS7). Similarly the total value of land in the detection zone is R1 200 million (VS1), R738 million (VS2), R168 million (VS5) and R8,2 million (VS7) (Figure 179).

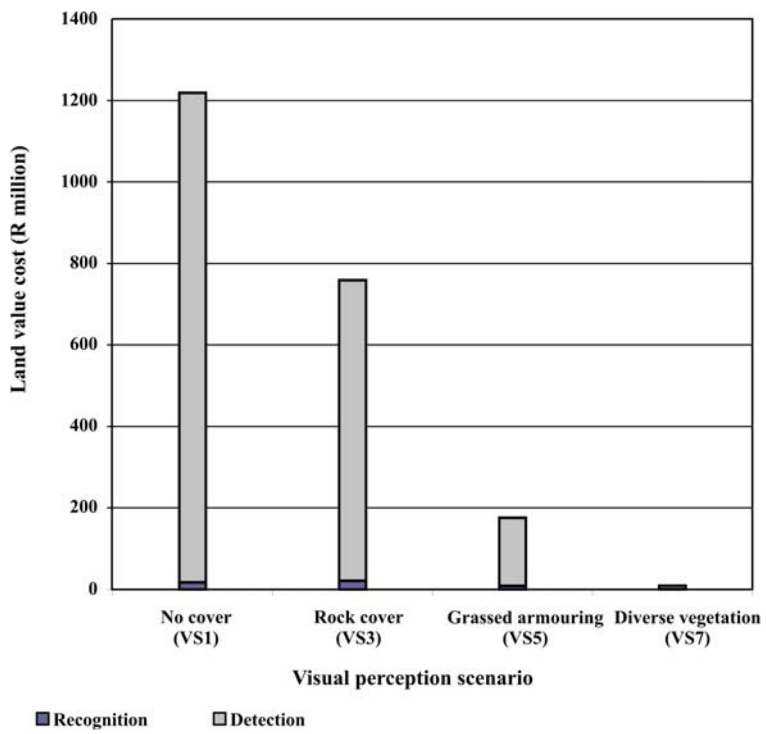

Figure 179: Total existing value of land within the visual perception zones of influence.

The size of the detection zone results in a total land value within the influence zone of up to R1 200 million. The existing value of land in the recognition zone is much less (R18 million) because the area of influence is much smaller. The value of land in the impoundment with no cover detection zone (VS1) is almost seventy times more than the value of land in the recognition zone. Similarly the no cover detection influence zone is more than three orders of magnitude greater than that of the impoundment covered in diverse vegetation (VS7). The value of land in VS7's recognition zone is just over R1,25 million whereas the land value in VS1's recognition influence zone is about R18 million.

In order to valuate the potential visual impact that could result from the tailings impoundment it is necessary to consider the potential land use incompatibilities and conflicts between different land uses. Potential incompatible land uses are proposed in Table 68, p. 290.

There are many examples, such as those illustrated in Figure 180, where low cost residential development has been constructed in the recognition visual perception zone of influence. It is however unlikely that high cost residential development will be compatible in the same zone. Similarly it may in certain instances be that there will be a conflict in developing high cost residences in the detection zone. There could also be conflict between game farming land with a tourism potential and the recognition and detection visual perception zones of influence.

Looking towards one of the Grootvlei Proprietary Mines tailings impoundment's with low cost residential land in the foreground.
[2] A view towards existing Krugersdorp West Mine residue deposits with a new residential development adjacent.

Figure 180: Residential development in the visual perception zone of influence.

The following sections consider ascribing values for land for high cost housing and land for tourism (game farming) and the potential loss in land value resulting from conflict with land used for impounding tailings.

Sterilising land for high cost residential property development

There is the potential that land in close proximity to a tailings impoundment, and more specifically land which lies within the visual recognition perception zone of influence, could be sterilised for future high cost residential development.

For the purposes of illustrating the potential sterilisation of high cost residential development within the tailings impoundment visual perception zone of influence it is best to focus on the recognition zone. The reasons are two-fold.

Firstly, the detection zone surface area is orders larger than the recognition zone and the valuation of the visual impact is sensitive to the area influenced by the impoundment.

Secondly, as mentioned before, research has to be undertaken to determine conflicting land uses and incompatibilities that will arise when constructing an impoundment in proximity to different land uses or vice versa. The costs for potential sterilisation for high cost residential developments within the detection visual perception zone of influence run into the thousands of millions of Rands.

The possible visual impact cost in the visual perception visual zone of influence is the difference in high and medium cost residential development property value (Figure 181). The impact is the potential change brought about by the tailings impoundment. The potential visual impact costs for loss in land value (high cost housing minus medium cost housing) are R30 billion (VS1), R20 billion (VS3), R9 billion (VS5) and R1,5 billion for the no cover, rock, grassed armouring and diverse vegetation covers.

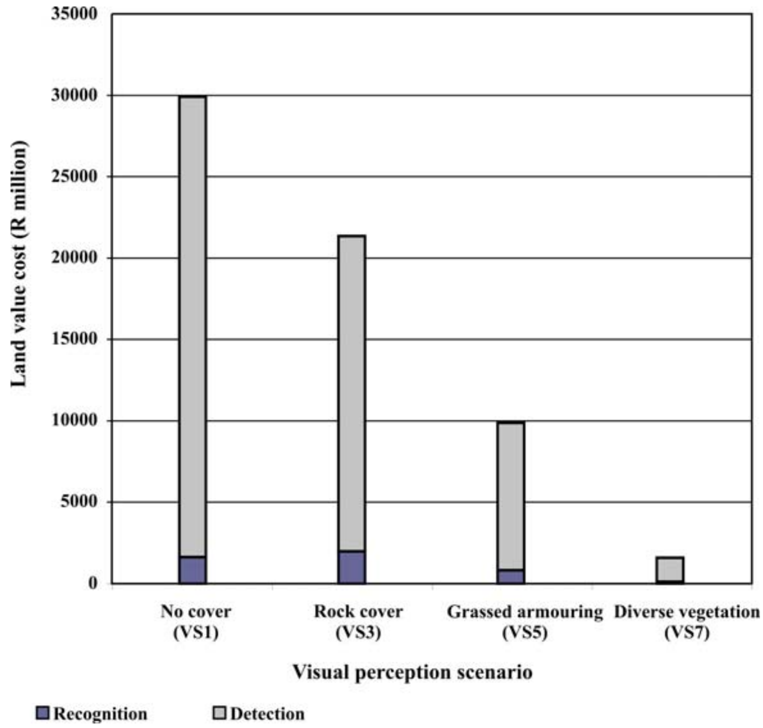

Figure 181: The potential total loss of property development value. The loss is the difference between high and medium cost residential property values within the visual impact zone.

The visual impact cost is indicative of the total change in land value over the entire area of visual influence. It is likely that the total cost will only be incurred over time as development is constrained as a result of the influence of the impoundment. The total visual impact cost has therefore been spread over a 20 year post-closure period which is the same as the time allowed in the engineering cost model for post-closure maintenance and management (Figure 182).

The development stage (design and construction) and the operation stage engineering costs are the same for the scenarios modelled and illustrated in this figure. The line between points A and C, which plots the costs, are therefore the same. There is a change in the engineering closure stage costs (lines between points C and D) depending on the type of cover. The lines between points D and E represent the integrated visual impact costs and engineering post-closure maintenance and management costs for the various cover types.

The high cost housing value in the visual perception recognition zone that will not be actualised are:

- R1,6 billion for the impoundment scenario without any cover (VS1);
- R1,9 billion for the rock cladding scenario;
- R800 million for the grassed armouring option; and
- R117 million for the impoundment scenario covered in diverse vegetation.

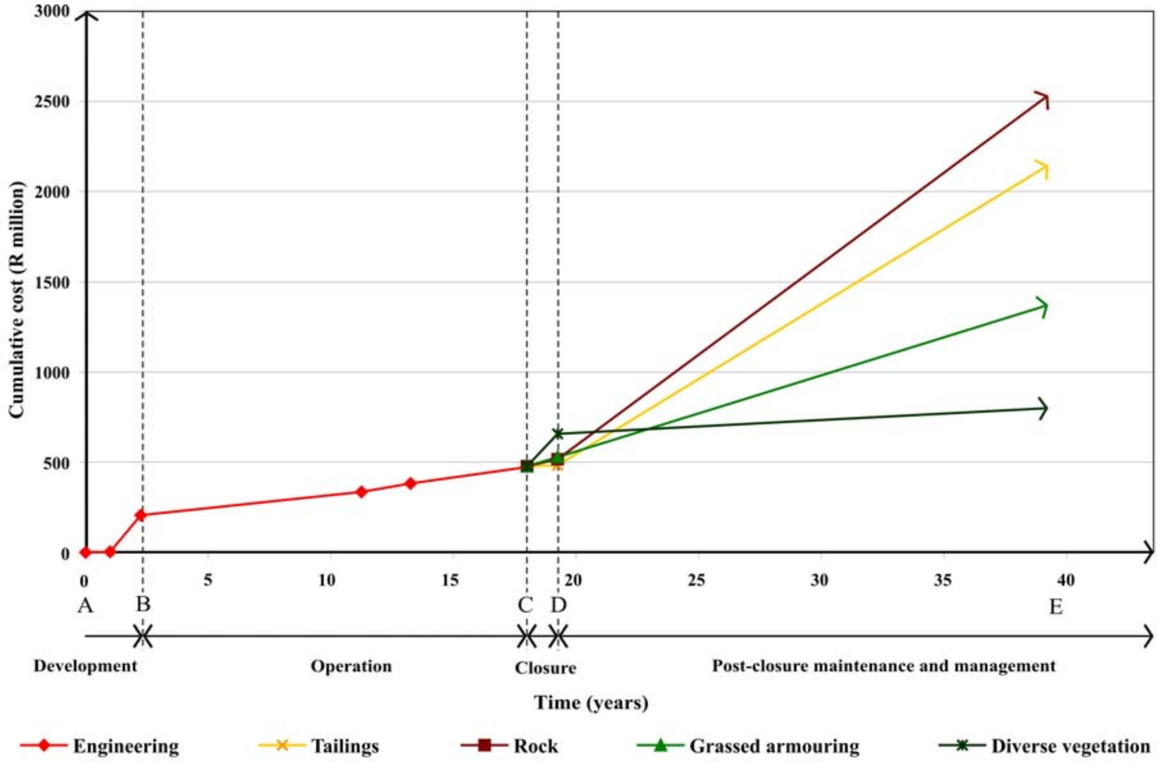

Figure 182: Potential visual impact life-cycle cost, spread over 20 years, resulting from the conflict in land use between the development of high cost residential property and the tailings impoundment within the visual perception impact zone.

