CHAPTER FOUR: RESULTS

4.1 Introduction

The previous section in the thesis describes the methods, technologies, and models used to predict and quantify the:

- visual perception zone of influence;
- air quality zone of influence; and
- change in mass flux and the impact on water quality.

The visual modelling required the determination of visual perception distances for various slope and cover configurations. It is however necessary to analyse the results and present such results to a panel of experts in order to reach consensus that what was predicted is typically what will be observed in the field. Details on the analysis of the visual perception distance results are provided in Section 3.4.9, followed by a description of the field work undertaken to apply the predicted results to the ERGO Daggafontein site. One of the overall objectives of this study is to identify elements for each of the key environmental aspects which can be either modelled or measured in order to quantify the possible change in environmental influence resulting from the change in impoundment configuration. The elements quantified for the key environmental aspects in this study are listed and summarised in Table 53. Lastly, the section presents the results from the quantification of the environmental aspects. Visual and air quality zones of influence are modelled, mapped and measured and the water quality change in sulphate mass flux predicated and quantified.

Table 53: Quantifiable elements for the various environmental aspects.

Environmental aspect	Description of quantifiable element
Visual	Recognition, detection and awareness visual perception distances are used along with zone of visual influence mapping to determine surface areas of influence. The visual perception area of influence results can be expressed in hectares (Figure 148, p. 252).
Air	Upon calibration of the predictive models both the dustfall (TSP) and concentrations of particulates in the air (PM_{10}) can be modelled, mapped and surface areas of influence determined. The air quality influence area results can be expressed in hectares (Figure 150, p. 254).
Water	An analytical model is described and used to quantify the change in sulphates for the various configurations. Although the technology exists to model the dispersion and zone of influence in three dimensions, it was decided that it is sufficient to calculate the increase or decrease in load for the various configurations. However, a steady-state groundwater flow and sulphate transport simulation was undertaken (Figure 153, p. 258) to determine the anticipated zone of influence and illustrate that it can be expected that the Blesbokspruit and one of its tributaries will capture most of the surface water runoff and discharge to groundwater.
Soil and landform	Best practice requires the construction of stormwater control structures to contain dirty water runoff from embankment side slopes. Although this is an important aspect, especially in terms of the long term stability of side slopes, exact numbers for the change in load have not been quantified as a result of change in embankment configuration.

4.2 Visual perception

The following sections present the results from the Nominal Group Technique (NGT) study method which was used to rate the visualisations of different tailings impoundment configurations. The objective of the study was to express visual impacts of tailings impoundments in quantifiable terms with the purpose of including such in an overall environmental impact and engineering costing system.

The level of visual perception over viewing distance for various impoundment configurations was determined by employing the NGT study method. This technique is used as it presents researchers with a method to reach consensus on results within fields of study often considered to be subjective.

The ERGO Daggafontein tailings impoundment was photographed at various distances. The panorama photographs were manipulated to simulate the different impoundment configurations. The visualisations were presented to a panel of experts within a controlled experimental environment in accordance to steps recommended by Crance (1987).

Each scenario (impoundment configuration) is visualised from different viewing distances. This is done in order to determine the relationship between visual perception and distance. For example, the grass covered 1:3 side slope scenario was visualised at 6 distances ranging between 1000 m to 8200 m (Table 54).

Table 54: Typical scenario descriptions for impoundment with a 1:3 side slope and grass cover.

Slope	Cover	Season	Distance (m)	Reference code	Visualisation reference number	Visualisation slide sequence
1:3	Grass	Summer	2000	2000SG3	10	33
1:3	Grass	Summer	3000	3000SG3	16	46
1:3	Grass	Winter	1000	1000WG3	5	17
1:3	Grass	Winter	3600	3600WG3	21	15
1:3	Grass	Winter	7200	7200WG3	27	58
1:3	Grass	Winter	8200	8200WG3	32	3

S denotes summer W denotes winter G denotes grass

Figure 128 and Figure 129 presents the initial results from the individual experts' ratings before discussion and reaching consensus. Figure 128 presents the initial results from the individual experts' ratings for the visualisation of an impoundment with an overall embankment side slope of 1:3 and which is covered with grass whereas Figure 129 presents the results of an impoundment with the same slope but not covered (tailings in situ). Figure 128 shows 33 diamond-shaped result points and Figure 129 indicate 22 points. Although the figures only show 33 and 22 results respectively they represent 72 results each time. There are 12 panellists and 6 distances visualised which provides a total of 72 results presented in each figure. The reduced number of points are, as could be expected, the consequence of an overlap of some of the points which results from experts giving the same rating to the visualisations.

Each visualisation was projected and discussed until consensus could be reached on the rating for each visualisation. The diamond-shape points on Figure 130 and Figure 131 show the consensus results for the same visualisation plotted in Figure 128 and Figure 129 after discussion amongst the experts and consensus has been reached by the panel.

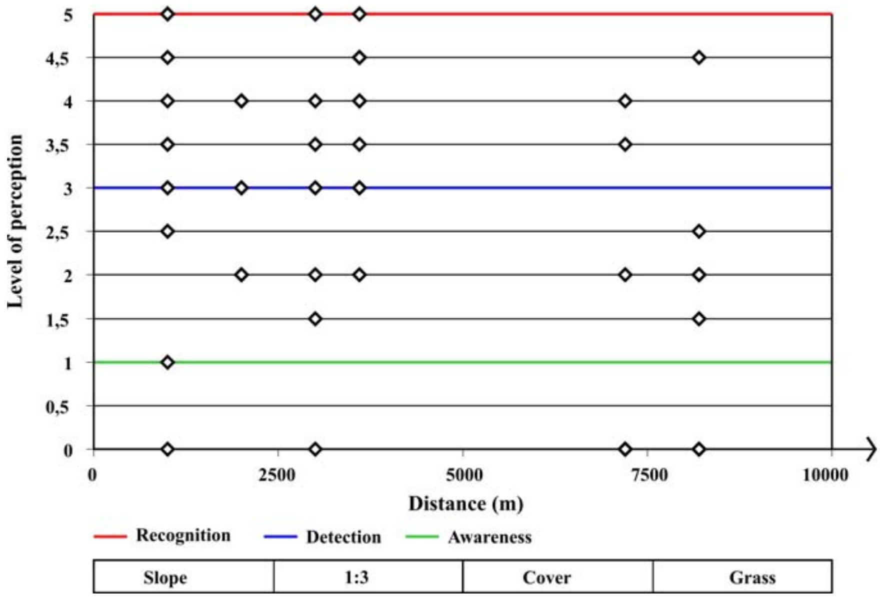

Figure 128: Initial results of all participants for the grass covered 1:3 side slope scenario.

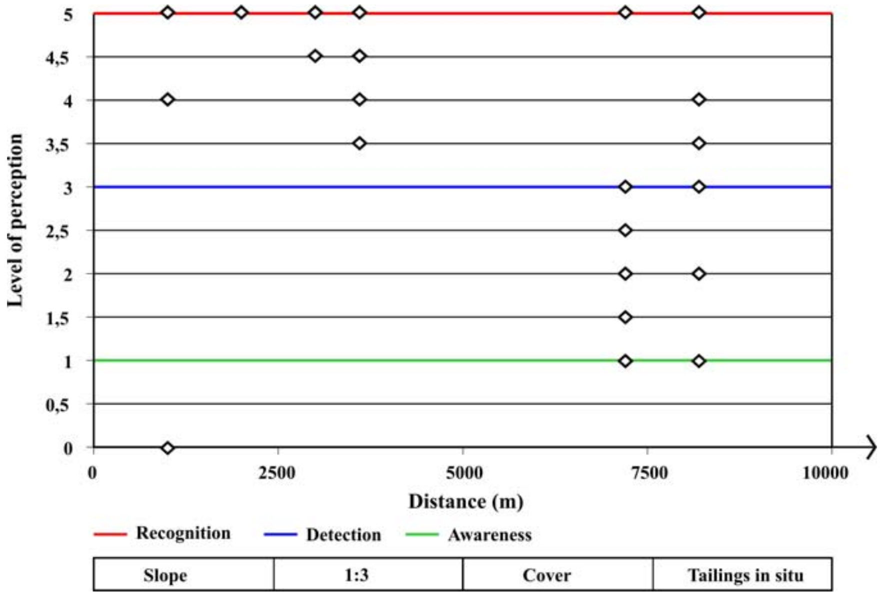

Figure 129: Initial results of all participants for the tailings in situ covered 1:3 side slope scenario.

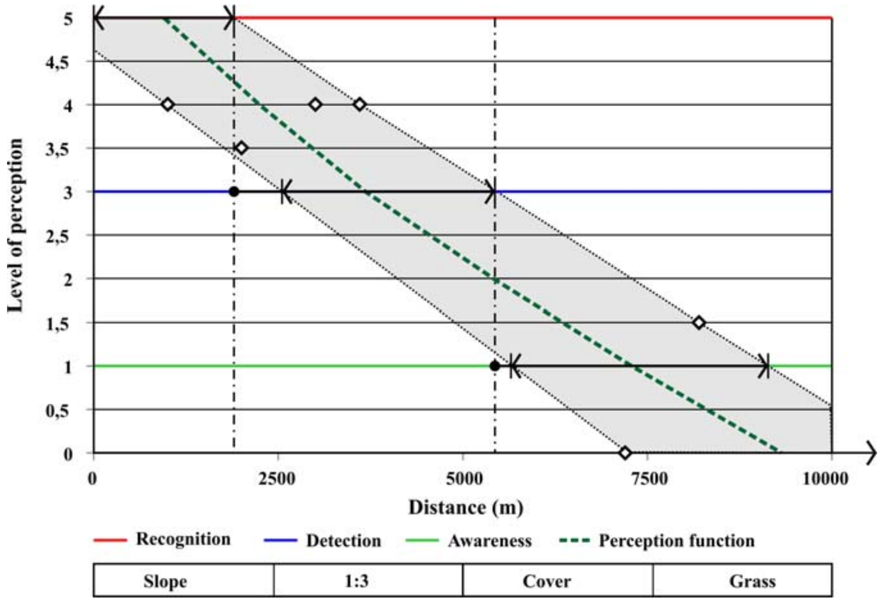

Figure 130: Consensus results and envelope indicating the range of perception level distances for the grass covered 1:3 side slope scenario.

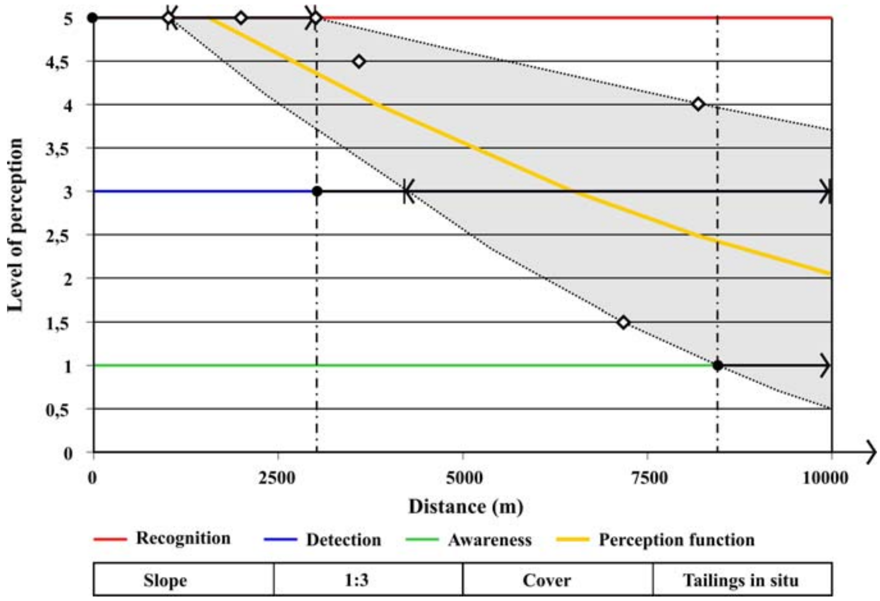

Figure 131: Consensus results and envelope indicating the range of perception level distances for the tailings in situ covered (no cover) 1:3 side slope scenario.

The expert consensus results of the scenario, once enveloped, are shown as an envelope which follows the obvious rational trend that the perception levels are a direct function of the viewing distance. The outer limit consensus results envelope indicates the range of the probable minimum and maximum distances for each perception level.

