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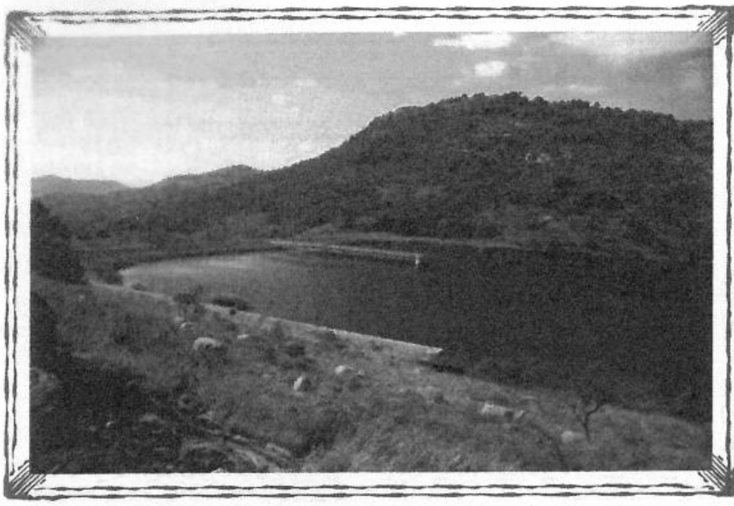
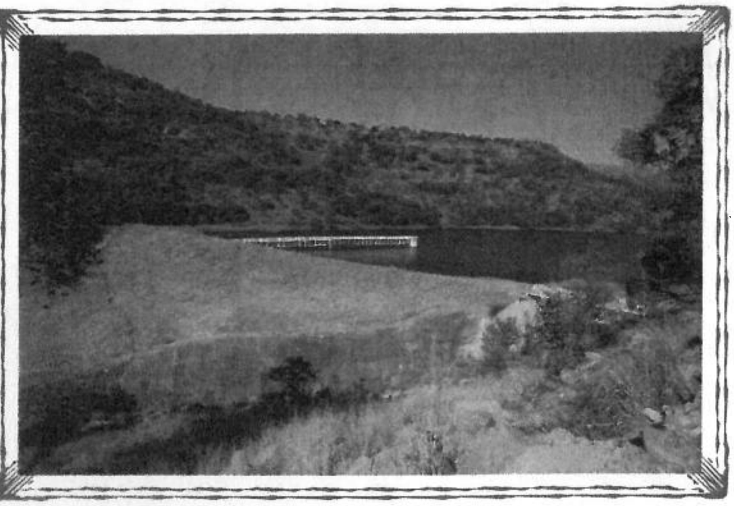


Der Brochen Dam

FOURTH DAM SAFETY EVALUATION REPORT

DAM SAFETY INSPECTION CARRIED OUT ON 27 JULY 2010 AS REQUIRED IN TERMS OF GOVERNMENT NOTICE R. 1560 OF JULY 1986

February 2011



NWRI BRANCH STRATEGIC ASSET MANAGEMENT	Department of Water Affairs and Forestry Private Bag X313 Pretoria 0001 South Africa