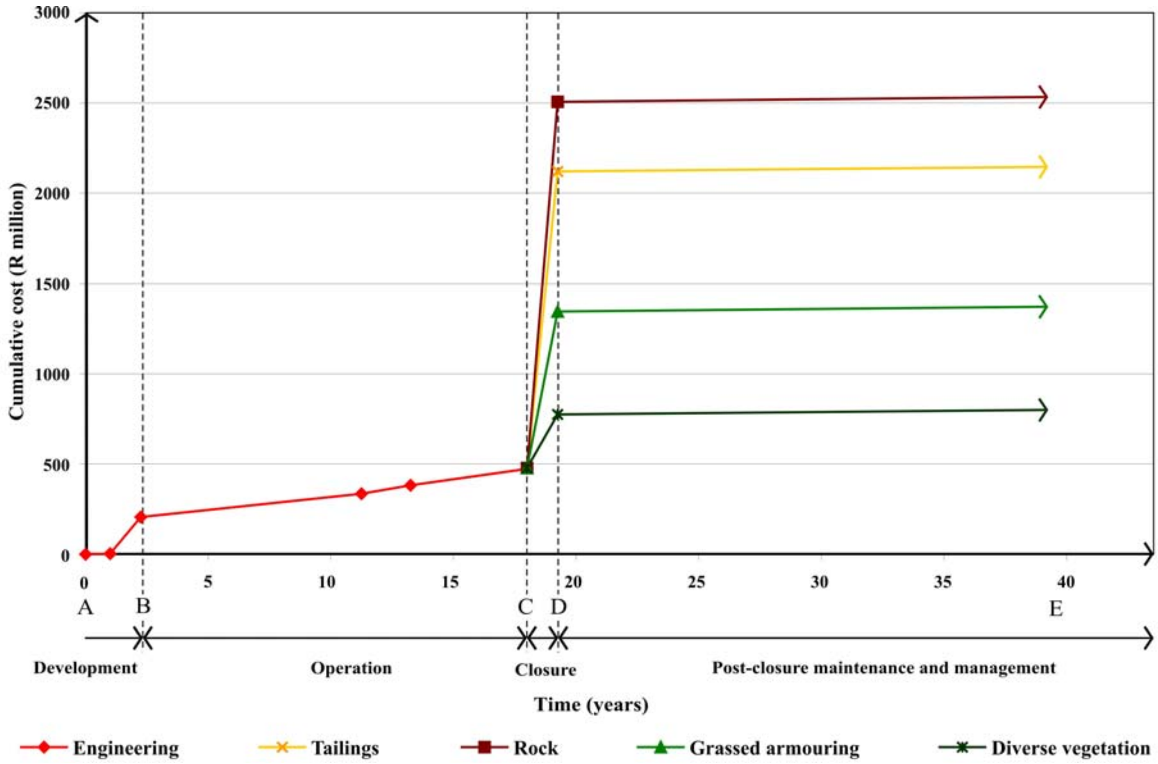

Figure 183: Potential visual impact life-cycle cost indicated as an event during closure resulting from the conflict in land use between the development of high cost residential property and the tailings impoundment within the visual perception impact zone.

The visual impact cost (loss of property value) can also be indicated as a once off event which may be the case where there is an immediate and total loss in land value resulting from the impoundment (Figure 182, p. 296).

Irrespective of the visual impact indicated as a once off event or spread over 20 years the potential sterilisation of high cost property development in the no cover recognition zone is fourteen times more than that of the diverse vegetation zone. The high cost property development sterilisation in the grassed armouring recognition zone is about half of that of the no cover scenario. A 50 % reduction on land value sterilised can therefore be achieved by covering the impoundment with a grassed armouring as apposed to doing nothing.

Sterilising land for game farming tourism potential

The following case study will illustrate the possible effect on the costing of property values if the ERGO Daggafontein impoundment was surrounded by game farms with tourism potential. The site is in the North West Province located immediately North of the Pilanesberg National Park (PNP). Mining North of the PNP could impact on several tourism initiatives one of which includes the establishment of a corridor linking the PNP and Madikwe Game Reserve. Figure 184 illustrates the proposed corridor initiative which has the potential to act as a catalyst for future investment.

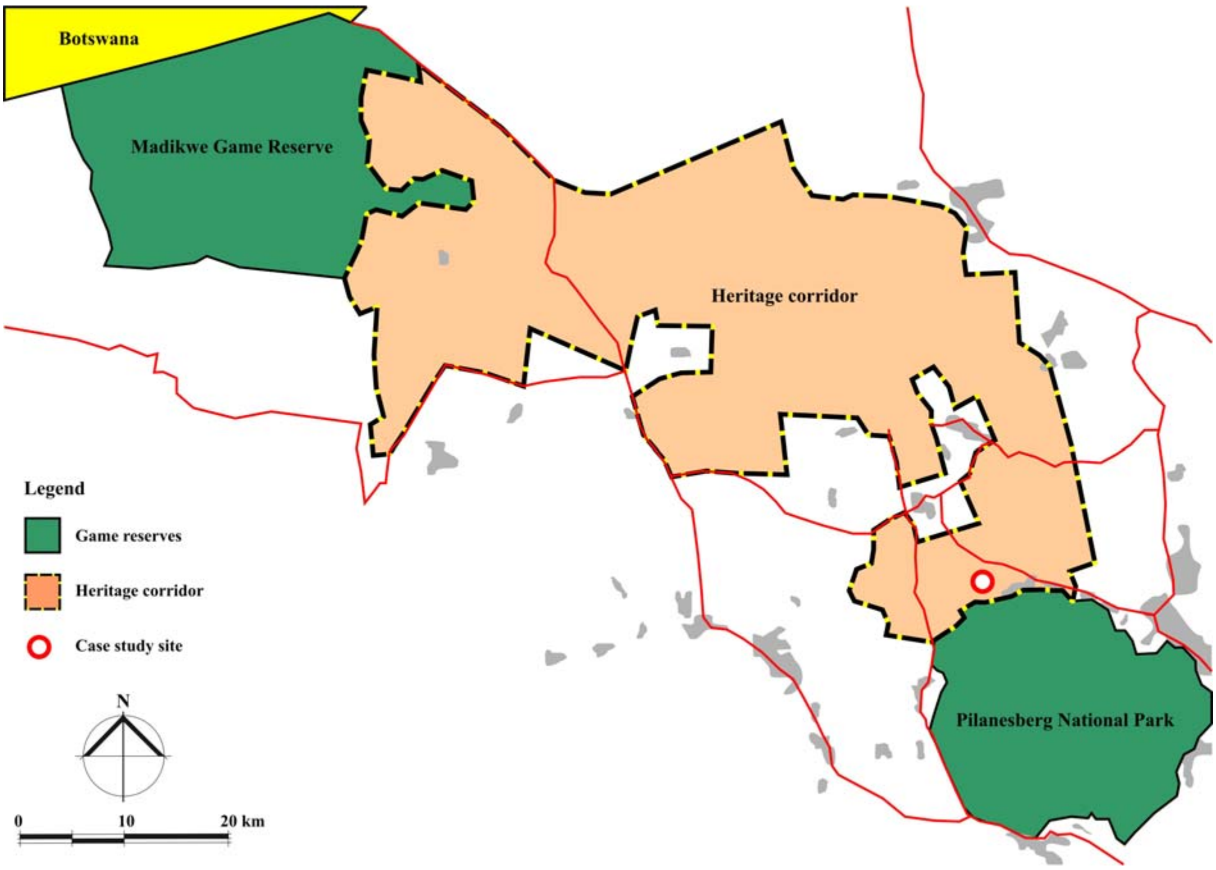

Figure 184: Proposed heritage corridor linking the Pilanesberg National Park with the Madikwe Game Reserve (SEF, 2002).

The potential for conflict between mining and conservation land use exists. After decommissioning and closure of a mine the tailings impoundment and rock dumps will remain which could result in a continued negative visual impact. The terrain is flat and depending on the impoundment configuration it could result in a significant visual zone of influence, comparable to that of the ERGO Daggafontein study site.

Because of the impoundment's locality in terms of tourism initiatives, it can be expected that the long term post-closure visual impact may be of greater concern than for example the potential impact on water. The reasons are that platinum tailings' chemical properties is less toxic than that of gold tailings, the site is underlain by soils which inhibit seepage, and water runoff can be effectively controlled by implementing standard practice engineering design principles.

Typical platinum tailings contain a mixed blend of approximately two thirds UG2 and one third Merensky ore. Extensive chemical analysis of various individual or mixed platinum tailings streams indicate that metal concentrations are generally low in the solid phase indicating that seepage pose a minor to insignificant risk to the environment. The liquid phase of the tailings slurry also generally show that metal concentrations to be low. However, salinity can impact on the soils, surface water and the groundwater. Platinum tailings generally classify as general waste material (SRK, 2003).

The conceptual design for the proposed tailings impoundment will need to:

- keep the post-closure visual detection perception zone of influence as small as possible, especially if the Pilanesberg National Park is to expand;
- allow for embankment slopes that can be ploughed, vegetated and mechanically maintained;
- keep the air quality zone of influence as small as possible; and
- integrate the impoundment, through proper slope and cover design, into the anticipated post-closure surrounding land use.

Potential sterilisation of land for use as game farming with tourism potential within the recognition and detection visual perception zones of influence are compared in Figure 185 and the costs in the recognition zone plotted in Figure 186. The cost is the difference in land value and is determined by subtracting the average value of agricultural grazing land (R8000) from the lowest value of land used for game farming with tourism potential (R25 000) (Table 71).

Table 71: Typical land values for agricultural and game farming land in the North West and Limpopo Provinces.

Province	District	Use	Area (ha)	Selling price (R)	Land value (R/ha)
North West	Koster	Agricultural grazing	216	1 480 000	6 852
	Bloemhof	Agricultural grazing	604	5 500 000	9 106
	Rustenburg	Game farming	200	5 000 000	25 000
	Zeerust	Game farming	30	1 500 000	50 000
Limpopo	Naboomspruit	Game farming	55	2 600 000	47 273
	Bela-Bela	Game farming	45	3 200 000	71 111
	Mabula	Game farming	340	40 000 000	117 647

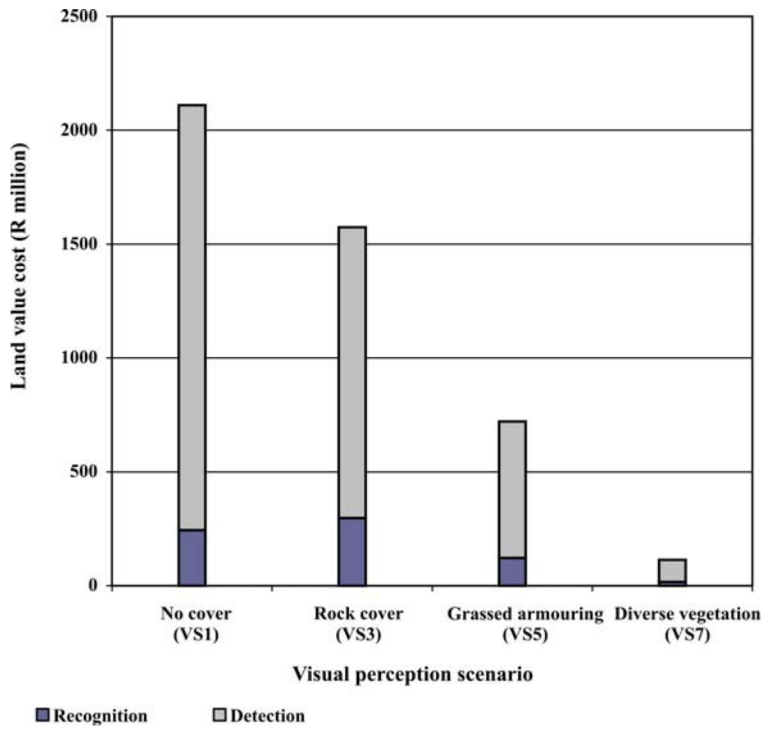

Figure 185: The potential total loss in game farming land value. The impact is the difference in values between game farming and typical farmland used for grazing within the tailings impoundment visual impact zone.