This approach allows for expected variance resulting from aspects such as:

- differing external environmental factors;
- the reliability of each visualisation; and
- the notion that perception thresholds are rarely an absolute event.

The vertical dashed lines in Figure 130 indicate the outer limit of each maximum perception level distance range and also indicate the starting viewing distance for the following perception level range. A perception over viewing distance envelope and function could be determined for each of the eight scenarios defined in Table 21 (p. 162).

Visual perception distance functions were determined and composed by plotting trendlines through the mean values of the perception ranges such as described by Schroeder (1984:573). The consensus mean visual perception distance functions for all of the scenarios are presented in Figure 132.

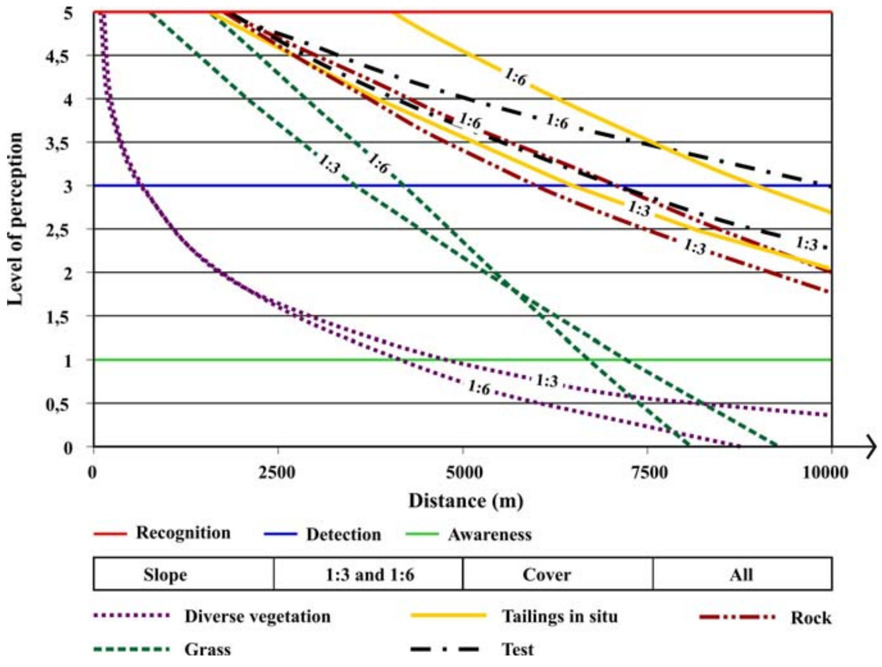

Figure 132: Mean perception over distance functions for all scenarios.

The results presented in Figure 132 were shown to the panel of experts in order to reach agreement as to the findings of the first round of the Nominal Group Technique (NGT) study process. The presentation process of the findings to the panel of experts is discussed in the following section, Section 4.2.1.

4.2.1 Validation of results

The visual perception distance results in Figure 132 were analysed and presented at another seminar to the same group of experts. This was the second and last round of the NGT. The last round of the NGT was a closing seminar at which the results were presented to nine experts and evaluated (Appendix A.1 includes the particulars of the participants). In this part of the study active participation of the experts were crucial.

The objectives of the follow-up session were to:

- discuss the results from the previous round;
- note observations; and
- reach consensus on the:
    - overall experimental procedure;
    - interpretation of the consensus results derived from the first round;
    - application of the results in the field at the ERGO Daggafontein impoundment;
    - ratings of the photographs taken from predicted view points;
    - possible research gaps; and
    - opportunities for future research to be undertaken.

A copy of the slide presentation to the experts is included in Appendix A.3. The application of the interpreted consensus results has not been discussed and requires some discourse. The ERGO Daggafontein tailings impoundment was used to check the reliability of the predicted results.

Although the impoundment was previously photographed and used in the determination of the visual perception distances for various impoundment configurations it was not considered to be a problem applying the results to the same impoundment in the field confirmation exercise as:

- the ERGO Daggafontein impoundment was used to isolate photorealistic textures at the various distances, applying these to the entire impoundment surface; and
- completely different sightlines and viewing distances as what were used in the visual perception distance study were used in the testing of the results.

Applying the results in the field entailed compiling a map (Figure 133, p. 239). The map indicates:

- The zone of visual influence (the locations from which the scheme us visible) which was determined by means of a GIS software package developed for this purpose. The areas shaded in light green presents the surface area in the landscape from which the impoundment is visible.
- The mean visual perception distance values for a 1:3 slope and impoundment covered in grass. This was used for reference purposes, provided scale, and provided general orientation while in the field. The visual perception distance plots also helps to identify candidate points to photograph the ERGO Daggafontein impoundment from.
- Suitable candidate photographing points are indicated on the map. These are determined by overlaying the information on an aerial photograph as well as considering access to the points from which to take the panoramic photographs.

Once the map was compiled another visit to the surrounding landscape was organized during which photographs were taken from the points indicated on Figure 133, p. 239. The base map, prepared prior to further field work, assisted in finding suitable photographing points providing unobstructed views of the ERGO Daggafontein tailings impoundment. The co-ordinates of the viewpoints were captured using a GPS and were used to prepare the map presented in Figure 133.

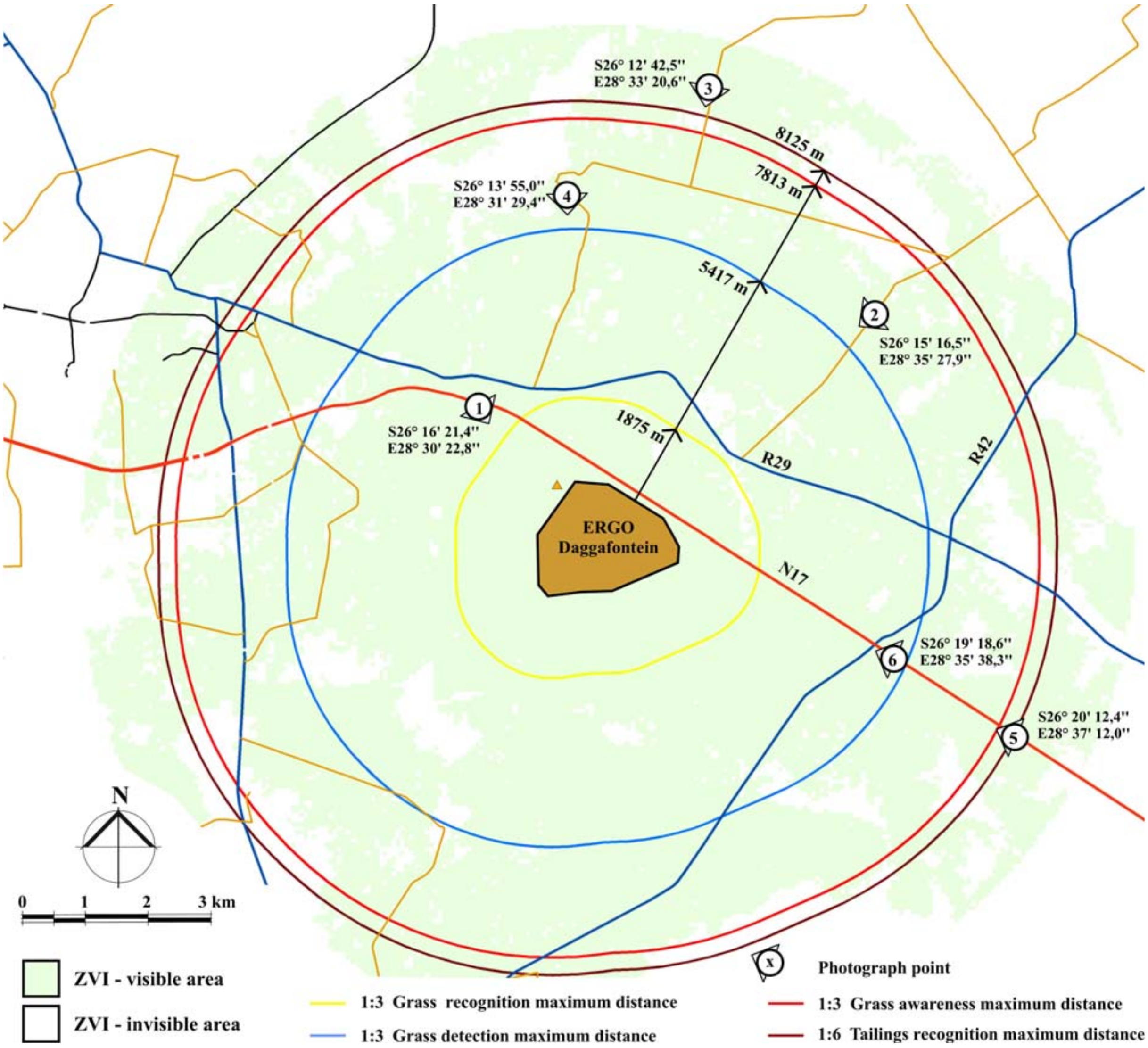

Figure 133: ERGO Daggafontein visibility map indicating photographing points.

Panorama photographs of the ERGO Daggafontein tailings impoundment were taken from six photographing points, stitched, cropped, adjusted to true viewing height, and presented to the panel for further discussion.

Discussions of the panoramic photographs provided information pertaining to:

- what the panel observed;
- the level of perception for each view;
- what could be perceived and whether the impoundment was detectable or recognisable from that particular viewing distance; and
- the factors contributing to the level of perception for each panorama photograph.

The black rectangular boxes on the following images indicate the visible sections of the panorama photographs which were shown to the panel in the slide show. The size of the images on the screen relates to the apparent size of the impoundment in the landscape. Equations 31, 32 and 33 were used to adjust the size of the impoundment on the screen until it represented the true size at that specific photograph viewpoint.

Photograph 1

Effortless recognition takes place at approximately 2700 m. The white appearance of the in situ tailings causes the viewer to not only detect but also recognise the man-made landform to be a tailings impoundment in photograph 1, Figure 134.

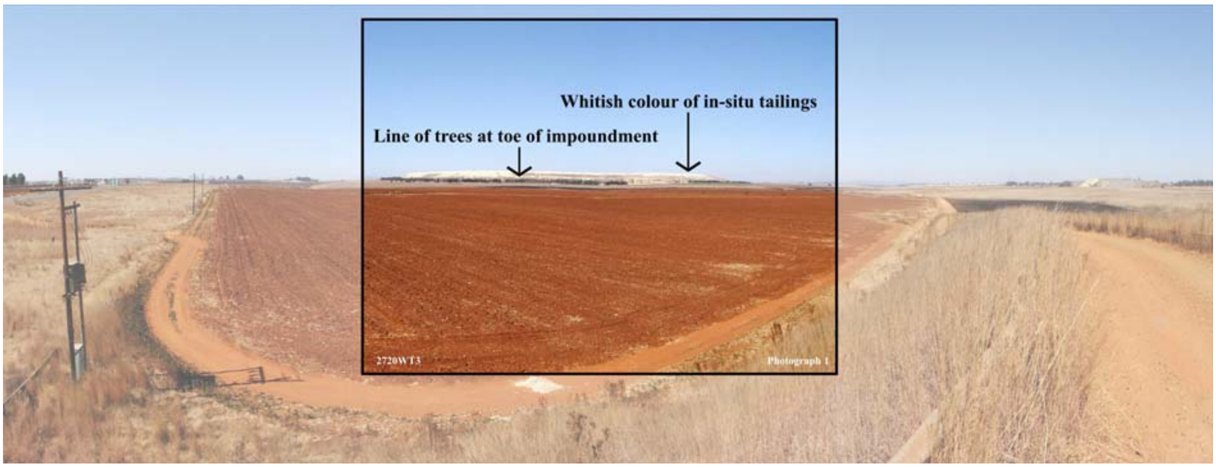

Figure 134: Photograph 1 taken at a distance of 2720 m from the impoundment presents a view of the impoundment looking in a south-easterly direction.