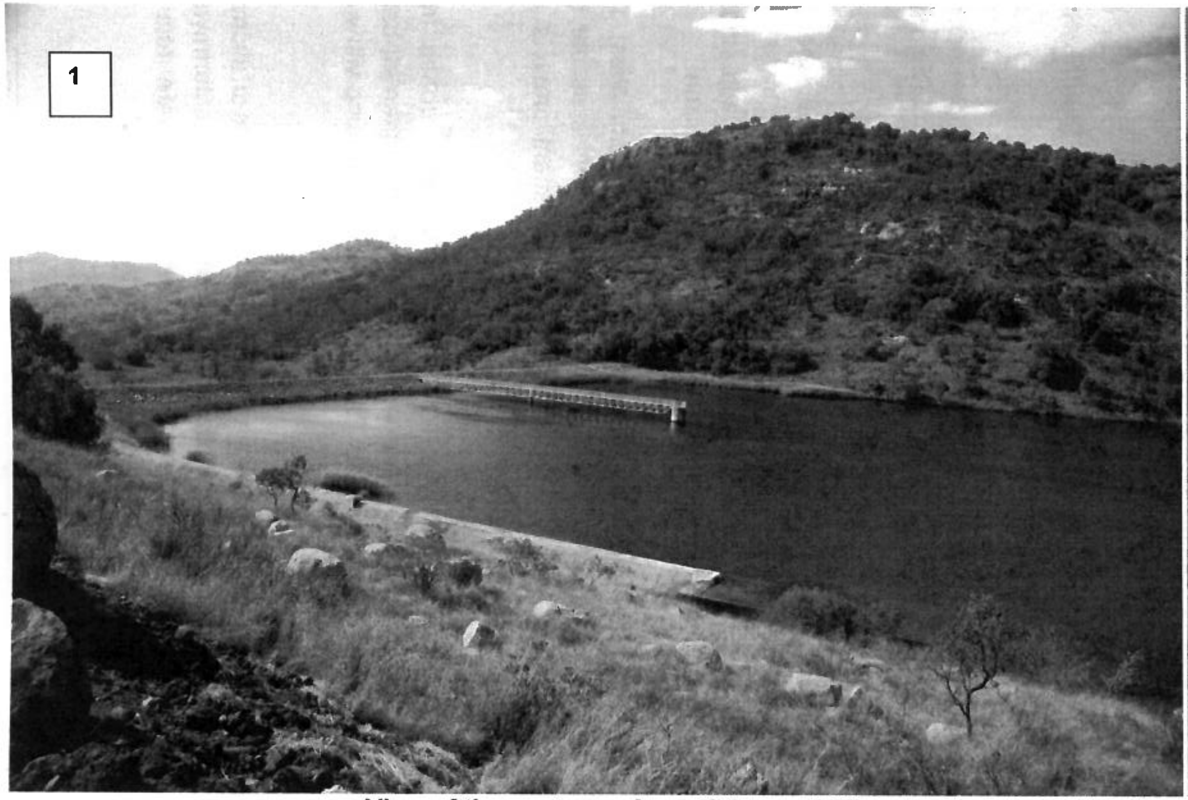
GLEN BOYD DAM

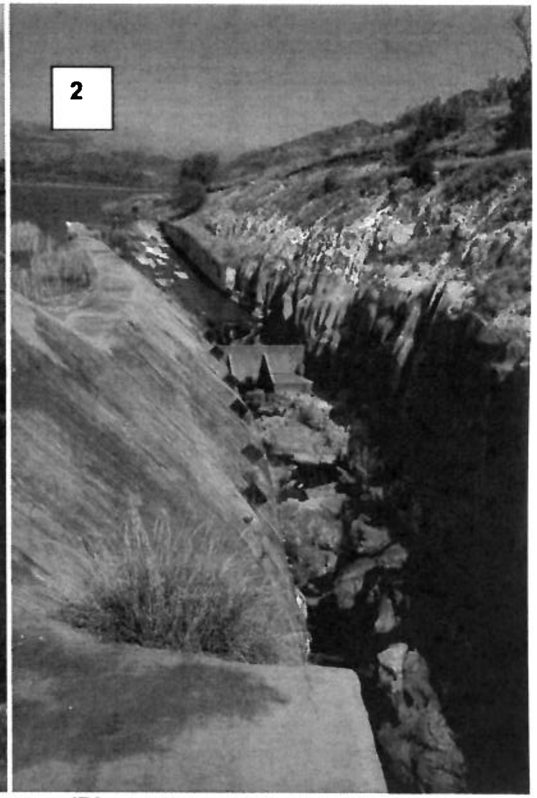
DOCUMENT CONTROL SHEET

Report No:	**20/2/Q930-14**
Title:	**THIRD DAM SAFETY EVALUATION REPORT** **February 2011**
Sub Title:	**DAM SAFETY INSPECTION CARRIED OUT ON 20 JULY 2010 AS REQUIRED IN TERMS OF GOVERNMENT NOTICE R. 1560 OF JULY 1986**

Originator		**Reviewed by**	
Name	**Signature**	**Name**	**Signature**
HJ. Wright		**F. Druyts**	