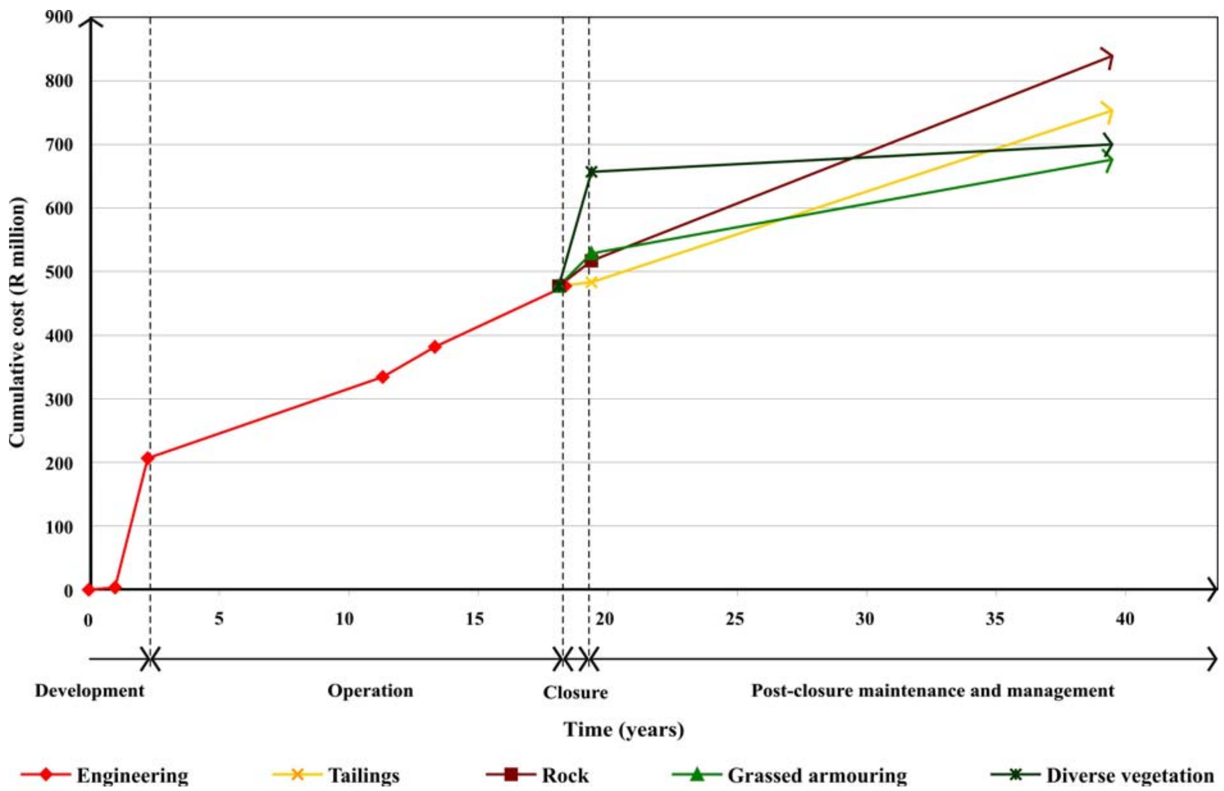

Figure 186: Potential visual impact life-cycle cost, spread over 20 years, resulting from the conflict in land use between the use of land for game farming with tourism potential and the tailings impoundment within the visual perception impact zone.

Similar to the previous discussion on high cost residential development, if the value of land had to be valuated for both the recognition and detection zones of influence the total cost will run into billions of Rands (Figure 185). Research will have to be undertaken to confirm the sensitivity of game farming land with a tourism potential within the detection zone of influence. However, for the purposes of this study it is assumed that there will be an incompatibility in the impoundment recognition visual perception zone of influence (Table 68, p. 290).

The difference in property value as agricultural grazing land and game farming with tourism potential is indicated in Figure 186. The figure divides the total cumulative cost of the visual impact post-closure over 20 years. By covering the impoundment with diverse vegetation (VS7) similar to that of the natural surroundings reduces the land value by R17 million whereas not covering the impoundment and leaving the tailings bare will result in a cost of R245 million. Grassed armouring (VS5) will reduce the value of land by R122 million and rock (VS3) by R297 million (VS3). Camouflaging the impoundment by using a diverse vegetative cover as the advantage that it can reduce the potential cost by up to seventeen times when compare to using rock and by fourteen times when compared to doing nothing. These are significant improvements in any terms.

6.2.2 Air

Until recently there has been little guidance about the calculation of the costs of air pollution and using these costs to evaluate alternative air pollution control strategies. Rational decision making requires quantification of impacts. Valuation of impacts is but one approach to quantify impacts. It does have certain advantages in that control technologies can be compared in monetary terms. This study describes a method to quantify costs and benefits as a result of changing the design of an impoundment.

The costs of implementing for argument a more expensive and rigorous cover which are aimed at reducing emissions can be offset by the reduction in health risk. The health risk cost must be factored into the total impoundment cost. The difference in the intervention cost and the subsequent health risk cost provides an indication of the true total cost related to the impoundment configuration choice. Valuating the air quality impact provides decision makers with the opportunity to test and compare different closure options in Rand terms using engineering costs and air quality costs.

Health impacts, as discussed in Section 2.11.5, will be used to cost the impact of impoundments on air quality as there is a clear cause and effect link. The causal sequence of air quality impacts is important. There must be a clear link between the source, emission, ambient levels, exposure, health outcomes, and finally the costing of the ill-health effects.

The following were determined and used to estimate the value associated with changes in air pollution as a result of the release of particulates released from an impoundment:

- Estimation of change in PM_{10} concentration. Emissions were estimated, dispersion modelled, and spatially mapped to determine the 25 $\mu g/m^3$ PM_{10} air quality influence zone.
- Determining the susceptible population.
- Applying dose-response relationships (respiratory hospital admissions dose-response relationship was used). Refer Section 2.11.5 for information on the valuation approach.
- Economic valuation of the health endpoint (costs associated with respiratory hospital admissions).

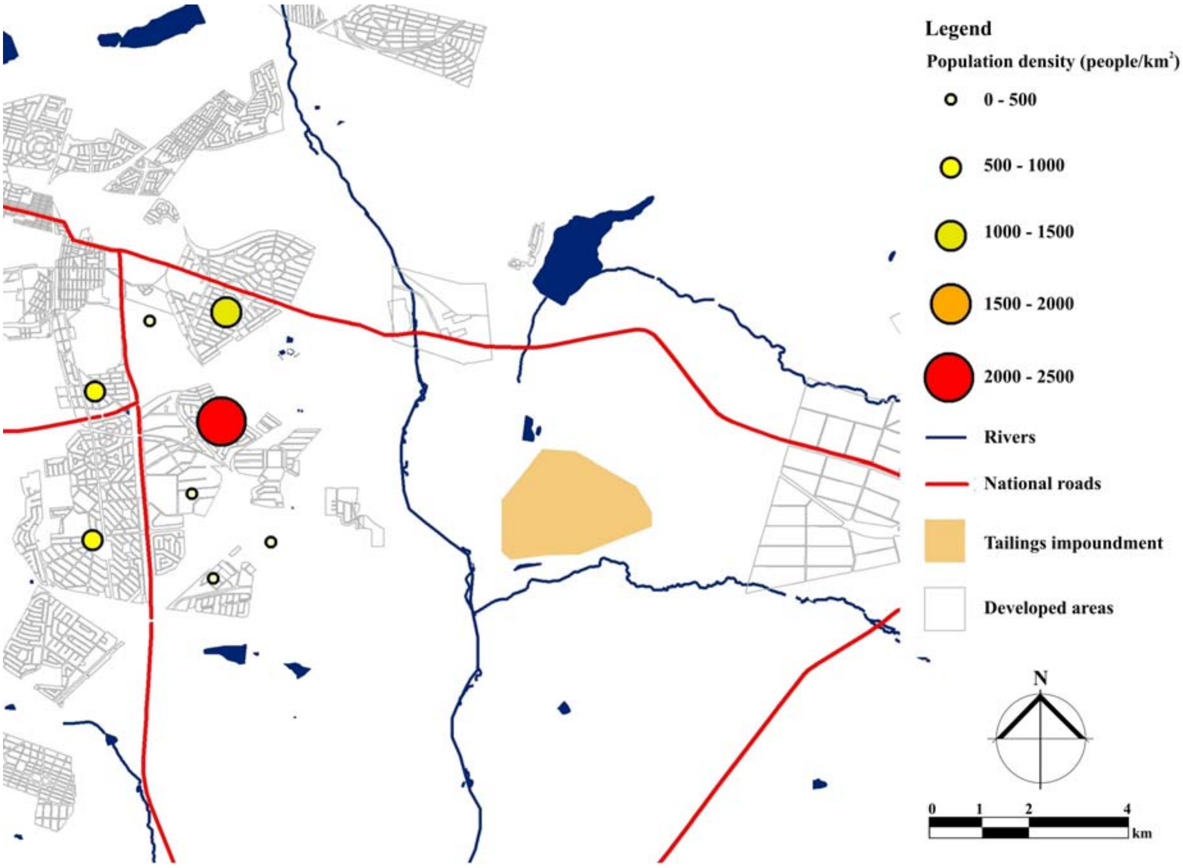

Figure 187: Population densities in the vicinity of the ERGO Daggafontein case study site.

The 25 µg/m³ PM_{10} and TSP air quality influence zones for the no cover (AS2), rock cladding (AS6), grassed armouring (AS10), and diverse vegetation cover (AS14) configurations are provided in Appendix B.1. One of the factors used in the dose-response relationship is information on the population at risk of health effect in the air quality influence zone. Applying the respiratory health effect costs (Table 12, p. 104) to different population densities for the covers modelled, annual costs can be estimated and are provided in Table 72 and Figure 188

Table 72: Potential health risk costs as a result of a 25 µg/m³ increase in PM_{10}. The costs reflect the change in population density within the influence zone.

	(R million/annum)					
Densities	**250 people/ha**	**80 people/ha**	**25 people/ha**	**15 people/ha**	**10 people/ha**	**5 people/ha**
AS2	163,0	52,2	16,3	9,8	6,5	3,3
AS6	0,0	0,0	0,0	0,0	0,0	0,0
AS10	102,2	32,7	10,2	6,1	4,1	2,0
AS14	2,2	0,7	0,2	0,1	0,1	0,0

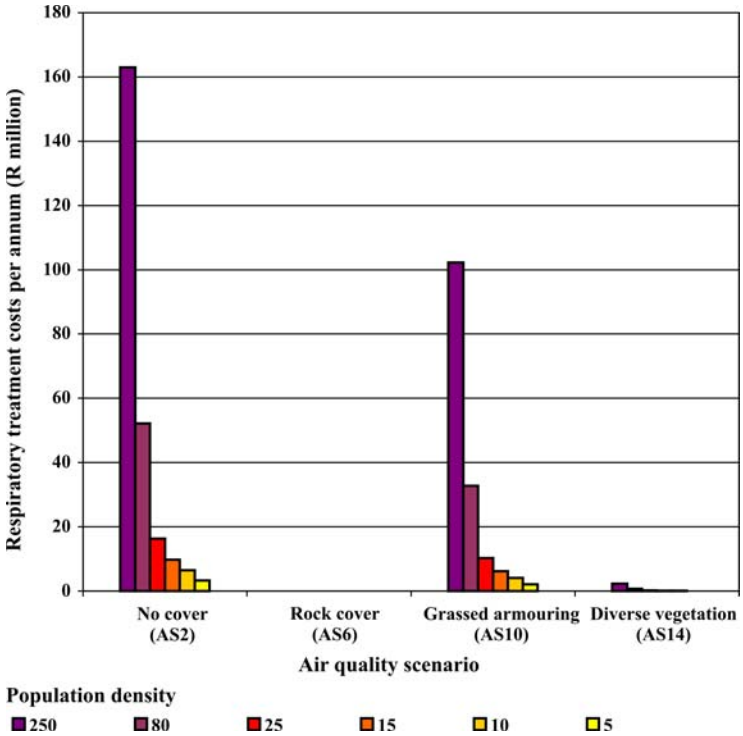

Figure 188: Indication of annual respiratory treatment costs for different population densities.