Two key aspects contribute to the recognition, namely the trees planted at the toe of the deposit and the colour of the impoundment's outer surface. The embankment face of the ERGO Daggafontein impoundment, shown in this view, has not yet been rehabilitated and presents a section of the impoundment that can best be described as uncovered and of which the outer surface is the in situ tailings originally deposited. The straight line of blue gum trees at the toe of the impoundment contributes to the effortless recognition of the impoundment as a result of the contrast between the trees and the in situ tailings in the background. Furthermore, it can be argued that trees planted for dust control purposes at the base of mine residue deposits are synonymous with this type of activity in the South African landscape. The whitish colour of the in situ tailings is distinctive and contrasts with the reddish colour of the ploughed land in the foreground of the photograph.

Photograph 2

The white section on the tailings impoundment allows detection to take place at 6500 m (Figure 135).

Although the man-made landform is detected in the natural landscape, it could not be recognized as an impoundment. The impoundment embankment which has been rehabilitated and covered with grass is not detectable. The rehabilitated portion of the embankment lies immediately adjacent to the left of the uncovered impoundment section

A red line is used in the image to indicate the outline of the impoundment on the horizon and arrows indicate the rehabilitated and uncovered portions of the impoundment. It therefore leads to the conclusion that if the tailings impoundment was completely covered in grass it would probably not have created any awareness and, at worst, been detectable with a great deal of effort as a man-made landform within the landscape.

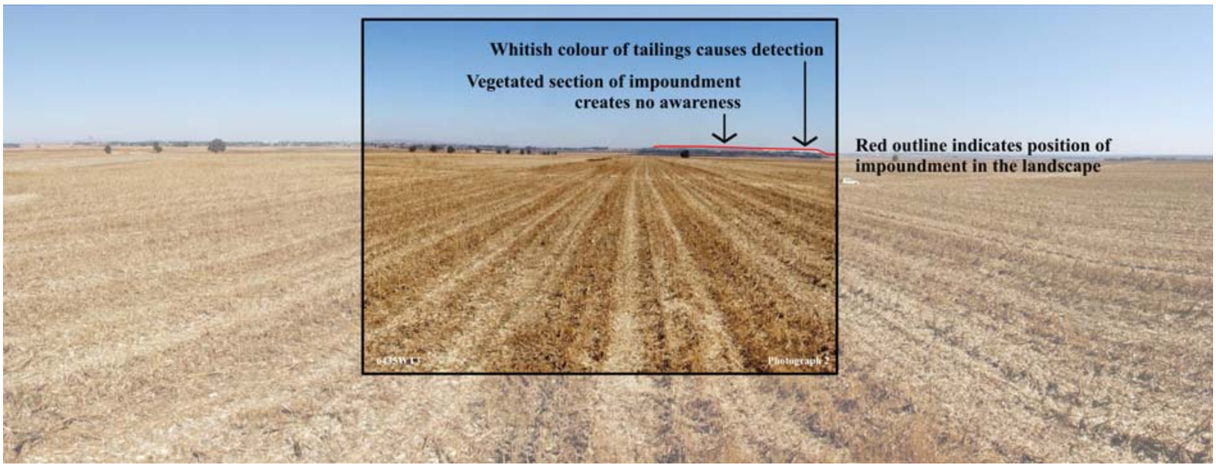

Figure 135: Photograph 2 presents a view at 6435 m of the impoundment looking South.

The results presented in the previous section indicate that one could expect detection to take place up to and exceeding distances of 10 000 m if an impoundment is left uncovered. Also, the results indicated that should the impoundment have been covered with grass that it would not have been detectable. The limit of the detection distance in the visual perception study was given as 5417 m. The distance at which this photograph was taken is just more than 1000 m further at a distance of 6435 m.

Photograph 3

Similar to photograph 2 the white section in photograph 3 (Figure 136), characteristic of uncovered tailings, leads to detection whereas the portion which has been grassed does not even create awareness. The uncovered section of the impoundment is indicated with an arrow on the right in the photograph while the grassed section is on the left. It is expected that an uncovered tailings impoundment will be detectable from distances of about 7800 m and even up to and exceeding distances of 10 000 m.

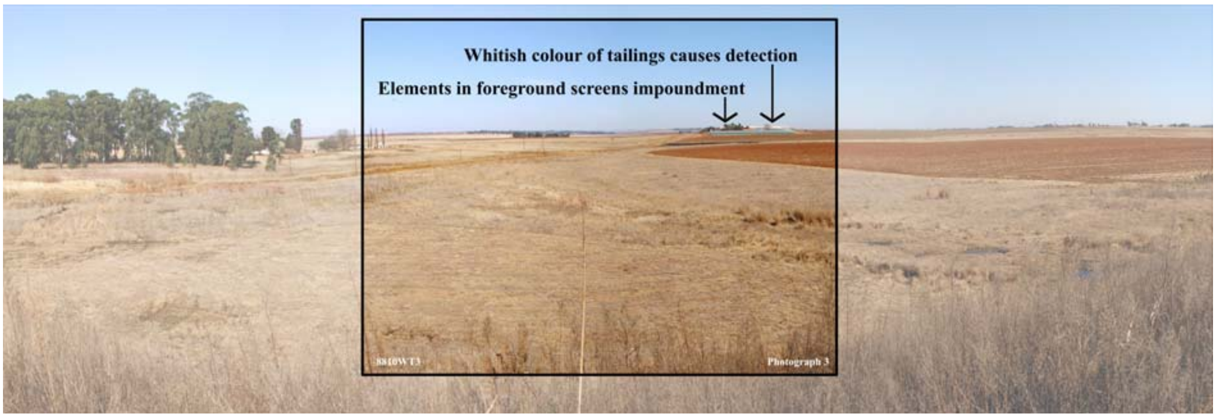

Figure 136: Photograph 3 is a view from 8810 m looking South towards the impoundment.

Photograph 4

Photograph 4, Figure 137, presents the same view at the same distance of two different covers on the impoundment with the grass cover creating no awareness and the tailings in situ leading to detection.

The impoundment is recognizable but with effort at approximately 6200 m as the visible embankment of the impoundment has not been grassed. The in situ tailings cover results in easy detection as a man-made landform in the landscape and although recognition takes place, it is with considerable effort. The results provided a distance of between 4700 m and 6100 m at which one can expect recognition with difficulty to take place.

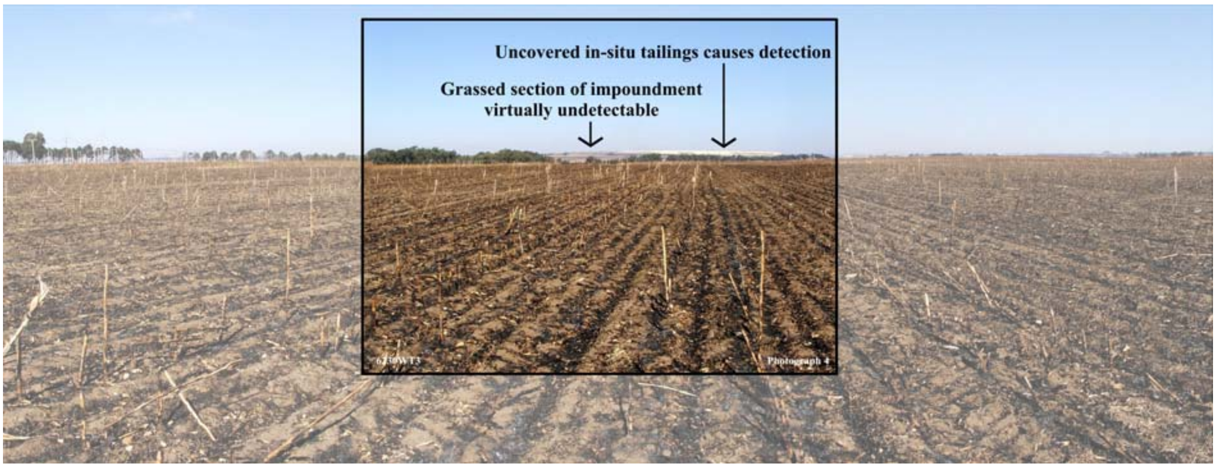

Figure 137: Photograph 4 was taken from 6230 m looking in a southerly direction towards the impoundment.

Photograph 5

No awareness takes place at 8190 m (Figure 138). The impoundment embankment viewed in the photograph is completely rehabilitated and covered in grass.

Figure 138: Photograph 5 was taken looking northwest towards the impoundment at a distance of 8190 m.

The results indicate that awareness is likely only to take place from distances of up to and less than 7800 m. The 8190 m distance is outside this limit and would therefore appear to support this finding. The view angle relative to the impoundment is such that the sides of the impoundment are seen as several surfaces with various textures and colours. From this viewing angle, what may look like a very flat embankment side slope, is in fact, the impoundment sides that disappear into the background.

Photograph 6

A foreign landform is detected in Figure 139, but with effort. This view of the impoundment is similar to that shown in photograph 5, but 3000 m closer.

Figure 139: Photograph 6 was taken towards the a northwest view of the impoundment at a distance of 5150 m.

The panel concluded that there is almost no detection of a foreign landform in the landscape from this distance. This is probably as a result of the effective grass cover on the visible section of the impoundment, the intensity of the light, and the angle of the sun. The photo point is within the expected detection zone. However, due to the reasons mentioned, it is difficult to detect the landform as being foreign.

4.2.2 Observations

The results in Figure 132 (p. 237) were presented to the panel of experts for discussion and input. General consensus was reached that the experimental procedure was sound with a logical progression in methodology combining elements of qualitative as well as quantitative research methodologies. It was observed that a clear distinction between the perception levels for the various covers is apparent.

The background and foreground play an important role and in certain instances can play a more significant role than the cover of the impoundment. Similarly the context and setting of the impoundment can contribute more to the level of perception than that of slope and cover. It can be expected that the horizon plays an important role.

Where the impoundment is below the horizon and has the natural landscape as backdrop it will be more difficult to detect the foreign landform especially if there is very little difference in colour and texture of the element in the foreground (tailings impoundment) and the background (natural landscape).

The visual impact of an object is also a function of the size. It was discussed that the shape and footprint of an impoundment could influence the ability to blend an impoundment into the surrounding landscape as it was argued that nature does not have straight lines. The sharp corners at the intersection between the flat top and the side slopes are unnatural and contribute to the recognition process.

The straight line of trees planted at the toe of the tailings impoundment to screen and control wind erosion is typical of mine residues in the South African landscape and is an element that contributes to recognise a man-made landform as a mine residue deposit. There are many examples where trees are planted to screen schemes visually and control wind erosion. Using trees to screen an object from sensitive viewers is a function of the viewer relative to the object being screened. The contrast in colour between the darkish tree planting at the toe of the deposit and the light coloured tailings in the background contributes significantly to the recognition process and exacerbates the problem. In many cases the impoundment height will exceed the tree tops two-fold, three-fold and, in certain instances, even more. A screen, whether tree planting or any other method, can be positioned in such a manner that it is most effective in fulfilling the intended task of screening sensitive viewers, view-points, or viewing zones from a scheme (Figure 140).

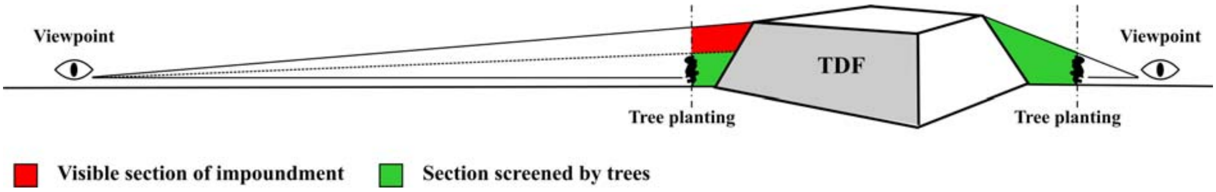

Figure 140: Using tree planting as screening of impoundments.

This research does not test the response or attitude of the viewer to the stimulus. It could be expected that a tourist in a game park will respond differently than a worker in a light industrial area, should both parties be able to recognize a man-made landform as something foreign and out of place. Landscape management zones are important as it controls and manages the types of developments that can or cannot take place within these zones. In certain instances money can maybe more wisely spent by finding sensitive viewpoints within the visual zone of influence and managing such, rather than trying to camouflage the entire impoundment by covering it with grass.

4.2.3 Visual perception results

The results are indicated in envelopes (Figure 130 and Figure 131, p. 237) with the upper and lower results delineating the outer boundaries thereof. When comparing the visual perception distance consensus ratings of the expert panel with the panorama photographs the following becomes apparent:

- The bright colours typical of the in situ tailings surface are better detected over the darker colours of the grass cover contributing to the visibility envelope falling in the perception and detection over further distances.
- The shape of the impoundment in terms of geometry, complexity, and orientation plays an important role in the stimulus, detection and recognition process. Some of the respondents felt that the flat top surface of an impoundment contribute significantly towards the recognition - especially at considerable distance from the impoundment.
- The visual angle and position of the sun, for example illumination, causes a variance in perception of the visualisations.
- The outline of the impoundment (silhouette) creates the initial awareness especially when there is sufficient contrast with the existing terrain.
- It was observed that some of the simulated textures such as the diverse vegetation covers were, maybe, not exactly what would be observed in natural conditions. The diverse vegetation texture, especially at background distances, is an aggregate of small combinations of shapes and colours forming continuous superficial configurations. It was difficult to simulate these accurately for some of the scenarios.

- The scale of the impoundment, that is the relation between the impoundment and its environment, contributes to the impoundment being recognised from far away.
- Tailings impoundment embankment slopes have less of an influence on perception than covers. It appears that the most significant change is brought about changing the impoundment cover.
- Covers contribute significantly towards camouflaging an impoundment, that is its ability to merge the man-made landform with the landscape, is demonstrated in the bar charts (Figure 141 and Figure 142).

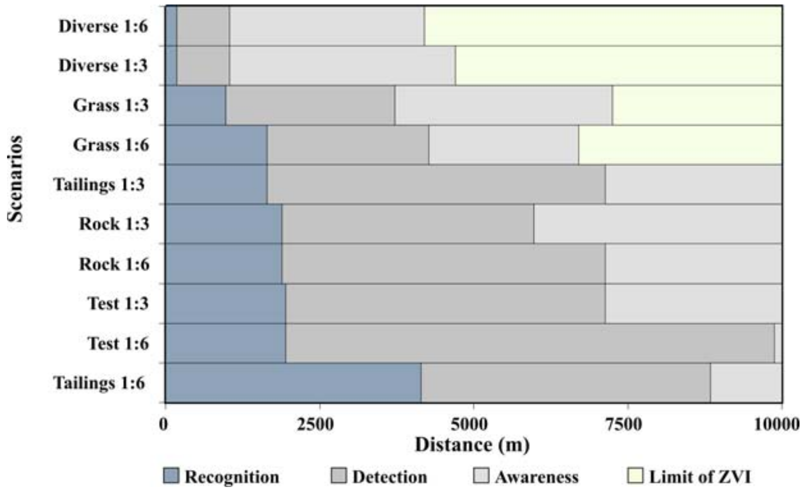

Figure 141: Mean visual perception distances for the scenarios visualised is stacked according to the increase in visual recognition.

When viewing the mean (Figure 141) and maximum (Figure 142) visual perception distance bar chart results it is apparent that for all of the covers (but the tailings in situ cover) the overall side slope has very little effect on visual perception distances.

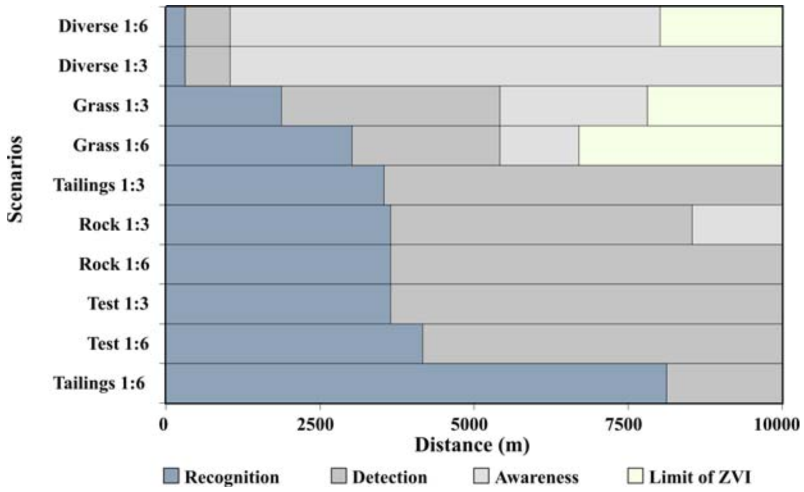

Figure 142: Maximum visual perception distances for the visualisations. The results are arranged according to the increase in visual recognition.

The difference in the maximum distance results between Tailings 1:3 and Tailings 1:6, represented in the bar chart (Figure 142), deserve some comment. Slide 10 (Figure 143) was used to visualise an impoundment with an overall embankment slope of 1:6 at a distance of 8200 m with no cover (tailing in situ). This slide can be compared to the slide which was used to visualise an impoundment with the same cover but with an overall embankment slope of 1:3 (Figure 144).

Figure 143: Visualisation of a view at a distance of 8200 m with an overall embankment of 1:6 and with no cover.

Figure 144: Visualisation of a view at a distance of 8200 m with an overall embankment of 1:3 and with no cover.

Both slides are visualisations of what an impoundment will look like from 8200 m if no cover is applied (tailings in situ). The only difference is the overall embankment side slope. When looking and comparing both these slides it is doubtful that an impoundment can be recognised in either of the slides. On the contrary, it is more likely that a man-made landform is detectable, albeit with effort, in the natural landscape. When the impoundments are seen in context of the full panorama photograph, that is a photograph taken of the 124 ° human binocular field of vision, it is even less likely that the impoundment will be recognisable within the landscape. The experiment projected views, although at the right scale, on a computer screen and did not show the entire panorama photograph due to the limitations of the computer screen width. The portion of the visualisation which was shown to the panel of experts during the experiment is indicated by the black frame in the figures. Although there is some variance in the perception distances when comparing embankment slopes for the same covers (Figure 141, p. 245) 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. The curves on Figure 145 (p. 247) are simplified representations of the results presented in Figure 132 (p. 237) after determining the average between the 1:3 and 1:6 slope curves.

Table 55: The following mean perception distance values were used for combined slopes.

	Diverse	Grass	Rock	Test	Tailings in situ
Recognition	180	1310	1890	2890	1950
Detection	1350	3230	6555	7990	8510
Awareness	4450	6975	-	-	-

The modified representation (Figure 145) of the results emphasise the fact that the covers play an important role in the cognitive process of determining the levels of perception distances of an impoundment.

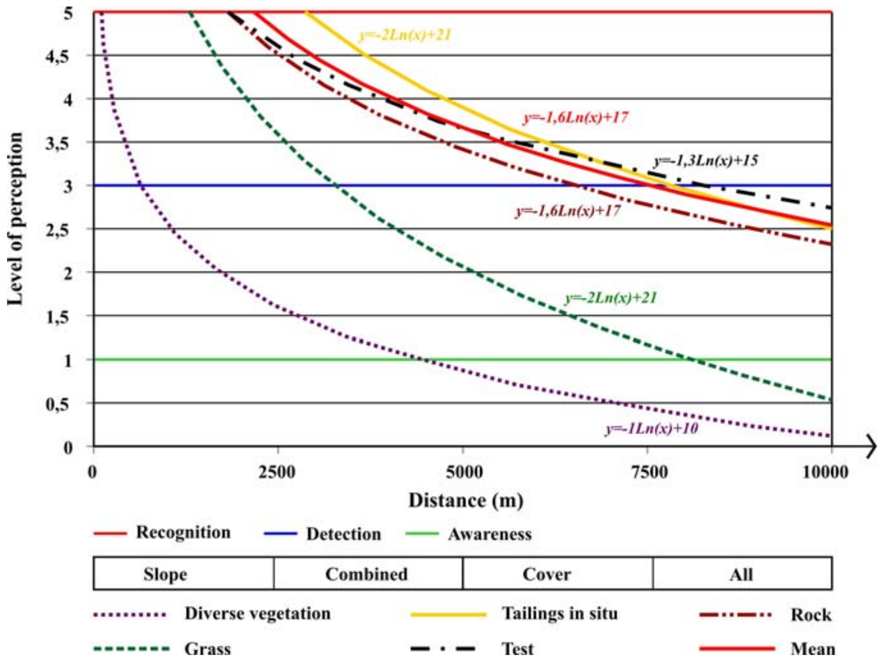

Figure 145: Probable mean visual perception functions of 1:3 and 1:6 slope data combined.

It would appear that the tailings in situ, rock and test covers fall within a similar results envelope and if simplified even further it can be represented by a mean curve indicated in the figure (solid red line). There is a definite decreasing relationship in the level of perception with the increase in distance from the object. This is not entirely surprising as there are many factors that contribute to camouflaging an object.

Some of the factors that influence the camouflaging of an object are:

- form (shape and size);
- line (silhouette);
- colour (shines, shadow and shade); and
- texture (surface);

of which the form and line are determined by the side slope and top configuration and the colour and texture are determined by the cover of an impoundment.

It is suggested in science that the intensity of radiation from a point source in three dimensional space would decline with the inverse of the square of the radial distance from the source. A line source of radiation would decline by the inverse of the distance (Armstrong and King, 1970; Sears and Zemansky, 1971).

Hull and Bishop (1987) found that there is a decreasing and non-linear relationship between distance and what they described as scenic impact. They found that a straight inverse relationship provided the best fit to quantify the results in their study. A logarithmic functional form provided the next best fit with nearly the same statistics as the inverse relationship.
However, the data presented here did not fit either the inverse of the square or straight inverse relationships. It might be that a landform is more complex than a point or line source of radiation. It was therefore decided to use a best fit trendline to represent the data in this study. The proposed equations therefore have no fundamental scientific reason to be logarithmic other than the fact that it best fits the data and could be used for interpolation.

It was not necessary to use the equations for interpolation purposes in this study as all the necessary data was directly available from the Nominal Group Technique (NGT) study process. They are useful to demonstrate the effect of different covers on visual perception. The simplified functions are given in Equations (35) to (40):

Diverse vegetation cover

$$y = -1Ln(x) + 10 \tag{35}$$

Grass cover

$$y = -2Ln(x) + 21 \tag{36}$$

Rock cladding

$$y = -1{,}6Ln(x) + 17 \tag{37}$$

Tailings in situ cover

$$y = -2Ln(x) + 21 \tag{38}$$

Test cover

$$y = -1{,}3Ln(x) + 15 \tag{39}$$

Mean of tailings in situ, rock cladding and test scenarios

$$y = -1{,}6Ln(x) + 17 \tag{40}$$

The results from the visual perception study are presented in two tables, Table 56 and Table 57 (p. 249). Table 56 presents the data of the maximum, mean and function visual perception distances measured from the edge of the impoundment whereas Table 57 presents the same results but using visual perception zone widths. Both these tables present the data for the tailings impoundment with an overall embankment side slope of 1:3.

Table 56: Maximum, mean and function visual perception distances measured from the edge of the impoundment for 1:3 overall embankment side slope.

		Distance from tailings impoundment (object) to perception threshold (m)		
		Recognition	**Detection**	**Awareness**
Grass 1:3	**Maximum**	1875	5417	7813
	Mean	975	3720	7250
	Function	1300	3241	8079
Test 1:3	**Maximum**	4167	10000	10000
	Mean	1950	7135	10000
	Function	1819	8257	37489
Tailings 1:3	**Maximum**	3542	10000	10000
	Mean	1645	7135	10000
	Function	2862	7800	21256
Rock 1:3	**Maximum**	3646	8542	10000
	Mean	1890	5975	10000
	Function	1819	6486	23132
Diverse 1:3	**Maximum**	313	1042	10000
	Mean	180	1035	4700
	Function	103	669	4341

Table 57: Maximum, mean and function visual perception zone widths for 1:3 overall embankment side slope indicating.