Figure 188 provides the costs per annum to treat patients suffering from respiratory ill-health effects and Figure 189 uses the same costs to indicate the cumulative effect over a period of 20 years after closure. Population density and area of influence significantly impact on the increase of air quality costs.

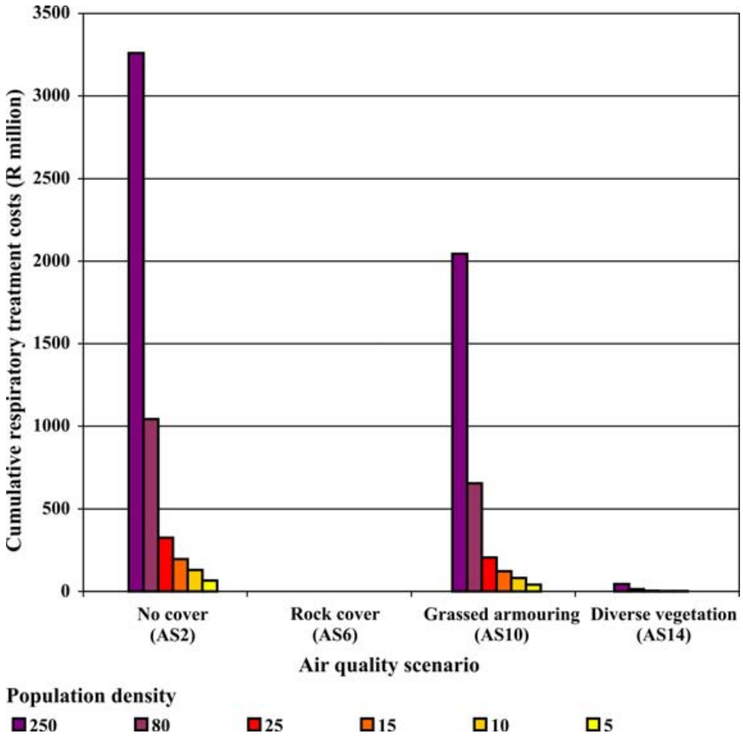

Figure 189: Total cumulative respiratory treatment costs over a 20 year post-closure period for various exposures.

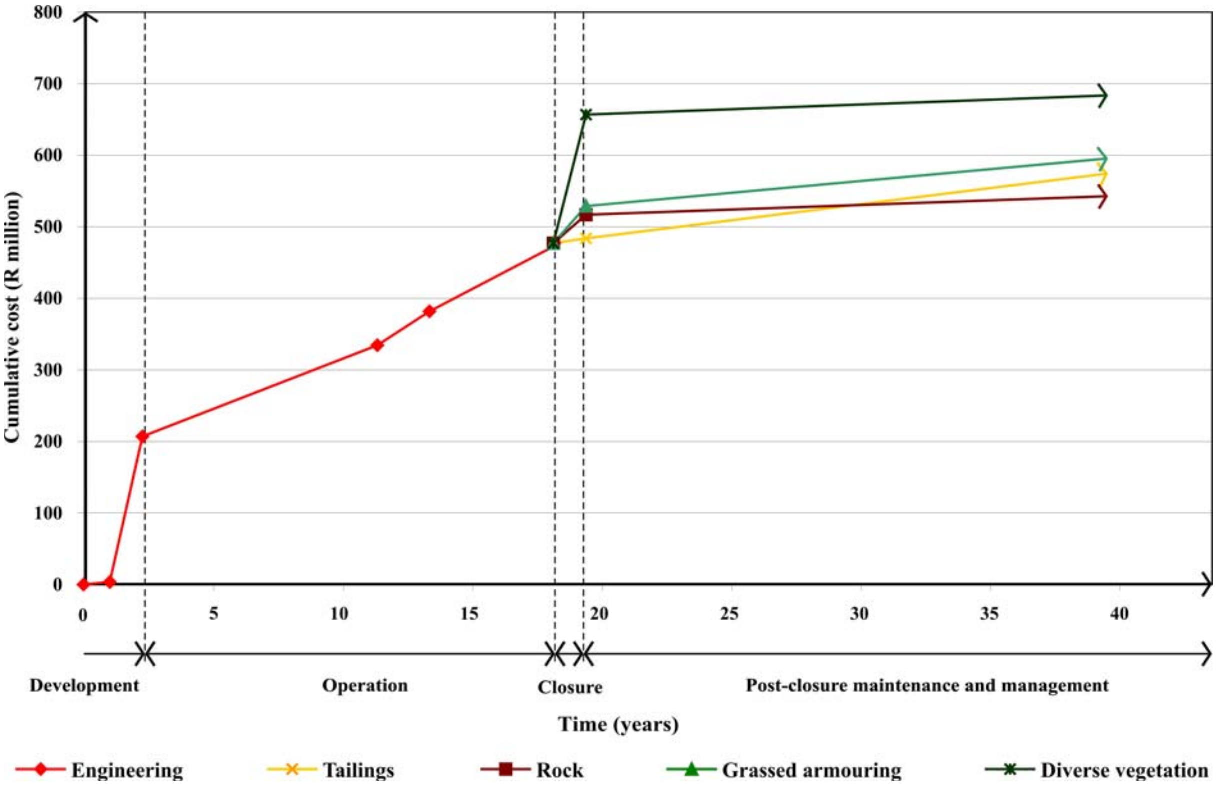

Figure 190: Integrating air quality life-cycle costs for 5 people/ha in the air quality zone of influence with the engineering costs.

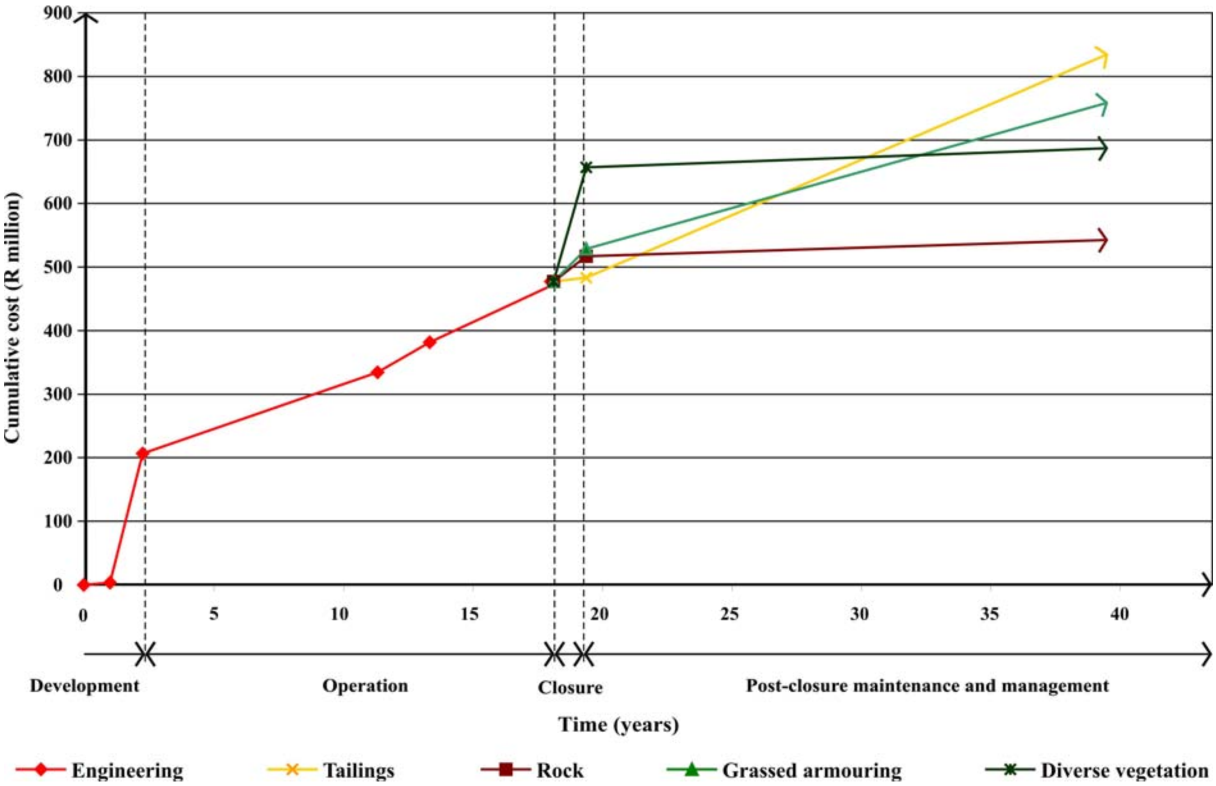

Figure 191: Integrating air quality life-cycle costs for 25 people/ha in the air quality zone of influence with the engineering costs.

The development stage (design and construction) and the operation stage engineering costs are the same for the scenarios modelled and illustrated in Figure 190 and Figure 191. Depending on the choice in cover the engineering closure stage costs change accordingly. The lines representing the post-closure stage include the air quality impact costs and engineering post-closure maintenance and management costs.

The current estimates of costs and benefits for changing an impoundment's configuration are based on broad averages and fairly simple assumptions. However, the examples used illustrate how engineering design decisions can change the 25 $\mu g/m^3$ PM_{10} influence zone which in turn translate into respiratory hospital admissions used to valuate the impact. These estimates provide the basis for comparing the various impoundment scenarios modelled.

When comparing the plots of cost over time for the 5 and 25 people per hectare densities it demonstrates to what extent the system is sensitive to the change in population density. It is therefore important to try and keep the exposure in the influence zone as low as possible or reduce the zone of influence. The zone of influence is important and can be readily dealt with by looking at the additional engineering costs for the cover types and choosing a cover type which, depending on the exposure, presents the best option.

There is still a great deal of uncertainty and controversy over valuating air quality costs. Recognizing this uncertainty the costs provided indicate a likely estimate of what would probably fall within a range with a lower and upper bound. In addition, the use of costs related to respiratory health admissions is only one of many health effects suspected of being associated with PM_{10}. Particulates blown from an impoundment is likely to be associated with non-health effects such as materials damage, soiling, vegetation losses and visibility degradation. These costs have not been included in this estimation and are therefore considered to be an underestimation of actual costs associated with exposure to PM_{10} for the impoundment scenarios modelled. The valuation does however provide an initial basis for assessing the potential which exists for offsetting the costs of implementing management measures aimed at reducing air pollution concentrations.

6.2.3 Water

Section 2.12.15 discusses various sulphate removal technologies and Section 2.12.16 provides information on the costs to treat water using the different technologies. The decision to use a specific technology will depend on cost and the need to meet some sort of water quality objective. Table 73 and Figure 192 compare the costs for the configurations modelled to remove sulphates using different technologies. It was assumed for this study that the slaked lime process will suffice. The total cumulative cost during the post-closure stage is illustrated in Figure 193.