		Visual perception zone widths (m)			
		Recognition	**Detection**	**Awareness**	**To ZVI outer limit (10 000 m)**
Grass 1:3	**Maximum**	1875	3542	2396	2187
	Mean	975	2745	3530	2750
	Function	1300	1941	4838	1921
Test 1:3	**Maximum**	4167	5833	-	-
	Mean	1950	5185	2865	-
	Function	1819	6438	29232	-
Tailings 1:3	**Maximum**	3542	6458	-	-
	Mean	1645	5490	2865	-
	Function	2862	4938	13456	-
Rock 1:3	**Maximum**	3646	4896	1458	-
	Mean	1890	4085	4025	-
	Function	1819	4667	16646	-
Diverse 1:3	**Maximum**	313	729	8958	-
	Mean	180	855	3665	5300
	Function	103	566	3672	5659

The difference between the two data sets is that the one presents the results as distances measured from the edge of the impoundment and the other as visual perception zone widths. Figure 146 illustrates the concepts of visual perception distances and visual perception zone widths. The visual perception zone widths for recognition, detection and awareness can be used to calculate the surface areas, measured in hectares, for each perception zone respectively. This can then be used to estimate what the influence of the visual perception zones are on the receiving environment. It is likely that there will be a difference in impact when comparing the influence of an impoundment within for example the recognition and detection zones.

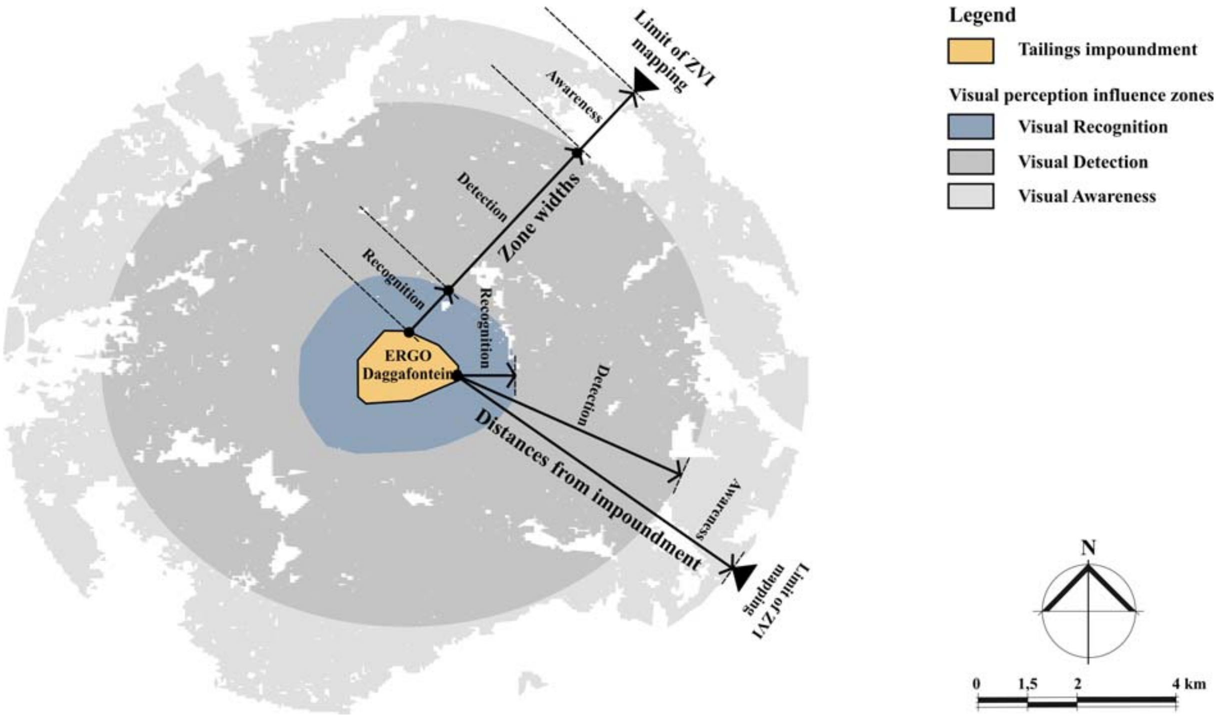

Figure 146: The conceptual illustration of visual perception distances and widths.

Comparing the mean distances of the different covers in Table 56 lead to the following conclusions:

- The diverse cover recognition perception distance is almost five times less than that of grass, and approximately ten times and nine times less than that of rock and in situ tailings covers respectively.
- The diverse cover detection perception distance is almost four times less than the grass cover, six times than the rock cladding and seven times less than a tailings in situ cover.
- The grass cover recognition perception distance is about half of that of rock, test and the tailings in situ cover recognition distances.
- The grass cover detection distance is about three times that of a diverse cover and 1,5 times less than a rock cover and almost twice less half of the tailings in situ cover.
- Leaving an impoundment uncovered (no cover, that is tailings in situ) could lead to recognition distances of 70 % further than for an impoundment covered with grass. The detection distance is 90 % further.

The diverse cover rehabilitation, should this be attainable, is by far better than covering an impoundment in grass, rock, and what could appear to be the worse-case scenario leaving it as is (not covering the in situ tailings). An impoundment covered with a diverse vegetation cover blends the most into the natural landscape.

It can be concluded that cover plays a significant role in the ability to become aware, detect and recognise a tailings impoundment. The data presented in this section is the direct result of making use of the Nominal Group Technique (NGT) study method and can be useful in describing the visual impact of an impoundment on the environment.

4.3 Visual perception zone of influence

The mean visual perception zone widths presented in Table 57(p. 249) were used to determine the visual perception zones of influence for the various impoundment configurations at the ERGO Daggafontein site. Figure 147 illustrates the graphical output generated in GIS for the impoundment configuration with an overall embankment side slope of 1:3 without any cover.

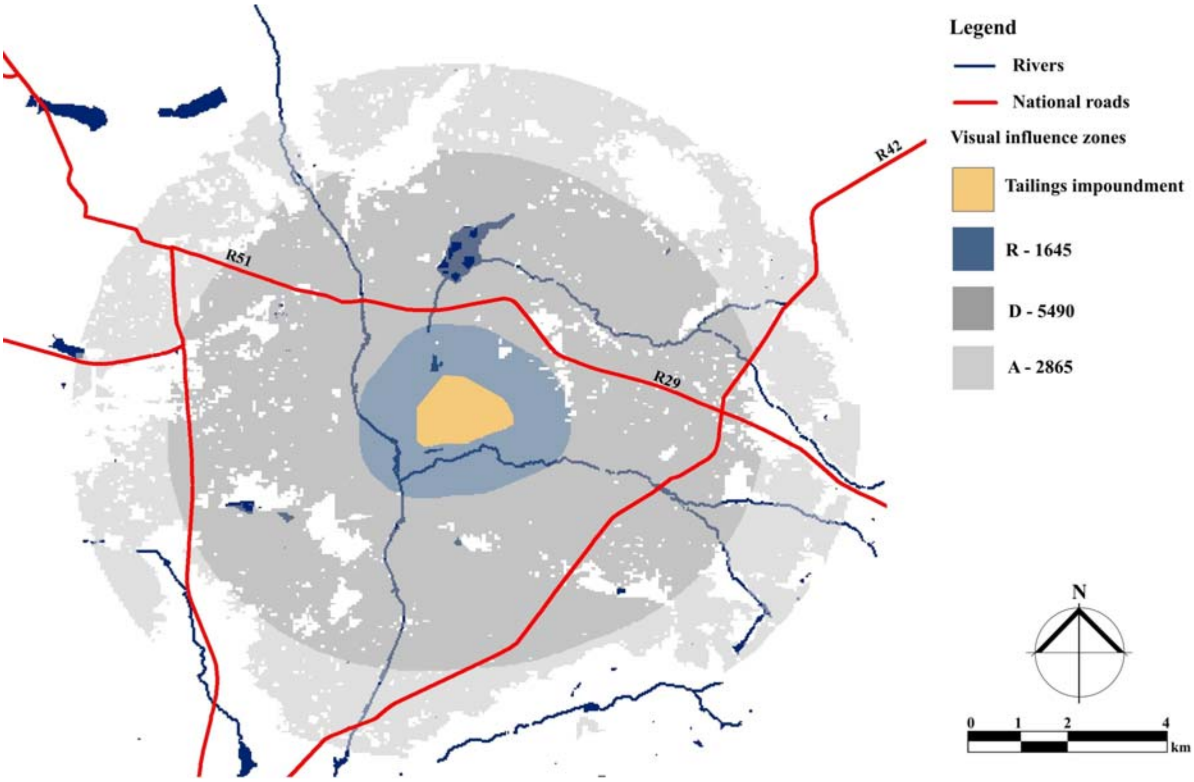

Figure 147: Visual perception zones of influence for an impoundment with a 1:3 overall embankment side slope and no cover.

Perception zone widths of 1645 m, 5490 m and 2865 m were used for the recognition, detection and awareness visual perception zones respectively. The spatially represented results of all eight configurations described in Table 21 (p. 162) are documented in Figures A.1 through A.8 in Appendix A.4. The surface areas for each visual perception zone were determined through:

- buffering the impoundment according to the various visual perception zone widths determined by the research;
- creating shapefiles in GIS using the union command;
- the resulting shapefile was then intersected with the property shapefile in order to run a multiple summary; and
- finally, the property intersects were then intersected with the visibility shapefiles (converted from a grid to a shapefile) and a second multiple summary was run to obtain the final results.

Using the procedure described above, the visual perception zone widths were used to map the surface areas of the zones of visual influence for the various configurations. Figure 148 presents a summary of the results for scenarios VS1 through VS8. The colours in the bar chart correspond with the colours used in the visual perceptions zone of influence maps. For easy reference purposes the bar charts are grouped according to type of cover and the embankment side slopes are annotated.

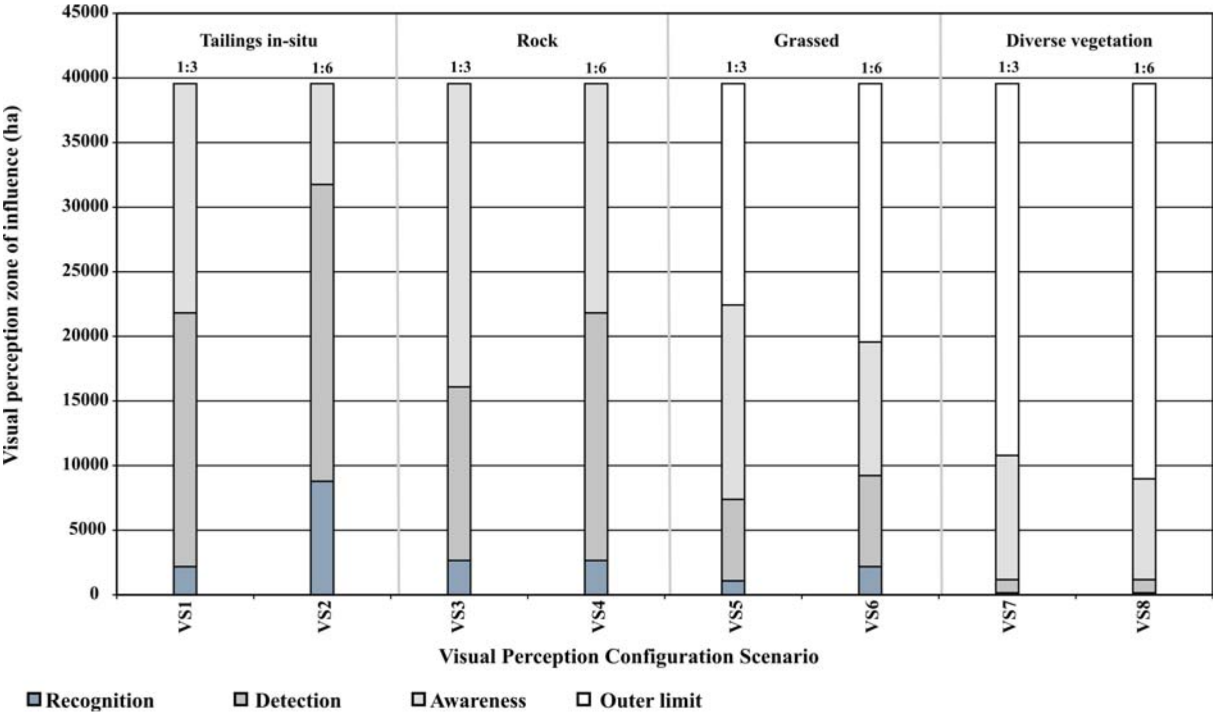

Figure 148: Visual perception surface areas for modelled configurations VS1 to VS8.

4.4 Air quality zone of influence

Once the surface roughness height was determined through the iterative process of modelling the emissions from the DRD 2L24 impoundment and comparing such with the data from the dustfall monitoring stations, the same methodology of emissions quantification and dispersion modelling could be applied to the different impoundment configurations described in Table 22 (p. 163), at the ERGO Daggafontein site.

Meteorological data from the Springs weather station was obtained for 2002, a period of one year. Emission rates for various scenarios were quantified using the now calibrated models. The calibration process of the predictive models used is described in Section 3.5.2.

The calibrated ADDAS model was used to quantify the emissions and the same US EPA dispersion model, ISCST 3 Breeze, was applied to calculate the fallout and concentrations at the ERGO Daggafontein site. All parameters used during the calibration process for the DRD 2L24 tailings impoundment were applied to the ERGO tailings impoundment configurations, with the exception of the physical dump size (length, width, height, side slope angle, and coverage). The variables for this purpose of the study are provided in Table 58, p. 253.

The results of the configurations modelled are used as input into the overall environmental impact and engineering cost model. Six side slope configurations were chosen with three emission scenarios, namely 0%, 80% and 50% control efficiencies. Table 19 (p. 160) and Table 20 (p. 163) contain the information describing the different scenarios' geometries, i.e. AS1 through AS12. Different cover efficiencies (0 %, 50 % and 80 %) or 'open fractions' are applied (1,0, 0,8 and 0,5) to each of the basic geometries resulting in twelve runs for the emissions.

Table 58: Varying parameters of each scenario for the ERGO Daggafontein tailings impoundment configurations.

		Varying tailings impoundment parameters for each scenario				
Scenario Code	**Slope 1V:?H**	**Control Efficiency (%)**	**Height (m)**	**Slope**	**East-West length (m)**	**North-South length (m)**
AS1	**1:1,5**	0[1]	37,28	0,58	2167	1396
AS5		100[2]				
AS9		50[3]				
AS13		80[4]				
AS2	**1:3**	0[1]	37,28	0,318	2203	1461
AS6		100[2]				
AS10		50[3]				
AS14		80[4]				
AS3	**1:6**	0[1]	37,28	0,165	2268	1585
AS7		100[2]				
AS11		50[3]				
AS15		80[4]				
AS4	**1:9**	0[1]	37,28	0,11	2323	1704
AS8		100[2]				
AS12		50[3]				
AS16		80[4]				

[1] 0% control efficiency indicates no cover and controls.

[2] 100% control efficiency indicates measures and controls implemented to ensure that 100% of the surface is not wind erodible.

[3] 50% control efficiency indicates measures and controls implemented to ensure that 50% of the surface is not wind erodible.

[4] 80% control efficiency indicates measures and controls implemented to ensure that 80% of the surface is not wind erodible.

Each scenario was simulated and ground level PM_{10} concentrations and deposition levels predicted. For PM_{10} the highest daily concentrations are depicted for a single isopleth representing 25 $\mu g/m^3$. Similarly for deposition, the ground level dust fallout is represented by a 250 $mg/m^2/day$ isopleth. Figure 149 (p. 254) plots the results for an impoundment configuration with an overall side slope of 1:1,5 and no cover.

The complete set of spatial representations for the various configurations is provided in Appendix B.1, Figure B.1 through Figure B.12. Scenarios AS5, AS6, AS7 and AS8 were not modelled using the predictive models as the scenarios are defined as having 100% emission control efficiencies which result in no emissions being released from the impoundment. Once the emissions are dispersed and the isopleths plotted, fallout and concentrations contours can be imported into and mapped in GIS. Using GIS, queries can be run to calculate the surface areas covered by each isopleth. Output summary data for the predicted PM_{10} concentrations and dustfall levels of the various scenarios can then be captured in an EXCEL spreadsheet and presented in the form given in Figure 150 (p. 254).

Similar to the results for the visual perception zones of influence, the air quality isopleths are mapped and used to determine surface areas for the various tailings impoundment configurations. The bar chart presents a summary of the results for scenarios AS1 through AS16. The colours in the bar chart correspond with the colours used in the dustfall and concentration zone of influence maps. The results are grouped for each cover with the embankment side slopes indicated for comparative purposes.

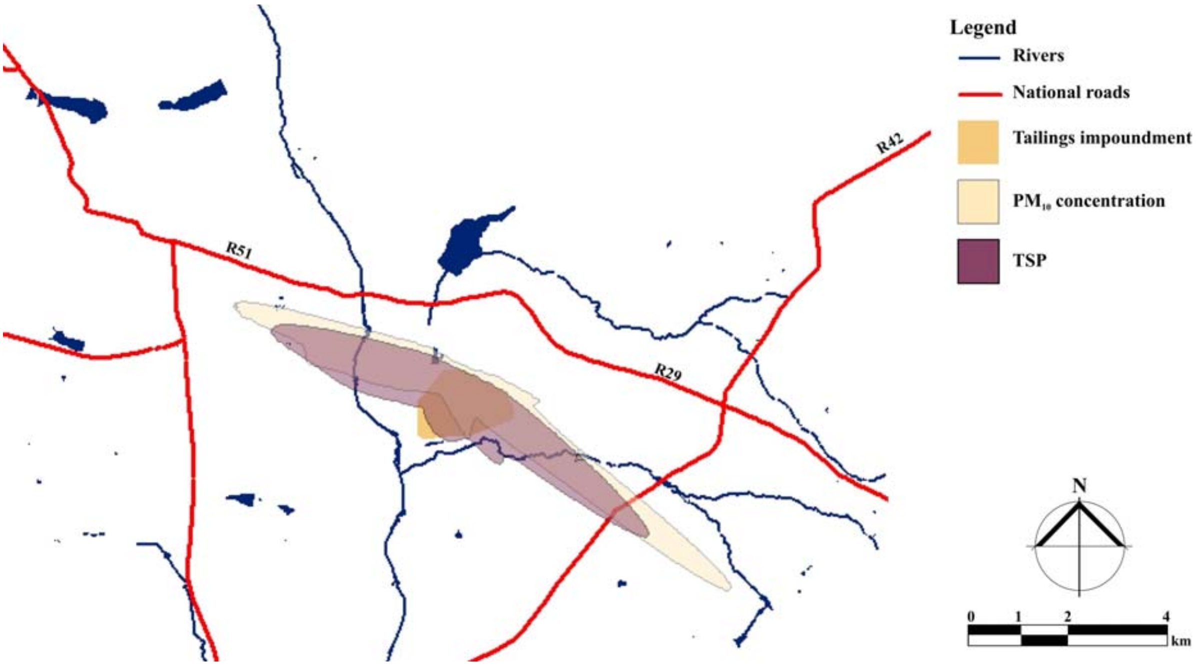

Figure 149: Plot of the dustfall and concentration isopleths for impoundment configuration AS1 with an overall embankment side slope of 1:1,5 and no cover.

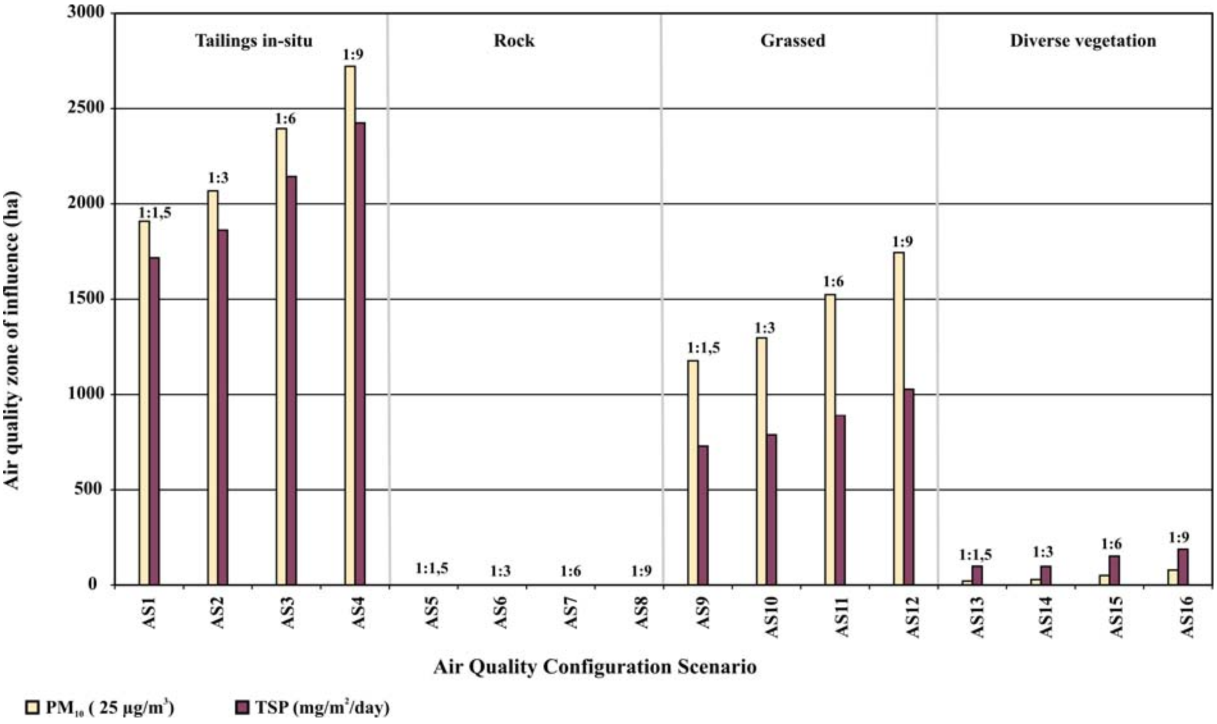

Figure 150: Air quality areas of influence for modelled configurations AS1 to AS16.

Presenting the isopleth data spatially in GIS allows for the accurate calculation of the surface area impacted on and it also communicates the change in influence zone visually. It is intended that the bar chart results can be used along with the zone of influence plots to illustrate how change in impoundment configuration results in change in such zone of influence.

4.5 Water quality influence

An analytical water flow and mass balance model was developed and used to evaluate the tailings impoundment configurations WS1 through WS16. Although conservative assumptions were made with regard to aspects such as the calculation of the water balance of the tailings impoundment, the results presented in the following section are detailed enough to compare the change in environmental impact resulting from the change in impoundment configuration. The following impoundment configurations were simulated using the analytical model previously described in Section 3.6.2. The results in Figure 151 indicate an increase in mass flux of sulphates to the Blesbokspruit ranging between 1000 t/annum to 3000 t/annum and depends on the impoundment configuration.

Table 59: Groundwater quantity and quality modelling configurations.

	Side slope configuration			
Covers	**1:1,5**	**1:3**	**1:6**	**1:9**
No cover (tailings in situ)	WS1	WS2	WS3	WS4
Rock cladding (300 mm)	WS5	WS6	WS7	WS8
Grassed soil-rock armouring (300 mm)	WS9	WS10	WS11	WS12
Diverse vegetation	WS13	WS14	WS15	WS16

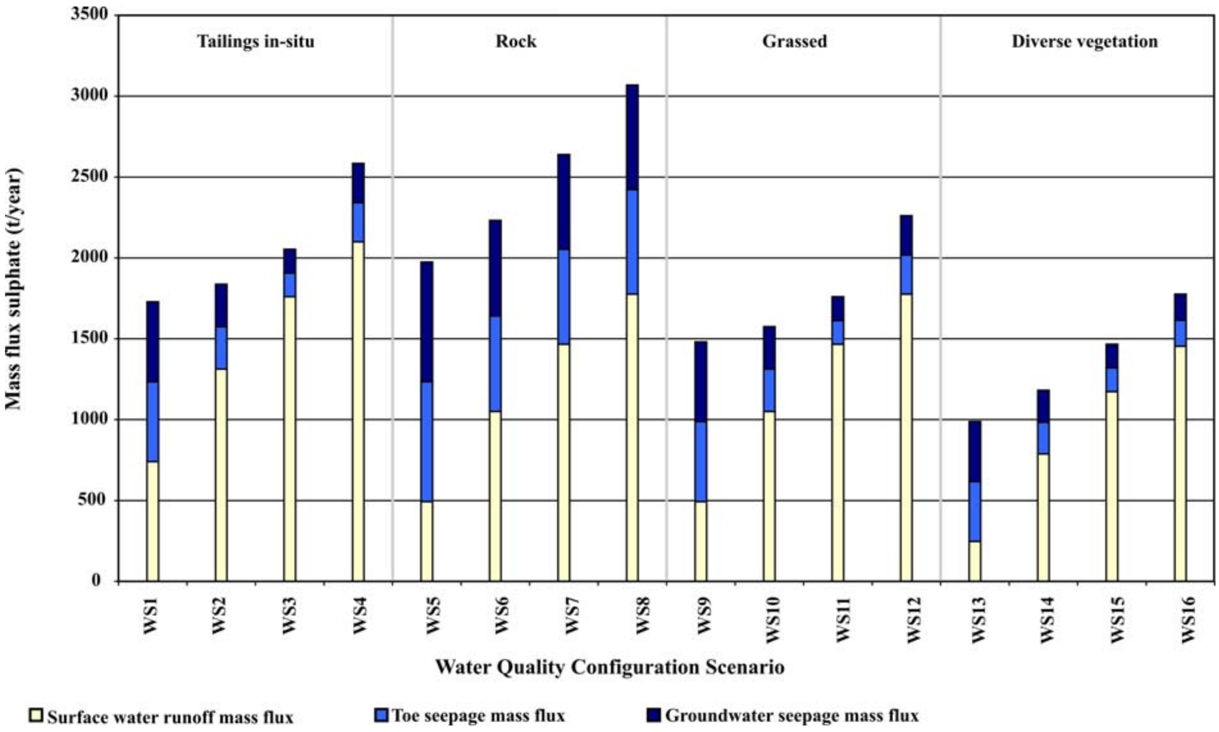

Figure 151: Mass flux for modelled configurations WS1 to WS16.