The cost to treat the discharge for the various configurations are R34 million (WS2), R42 million (WS6), R30 million (WS10), and R22 million (WS14) for the no cover, rock, grassed armouring, and diverse vegetation covers respectively. The membrane desalination process is the most expensive and costs almost four times that of the slaked lime process to remove the sulphates released by the tailings impoundment. The biological process is about 3,4 times more expensive than that of the slaked lime process.

Table 73: Comparison of annual sulphate removal costs of various treatment technologies.

		Scenario cost (R million)			
Treatment process	**Cost item**	**WS2**	**WS6**	**WS10**	**WS14**
Limestone	Capital cost	0,45	0,55	0,39	0,29
	Running cost	16,91	20,53	14,49	10,87
	Total cumulative cost	17,36	21,08	14,88	11,16
Slaked lime	Capital cost	4,34	5,27	3,72	2,79
	Running cost	30,14	36,60	25,84	19,38
	Total cumulative cost	34,48	41,87	29,56	22,17
Biological	Capital cost	23,48	28,52	20,13	15,10
	Running cost	110,28	133,91	94,52	70,89
	Total cumulative cost	133,76	162,42	114,65	85,99
Membrane based	Capital cost	25,53	31,00	21,88	16,41
	Running cost	91,90	111,59	78,77	59,08
	Total cumulative cost	117,42	142,59	100,65	75,49

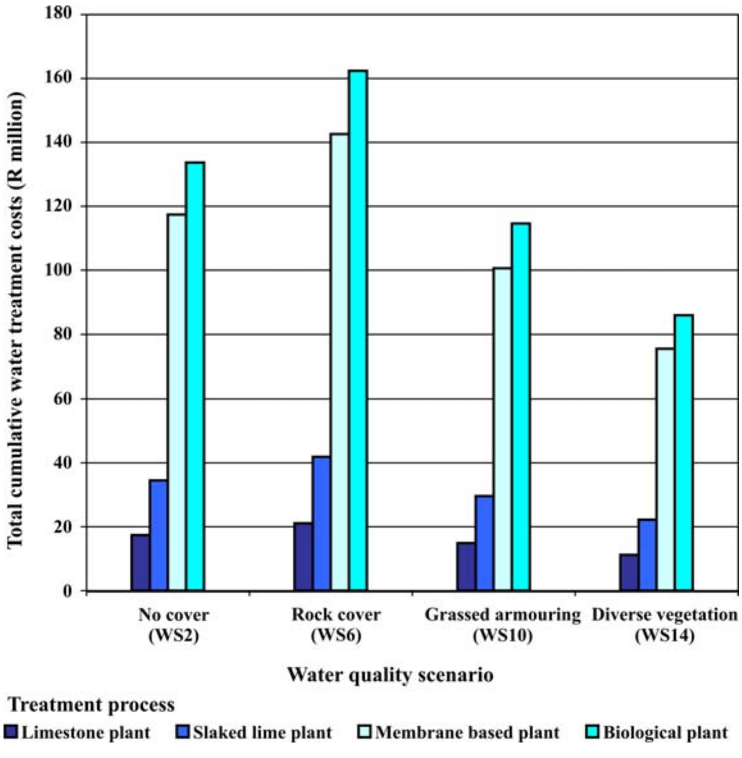

Figure 192: The column chart compares the cumulative water treatment costs for different treatment technologies.

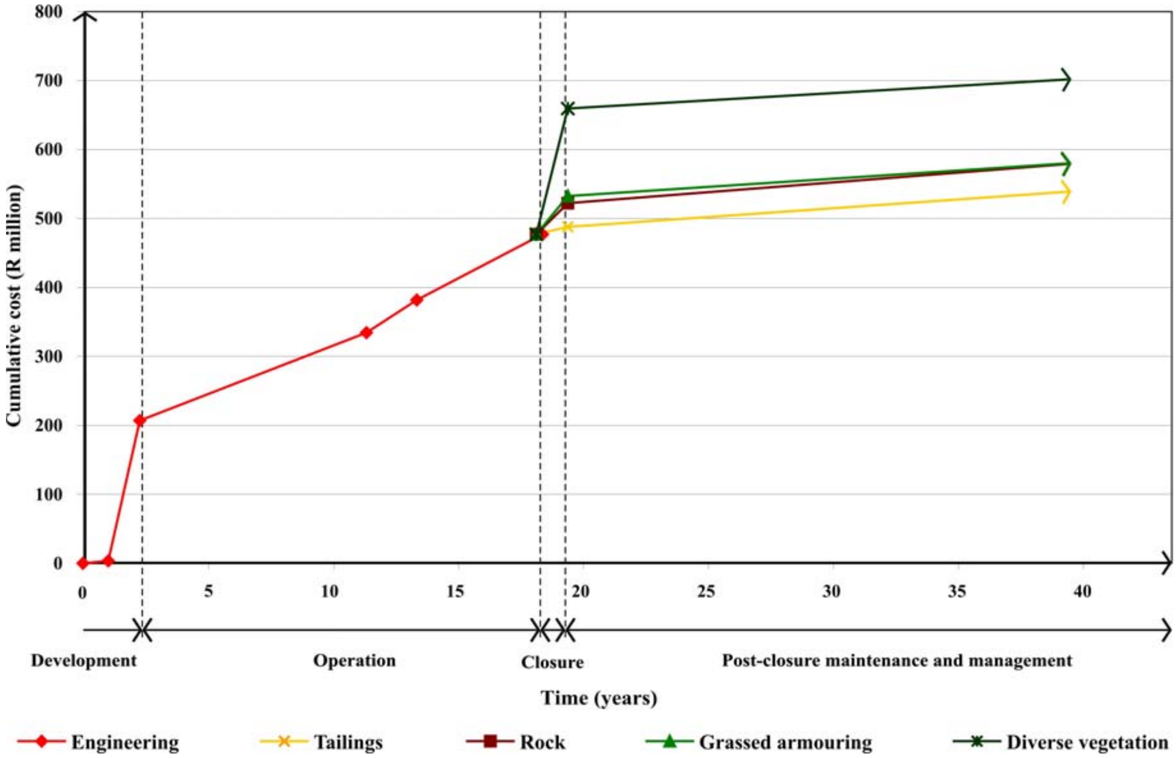

Figure 193: Impoundment life-cycle costs for various covers integrating the engineering and water treatment costs using the slaked lime process.

The development stage (design and construction) and the operation stage engineering costs are the same for the scenarios modelled in this part of the study (Figure 193). Depending on the choice in cover and the water treatment technology the closure stage costs change accordingly. The closure stage cost is the sum of the engineering cover construction cost and the water treatment plant capital (construction) cost. The lines representing the post-closure stage include the costs to treat and remove the sulphate load and the engineering post-closure maintenance and management costs.

6.3 Integrating environmental impact costs and engineering costs

Chapter 5 describes how environmental aspects can be combined with engineering costs. This section on the other hand has undertaken to integrate environmental impacts and engineering costs by ascribing costs to the environmental impacts.

The costing of environmental impacts has been accomplished through valuating quantifiable changes brought about by the influence of tailings impoundments on the environment. The preceding section of this chapter illustrates the valuation process for various tailings impoundment covers. Although this is in itself useful, the following section presents the integrated environmental aspect costs for the different cover types:

- no cover (tailings in situ);
- rock cladding;
- grassed armouring; and
- diverse vegetation

This study demonstrates how environmental impacts can be integrated with engineering design. At the onset of the research it was stated that the research will develop and describe a system which will integrate environmental impact costs and engineering costs using the same measure for comparison. The means of doing this is to quantify the environmental aspect impacts and evaluating their costs.

The cumulative life-cycle costs for the environmental impact costs and engineering cost of each scenario with an accompanying map presenting the spatial sphere of influence follows from page 308 to page 311. The environmental aspect influence zones are overlaid and synthesise spatial data graphically. Each cover can be compared and presented to decision makers communicating the costs and benefits associated with each impoundment configuration.

The last section of Chapter 6 sums the environmental aspects costs to provide a total environmental impact cost. The total environmental impacts costs can then be added to the engineering costs to provide the total integrated environmental impact and engineering cost for each cover type modelled. Comparisons can then be made between the total costs for the covers:

- no cover (tailings in situ);
- rock cladding;
- grassed armouring; and
- diverse vegetation.

No cover (tailings in situ)

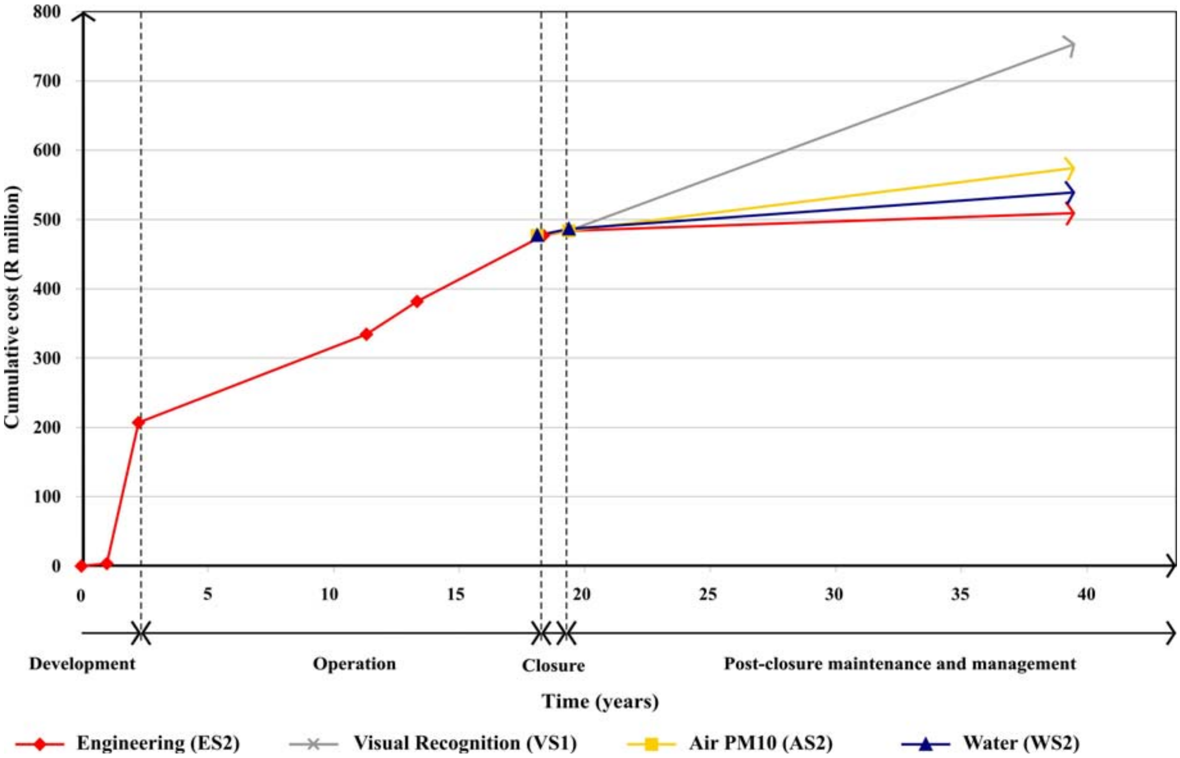

Figure 194: Total environmental and engineering costs for scenario without any cover.