The base case (scenario WS1) was used as a basis for the measurement of the efficiency of the management options. The model indicates the following:

- Scenario WS1 (base case)
  If no rehabilitation takes place, the mass flux of sulphates to the Blesbokspruit would be in the order of 1700 t/annum. Due to the flow volume and dilution, the increase in the average sulphate concentration of the Blesbokspruit would be very small from 200 mg/ℓ to 205 mg/ℓ.

- Scenarios WS2 to WS4
  Flattening the embankment side slope without capping or covering would increase the mass load by up to 50 % to the Blesbokspruit to 2500 t/annum. It would also increase the average sulphate concentration from 200 mg/ℓ to 210 mg/ℓ. This is due to the greater footprint area and increased infiltration on shallower slopes.

- Scenarios WS5 to WS8
  Flattening the embankment side slope and covering the impoundment with a rock cladding would increase the mass load by up to 80 %, releasing up to 3000 t of sulphate to the Blesbokspruit per annum. It would also increase the average sulphate concentration from 200 mg/ℓ to 215 mg/ℓ. The rock cladding with flattening to a slope of 1:9 seems to be the worst option. This is due to the significant increase in the physical footprint of the impoundment. It is however expected that that the rock cladding will reduce evaporation losses and runoff.

- Scenarios WS9 to WS16
  Reshaping the outer embankment and establishment vegetation would decrease the mass load to the river by up to 40 % to approximately 1000 t/annum. The average sulphate concentration in the river would be less than the baseline case (WS1).

The best case in terms of reducing the mass flux to the receiving water body is WS13, which is configured with a diverse vegetation cover with a 1:1,5 overall embankment side slope.

Table 60 Comparison of the results of the mass flux of sulphates for the various scenarios.

	Side slope configuration			
Covers	**1:1,5**	**1:3**	**1:6**	**1:9**
No cover (tailings in situ)	WS1	🟥 WS2	🟥 WS3	🟥 WS4
Rock cladding (300 mm)	🟥 WS5	🟥 WS6	🟥 WS7	🟥 WS8
Grassed soil-rock armouring (300 mm)	🟩 WS9	🟩 WS10	WS11	🟥 WS12
Diverse vegetation	🟩 WS13	🟩 WS14	🟩 WS15	WS16

🟩 Decreased mass flux 🟥 Increased mass flux

4.5.1 Validation of results

The groundwater component of the water impact model was validated by comparing it with the output results of the accredited model Pmwin 5.3 version of Modflow, MT3D, developed and described by Chiang and Kinzelbach (1999). The simulation results from the numerical model showed that the steady-state mass flux was 1480 m^3/day compared to the results of 1127 m^3/day calculated from the analytical model. The 24 % discrepancy can be ascribed to the 50 m x 50 m finite difference grid size that was used. A finer grid size would be able to assume the footprint of the tailings impoundment more accurately (Figure 152).

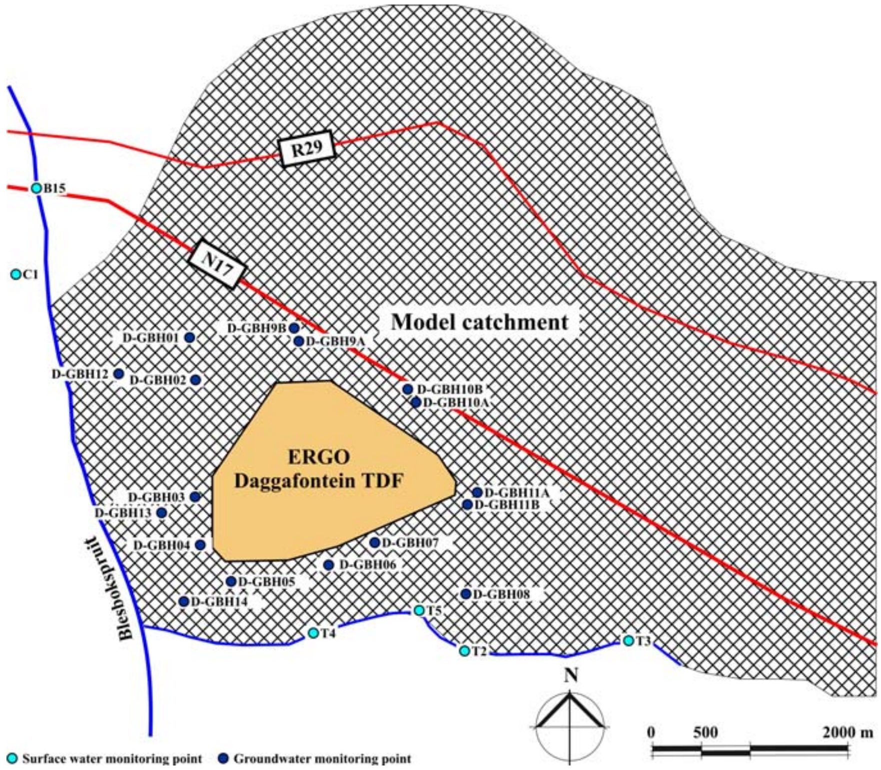

Figure 152: Modflow finite difference grid.

The numerical model has the advantage that it calculates dilution along the flow path which causes a smaller mass flux to the receiving water body (Figure 153, p. 258). This aspect would cause larger discrepancies between the two models the further the source is located away from the receiving water body. In this case, the dilution along the flow path must be taken into account. For this purpose, the analytical mass balance model was refined to take the steady-state dilution due to rainfall-recharge a one–dimensional section into account. A comparison between the numerical model (MT3D) and the analytical model shows that the results are comparable (Figure 154, p. 258).

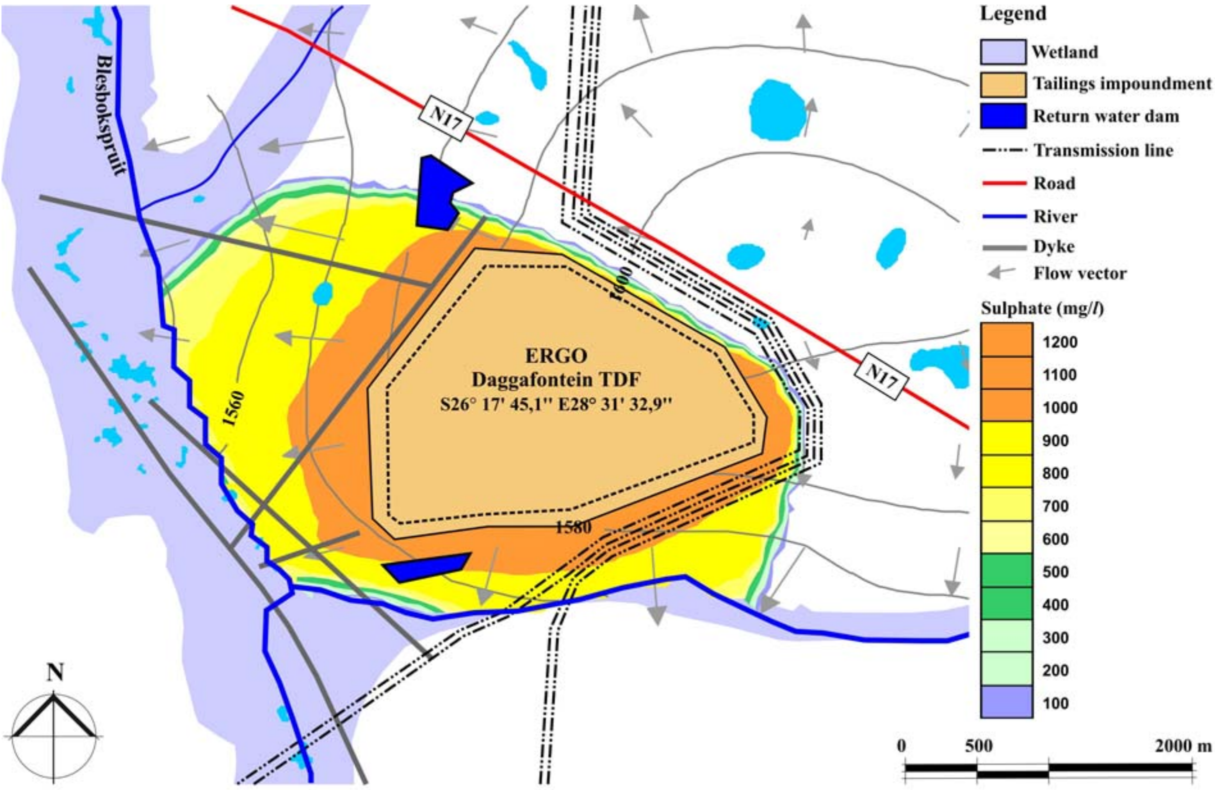

Figure 153: Simulated steady-state groundwater flow and sulphate transport.

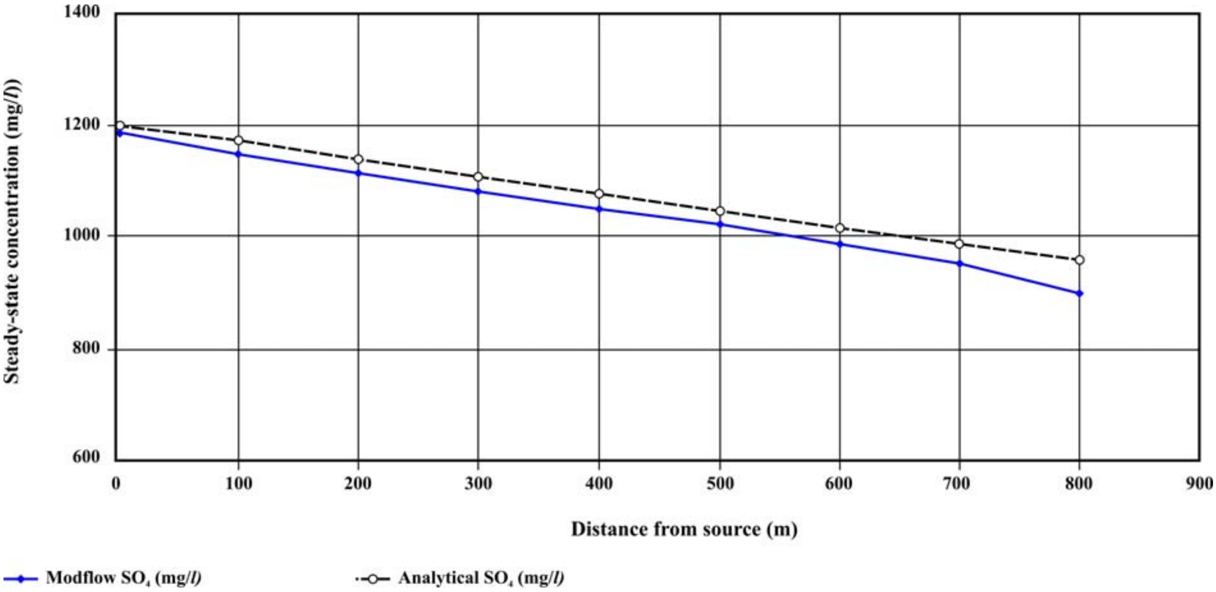

Figure 154: Comparing the dilution with distance from source results of the analytical model with Modflow.

4.6 Engineering costs

The engineering cost model can be used to determine the engineering costs for the design and construction (development), operation, decommissioning and closure, and post-closure maintenance and aftercare stages for tailings impoundments.

Engineering cost is a direct function of the impoundment shape and size (Figure 155). For example, the model can be used to compare the normalised cost per cubic metre tailings deposited of upstream spigotted ring-dyke impoundments. Modelling deposition rates between 990 000 tpm (large impoundment) and 50 000 tpm (small impoundment) with similar design parameters calculates normalised deposition costs varying between R5/m^3 and R16/m^3 tailings deposied. It is therefore more economical per cubic metre to deposit tailings for larger impoundments.

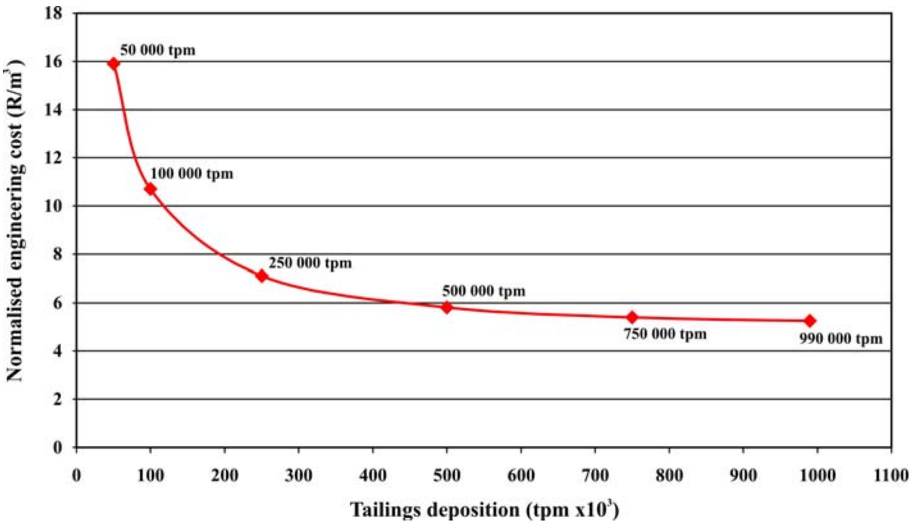

Figure 155: Normalised engineering costs to deposit tailings

The stacked bar chart (Figure 156) and the life-cycle scatter graph (Figure 157) on p. 260 plots the engineering cost results for the 28 tailings impoundment scenarios modelled as part of this study. The scenario codes for the configurations modelled are given in Table 20, p. 162. The deposition rate, final volume and height are constant for all the configurations modelled. Also, costs for a large impoundment with a deposition rate of 990 000 tpm and a final design capacity of 105 x10^6 m^3 are modelled.

The configuration results can be split into the two main groupings, namely:

- where the final embankment slopes are hydraulically deposited during the operation stage; and
- where the impoundments are constructed at a steep (1:1,5) overall embankment slope and flattened mechanically during the closure stage.

The configurations modelled are also arranged into sub-groups according to cover. For example, both scenario E16 and E28 allows for a 1:9 final overall embankment side slope and covered with 450 mm imported soil to support diverse vegetation. The difference between E16 and E28 is that the former's final embankment is constructed as part of the deposition of tailings during the operation stage and the latter's embankment slope is constructed through depositing the slope at a 1:1,5 side slope and then mechanically flattening it 1:9.

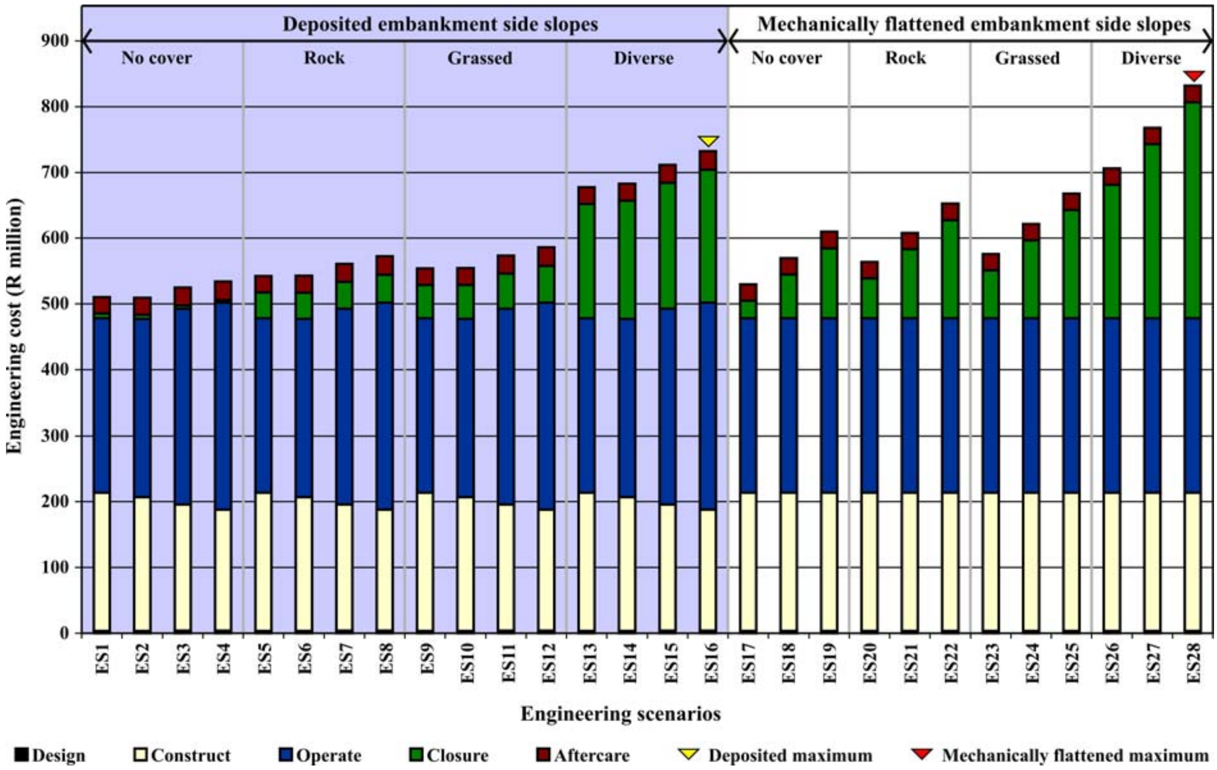

Figure 156: The total engineering costs for all the scenarios modelled indicating the relative costs for the different tailings impoundment construction stages.

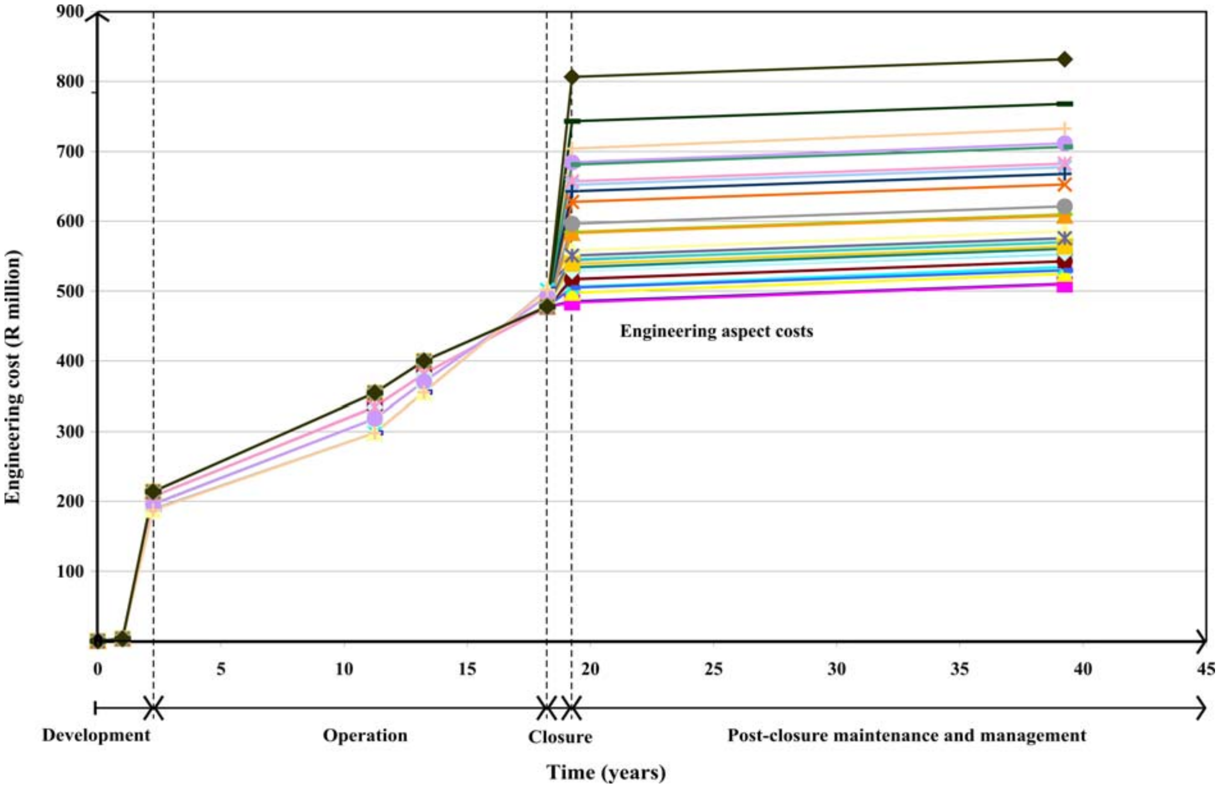

Figure 157: Cumulative engineering life-cycle costs for the 28 scenarios modelled.

The engineering costs for all the scenarios do not vary considerably up to the closure stage. It is at this point in the life-cycle that the tailings impoundment is rehabilitated. The difference in engineering costs at this point is approximately R25 million. On the other hand, the difference in costs at the point after closure and before the maintenance starts is more than R300 million.

Figure 157 plots the cumulative engineering costs over the life-cycle from initial planning through to the post-closure management and maintenance stage. The graph indicates the variance for all 28 scenarios modelled over the same period. Similar to Figure 156 it becomes apparent that variance in engineering costs occurs in the closure stage when comparing the different tailings impoundment configurations modelled.

The engineering cost model does not allow for the increase or decrease in maintenance costs resulting from for example measures required to combat erosion due to surface runoff. The maintenance and management costs for all of the options increase with the same amount annually irrespective of the final condition of the impoundment and include standard monitoring practice items such as:

- piezometer extensions;
- jet rodding of drain outlets;
- operator monitoring and inspections; and
- third party (external) monitoring and inspections.

4.7 Summary

This section presents the results of the various configurations, described in Section 3, for the:

- visual perception zones of influence for awareness, detection, and recognition zones;
- air quality zones of influence for total suspended particulates (TSP) and particulate concentration (PM_{10});
- water quality influence for sulphate flux; and
- engineering cost in Rands.

Where necessary the results are validated through additional experimental work or comparison with output results of accredited models. The environmental data is presented in such a form that it can now be combined, valuated and integrated with the engineering costs.

Zones of influence for both visual perception and air quality aspects are predicted and mapped, and the discharge in sulphate mass flux calculated. Although there is merit in evaluating the environmental aspects separately the true reflection of the possible impact on the environment can be best described by means of overlaying the separate aspects to form a sphere of influence. The sphere of influence is three-dimensional and represents on plan the total area upon which an impoundment will have an effect. This spatial representation is the overlay or sum of the different environmental aspect zones of influence of a particular configuration at a specific moment in time and is described in the following section, Section 5.