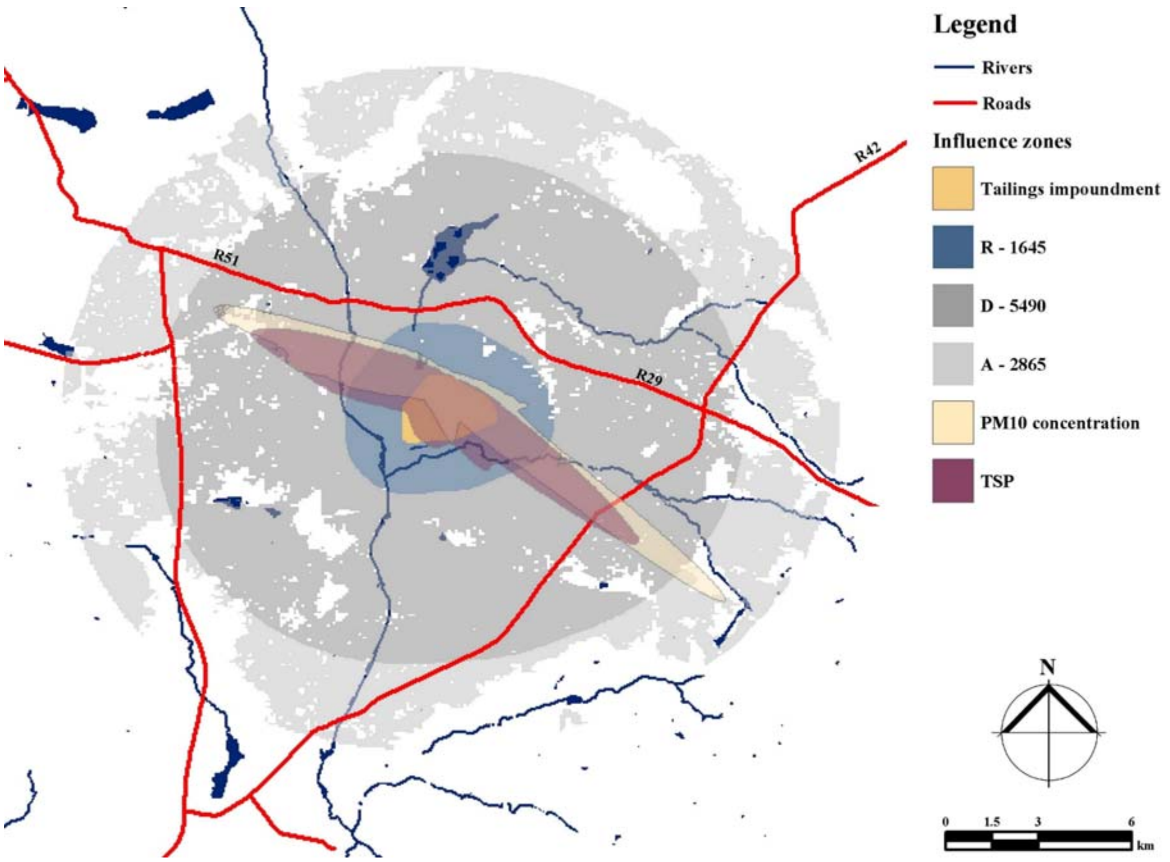

Figure 195: Sphere of influence for the impoundment scenario without any cover.

Rock cladding

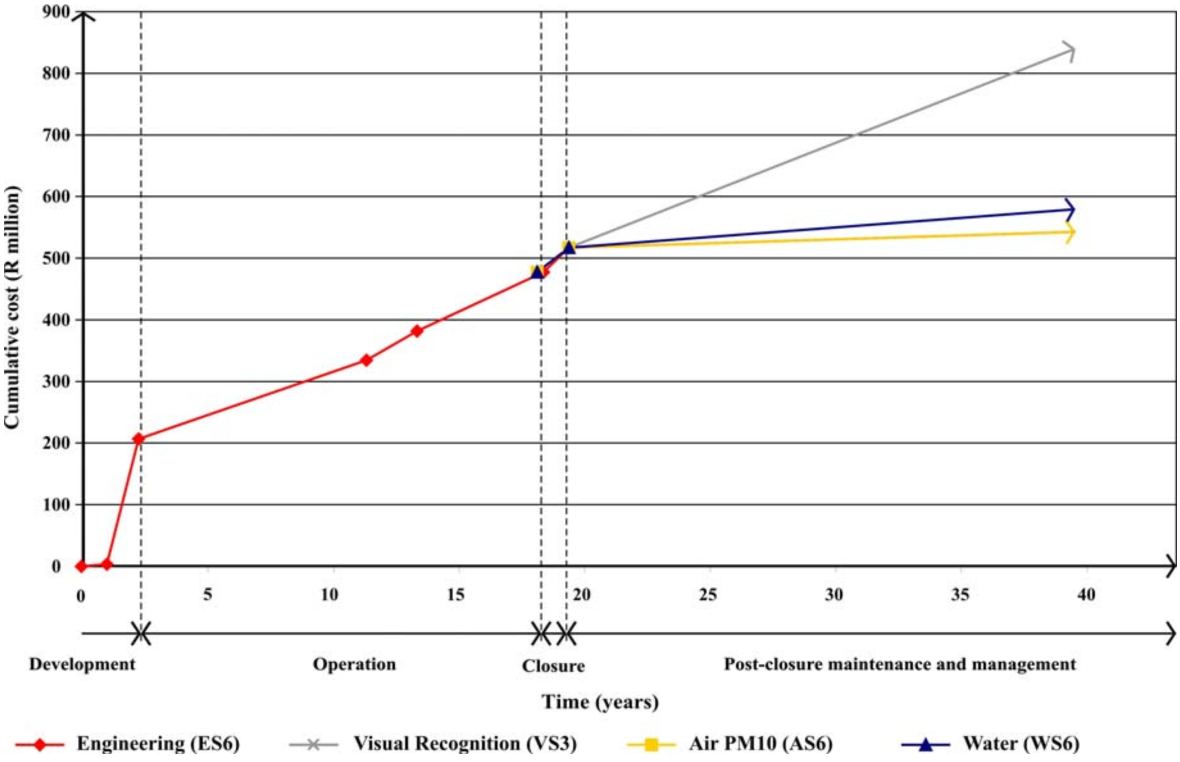

Figure 196: Total environmental and engineering costs for rock covered impoundment scenario.

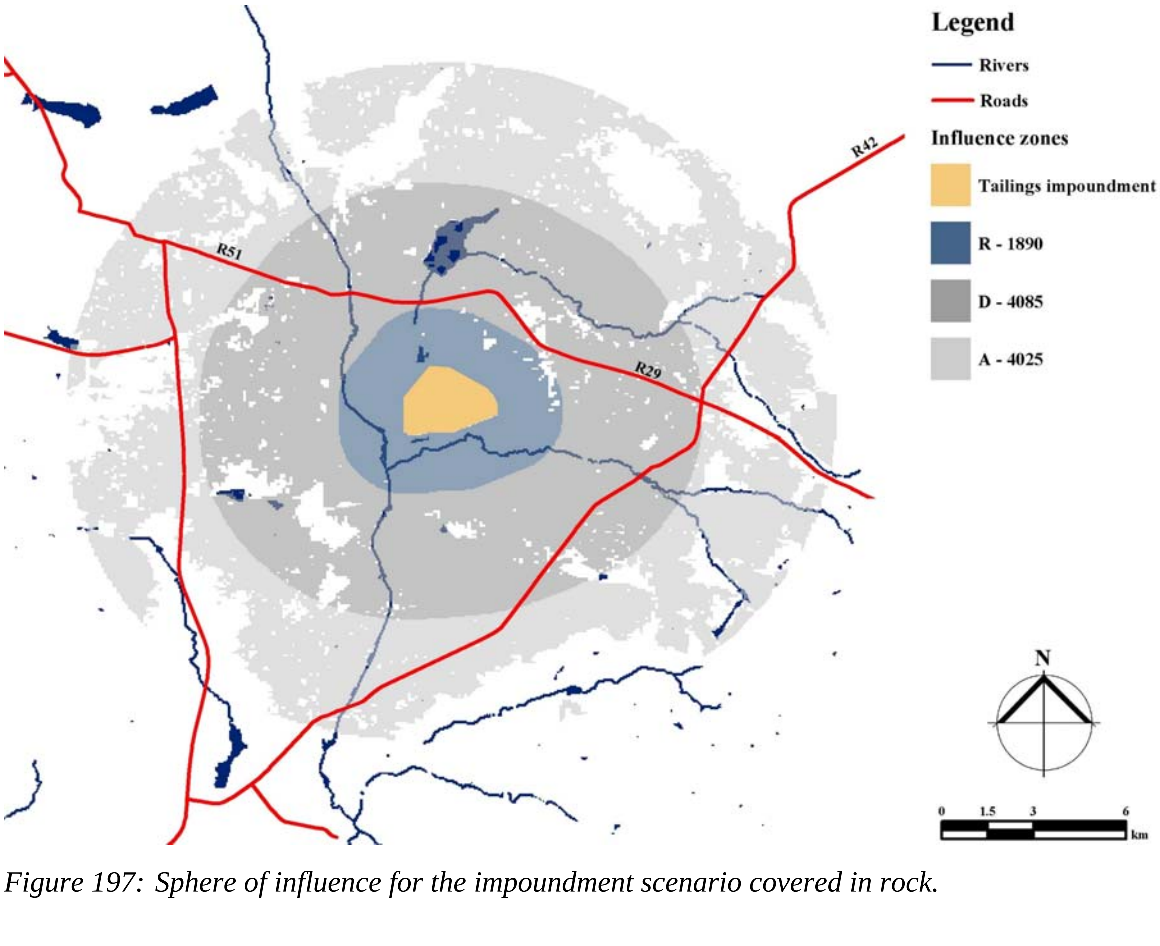

Figure 197: Sphere of influence for the impoundment scenario covered in rock.

Grassed armouring

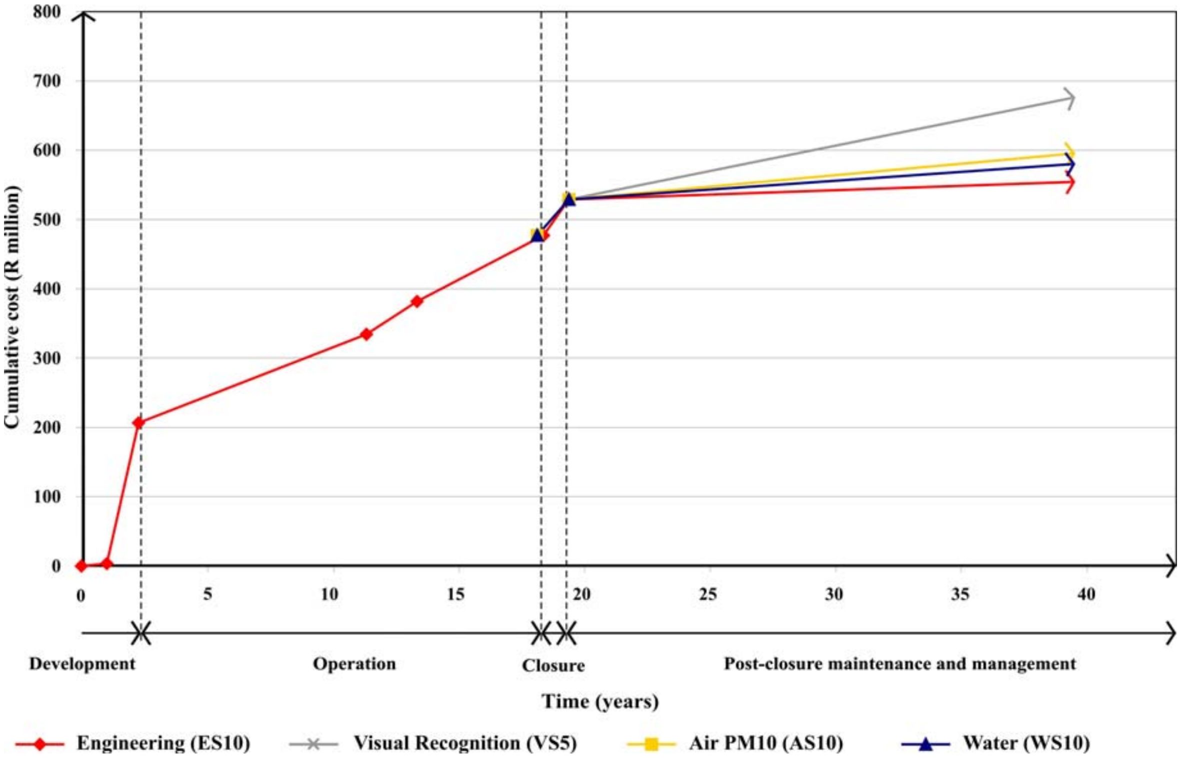

Figure 198: Total environmental and engineering costs for a grassed armouring.

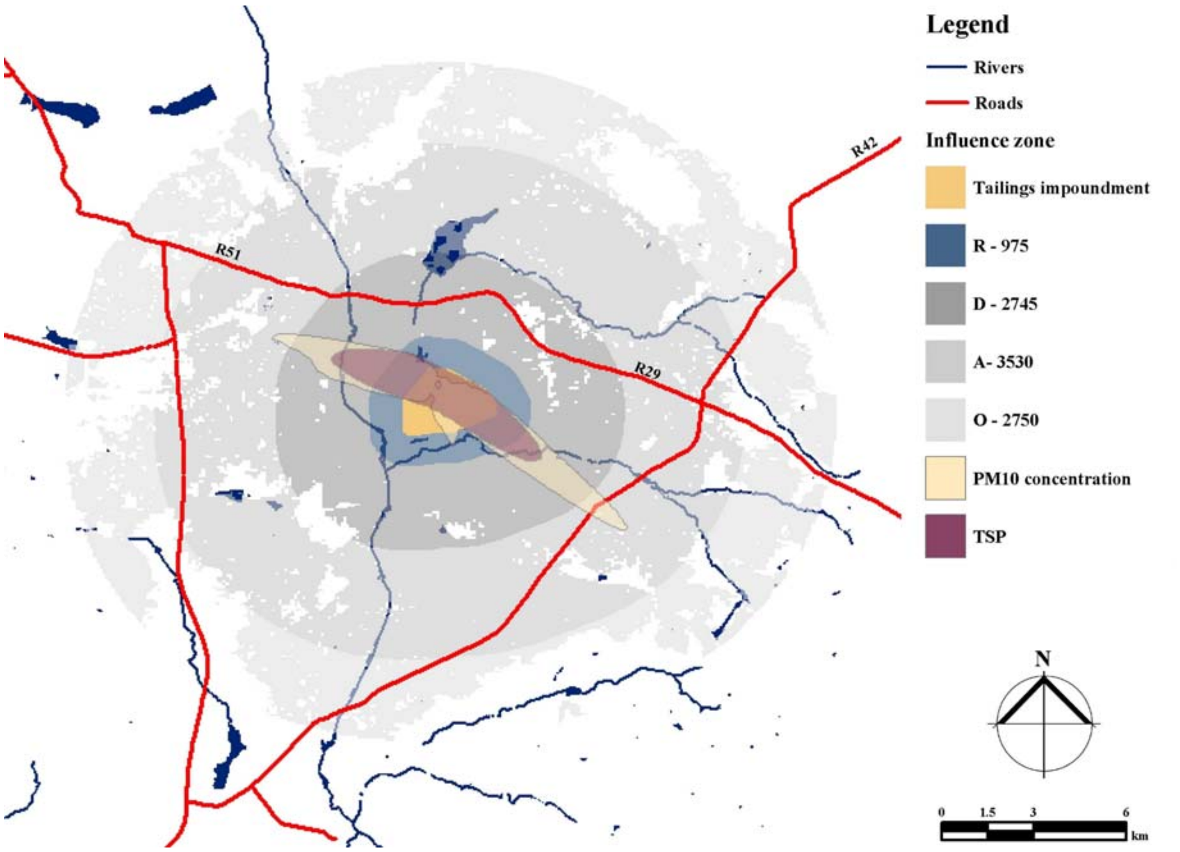

Figure 199: Sphere of influence for the impoundment scenario with a grassed armouring cover.

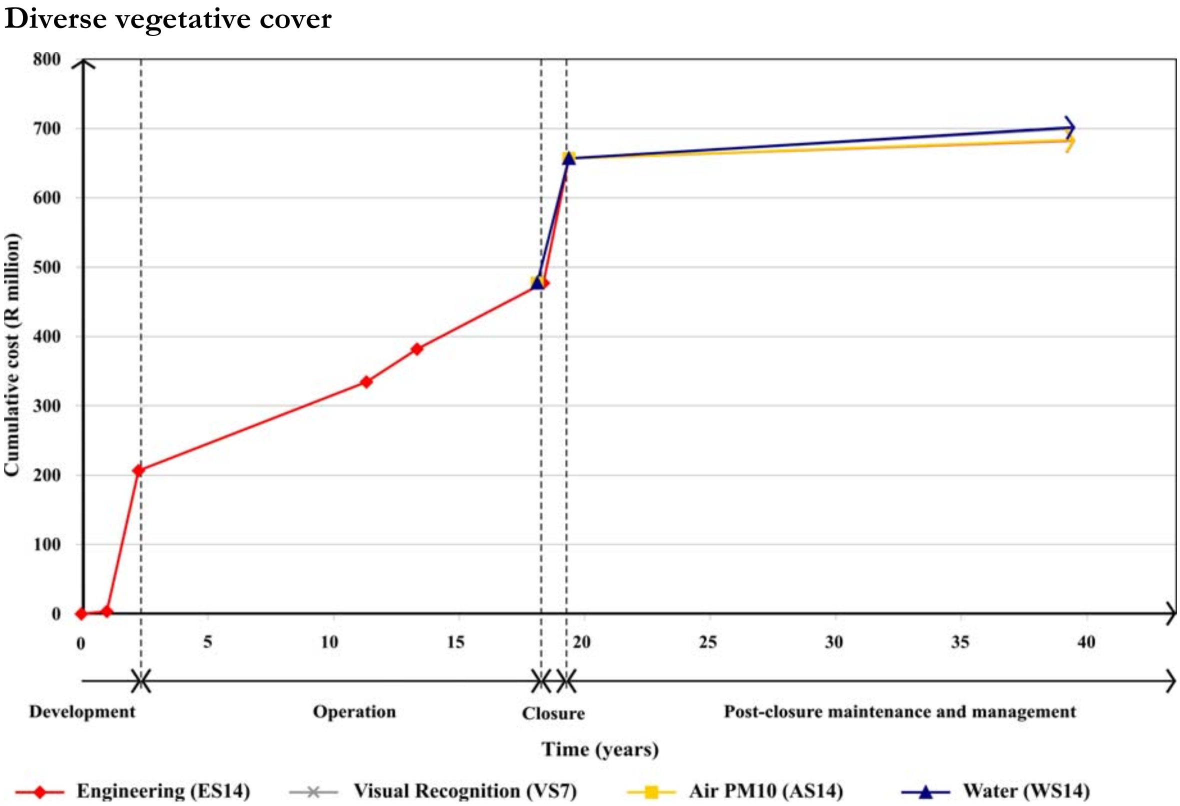

Figure 200: Total environmental and engineering costs for a diverse vegetative cover.

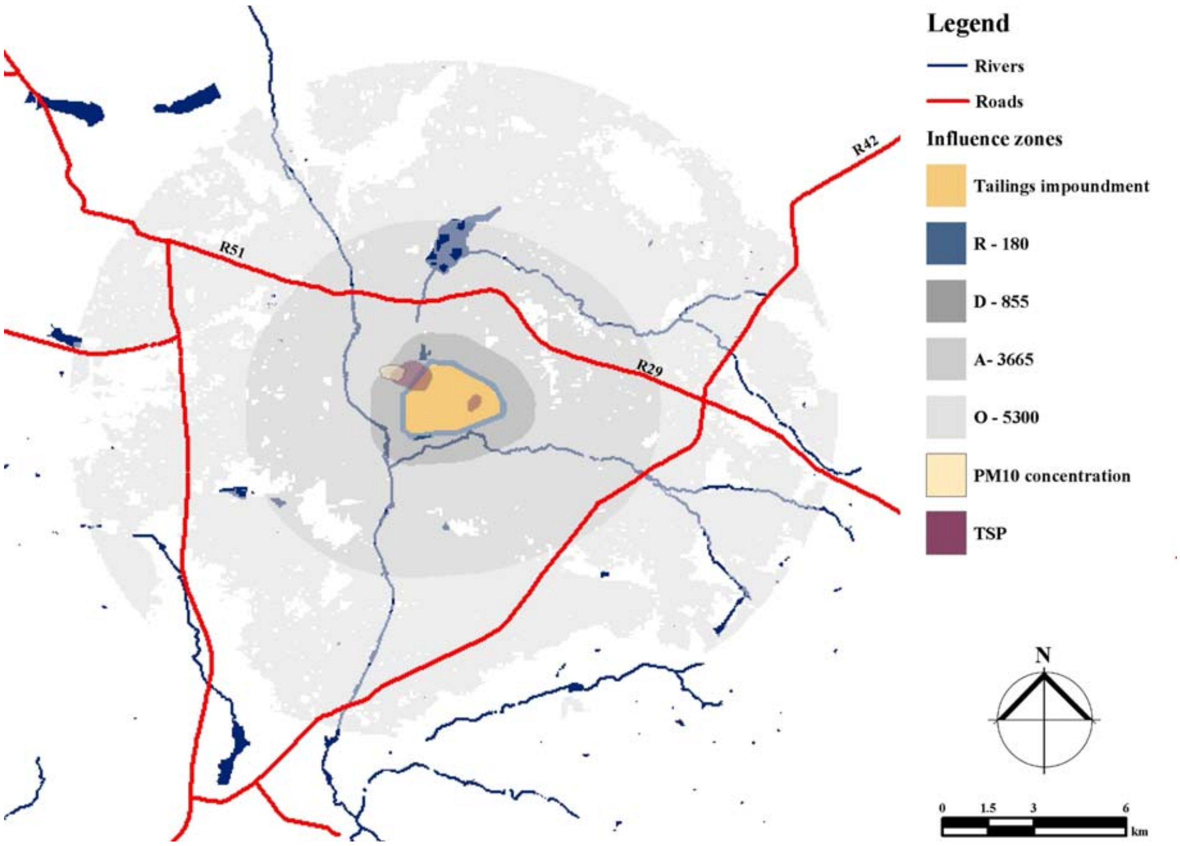

Figure 201: Sphere of influence for the impoundment scenario with a diverse vegetative cover.

6.4 Total integrated environmental impact costs and engineering costs

The total integrated cumulative environmental costs and engineering aspect costs for the configurations modelled are given in Table 74, Figure 202 and Figure 203 (p. 313). Figure 203 graphically illustrates the life-cycle integrated environmental and engineering costs for the different tailings impoundment cover types.

Table 74: Total integrated cumulative environmental and engineering aspect costs.

	Impoundment cover costs (R million)			
Cost item	**No cover**	**Rock**	**Grassed armouring**	**Diverse vegetation**
Total engineering cost	**509**	**543**	**555**	**683**
Construction and operation	477	477	477	477
Closure	6	40	52	180
Aftercare and maintenance	26	26	26	26
Total environmental cost	**344**	**339**	**193**	**40**
Visual recognition	245	297	122	17
Air PM_{10}	65	0	41	1
Water treatment SO_4	34	42	30	22
Total cost	**853**	**882**	**748**	**723**

The total engineering costs for the impoundment cover scenarios are R510 million (no cover), R545 million (rock), R555 million (grassed armouring), and R680 million (diverse vegetation). The engineering cost includes the costs for closure and standard practice maintenance. The total environmental costs for the same scenarios are R345 million (no cover), R340 million (rock), R190 million (grassed armouring), and R40 million (diverse vegetation) over the 20 year aftercare and maintenance period. It is interesting that although the initial diverse vegetation engineering cost is about R175 million more expensive than that of doing nothing, the total cumulative environmental cost after 20 years is almost R300 million less. The total environmental cost and engineering cost for this scenario over the life of the tailings impoundment is R130 million less than that of doing nothing. Similarly the grassed armouring may initially cost R45 million more than doing nothing at closure, but at the end of 39 years the total cost would be R110 million less than that of an impoundment with no cover.

By integrating the environmental aspect costs with the engineering aspect costs it is possible to make rational decisions as to the costs and benefits pertaining to post-closure land use and how the impoundment configuration is likely to impact on the environment over the life of the facility.

The comparative data for the various covers can be used to inform decision making pertaining to the configuration of tailings impoundments. Depending on the impoundment locality and the sensitivity of the receiving environment resources, decision makers can decide as to what alternative would least impact the environment and at what cost. It is not a given that the lowest total cost option may be the preferred option as a site may be located in a declared air quality management area which requires that no additional particulates can be released into the air as a result of the existing high ambient PM_{10} concentrations.

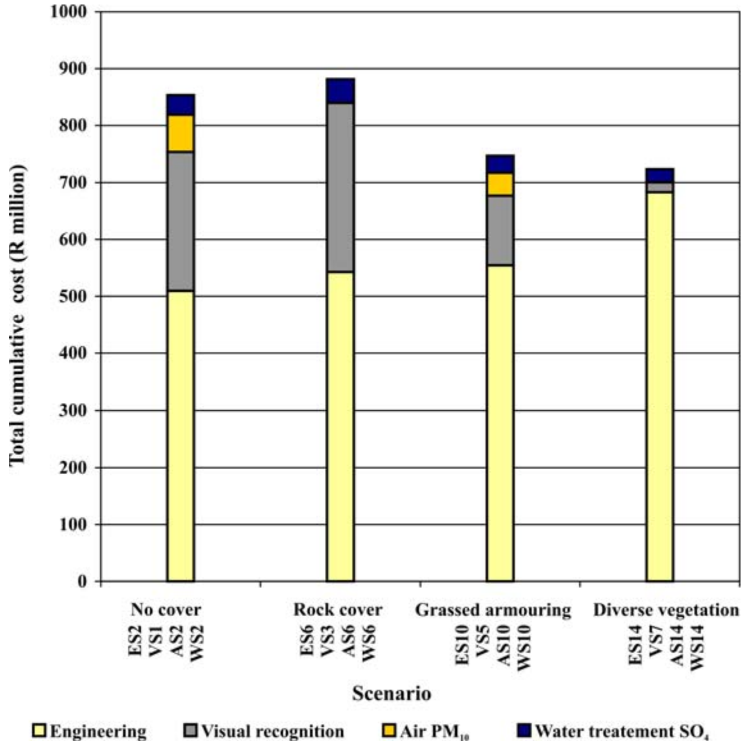

Figure 202: Total integrated cumulative costs for the various impoundment covers modelled.

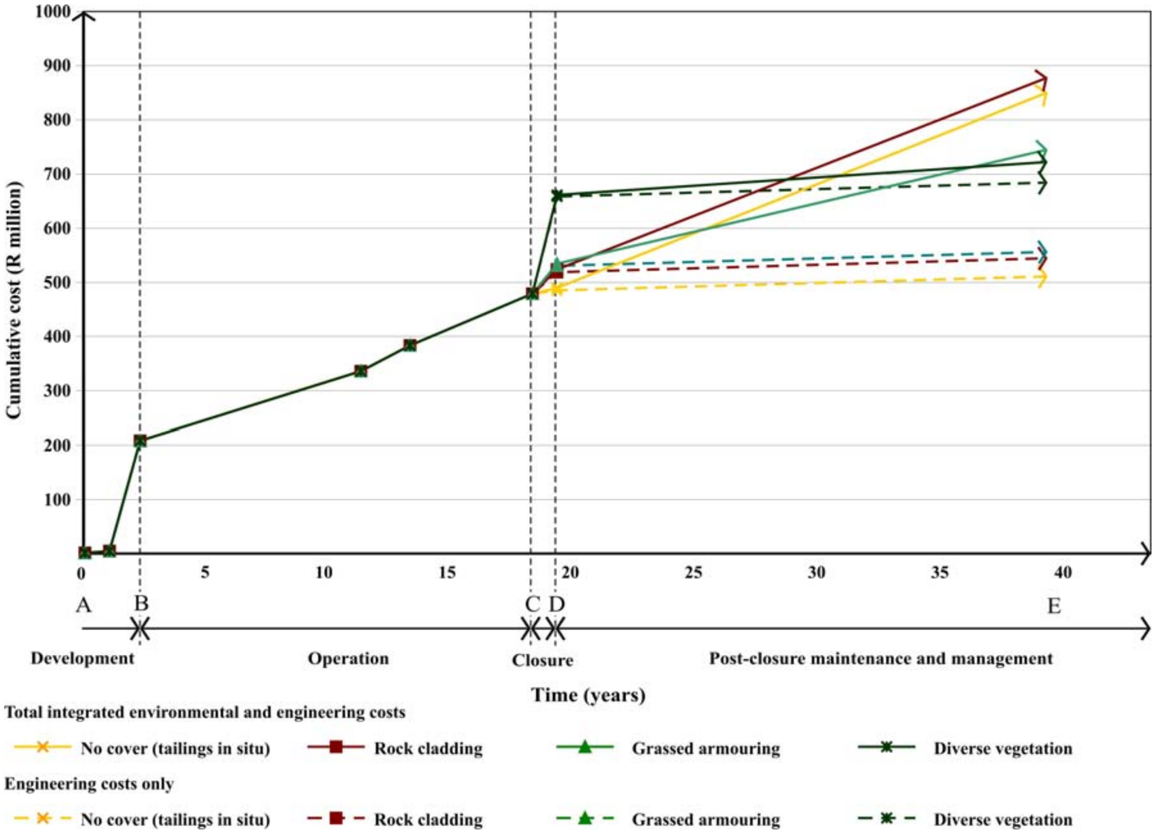

Figure 203: Total integrated environmental and engineering life-cycle costs for the different cover types modelled. The dashed lines indicate only the engineering costs whereas the solid lines are the total integrated environmental and engineering costs.

By covering the impoundment with rock it could probably be argued that post-closure dust will be effectively eliminated. This however comes at the highest total cost of R880 million. Similarly if an impoundment is in proximity to sensitive viewers such as discussed in the previous case study, it may be required to cover the impoundment with a diverse vegetation cover at an initial additional closure cost of R175 million but surprisingly at the lowest total cost of R720 million. The end result is that real environmental impact costs are added to the engineering costs for the closure and post-closure stages of the tailings dam development. This is illustrated by the following environmental and engineering cost model equation.

	Stage of tailings impoundment construction			
	Development[1]	**Deposition**	**Closure**	**Post-closure**
Engineering cost =	Eng cost AB +	Eng cost BC +	Eng cost CD +	Eng cost DE
Visual perception impact cost =	Eng cost AB +	Eng cost BC +	**VPI CD +**	**VPI DE**
Air quality impact cost =	Eng cost AB +	Eng cost BC +	**AQI cost CD +**	**AQI cost DE**
Water quality impact cost =	Eng cost AB +	Eng cost BC +	**WQI cost CD +**	**WQI cost DE**
Total cost AE =	Eng cost AB +	Eng cost BC +	**Total cost CD +**	**Total cost DE**

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

The total costs associated with the tailings impoundment can be used in the overall financial feasibility of a new mine by using the costs in a parallel equation which evaluates all other impacts, both negative and positive.

The graphical nature of the spatial representation of the environmental aspects provides a useful tool to communicate the possible extent of the environmental sphere of influence. This can be used to inform future strategic land development objectives and it can be used to pre-empt possible areas of land use conflicts (Figure 204).

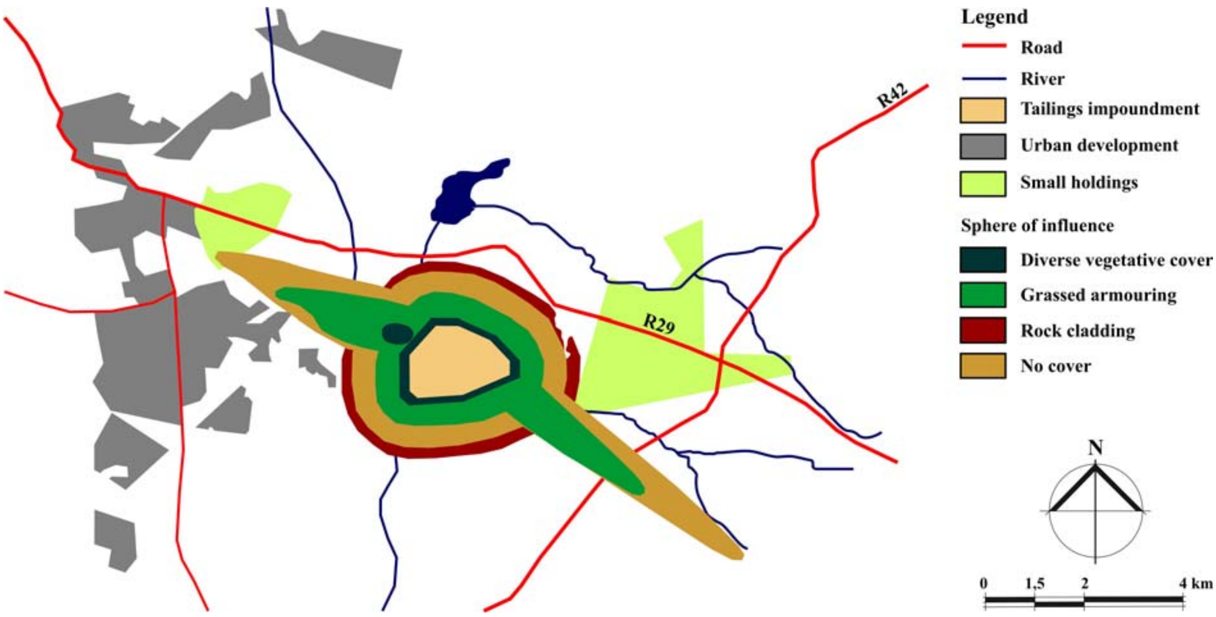

Figure 204: Combined visual perception and air quality environmental influence zones for the various impoundment covers modelled illustrating the change in possible impact zone as a result of change in impoundment design.