APP Approved		**CE : DSS Approved**	
Name	**Signature**	**Name**	**Signature**
J. van Zyl		**C. Oosthuizen**	
		D : SAM Approved	
		Name	**Signature**
		W v.d. Westhuizen	





View of the upstream face of the earthfill embankment and intake tower (Photo 1) and side-channel spillway on the left bank (Photo 2)

EXECUTIVE SUMMARY

De Brochen Dam situated in the Groot Dwars River, close to the town of Lydenburg in the Mpumalanga Province. This dam consist of an earthfill embankment with a side channel spillway and free-standing intake tower. The dam has a maximum height of 30,5 m and was completed in 1989.

The dam is founded on the Dwars River Subgroup anorthosites of the Rustenburg Layered Group, Bushveld Complex.

Der Brochen Dam has been categorised as a Category III dam in terms of the dam safety legislation, by the Dam Safety Office of the Department of Water Affairs.

The first dam safety inspection was conducted by Mr. DB Badenhorst of BKS Consulting Engineers as the Approved Professional Person (APP) in 1993.

The second dam safety inspection was conducted by Dr. C Oosthuizen of the Department of Water Affairs and Forestry as the APP, assisted by Mr. SS Kramer in 2002.

The third dam safety inspection was conducted by Mr. HFWK Elges of the Department of Water Affairs and Forestry as the APP, assisted by Dr. C Oosthuizen and Mr. IC Segers in 2006.

For this, the fourth Dam Safety Evaluation, the APP is Mr. JP van Zyl. The formal inspection was held on 27 July 2010. Mr. Van Zyl was assisted in compiling this report by Mr. HJ Wright. A follow-up inspection was held on 17 November 2010. The risk and impact assessment was done using the software and methods developed by Dr Oosthuizen.

A hydraulic model was constructed in the hydraulic laboratory of DWA in Pretoria West. The spillway capacity was found to be adequate, providing the total freeboard is as per the design. <u>However</u>, the <u>actual</u> available total freeboard to the embankment crest is <u>not sufficient</u> to pass the routed Safety Evaluation Flood SEF.

The soil slope above the concrete/shotcrete lining of the sides is being eroded from concentrated surface run-off from the drainage water berm situated on the higher left bank. Grass is growing in the cracks of the spillway crest. The loose spillway cladding will wash away during a flood event.

The embankment is in a reasonably good condition and does not show signs of distress. Erosion on the downstream slope close to the downstream toe is evident due to stormwater run-off over a large downstream surface. Manholes for the toe drain system were recently cleaned open and grass on the downstream slope was cut and burned.

No signs of leakage are visible on the downstream slope. The embankment stability is acceptable.

A presudo-static earthquake analysis (hand calculation) shows the intake tower to be not stable. A dynamic analysis is recommended as a matter of urgency.

Access to the dam is through the mine access control gate, across mine property. This is time consuming, and prior approval is required from the mine management. This makes daily access to and control of the dam cumbersome and difficult, although this restricts access for the general public.

No safety barrier of any kind as fall protection is present along the top of the side channel spillway return channel.and the safety of personnel working at the dam or members of the public gaining unrestrained access are put at risk.

The poor condition of the mechanical items especially inside the intake tower need to be addressed.

The letter by the Dam Safety Office (DSO) dated 02 November 2006 expressed concern that almost none of the various recommendations made in the previous DSI reports have received the required attention . The comments of the DSO in the above letter that have not been taken into account during the past 5 years, includes:

- Recommendations such as the urgent compilation of an EPP, grouting of cavities beneath the spillway crest, reinstatement/checking of the available freeboard and rehabilitation of the outlet works;
- Arrangement for continuous monitoring of seepage/leakage and settlement.
- Although a risk and impact assessment was done as part of this report, it is recommended that the recommendation by the DSO for a detailed re-assessment of the loss of mining establishments downstream be done as part of the preparation of the EPP.

A table with recommendations based on this inspection has been included in Section 11 of the report. Recommendations w.r.t. mechanical and electrical works are also made.

TABLE OF CONTENTS

LIST OF APPENDICES

DEPARTMENT OF WATER AFFAIRS

DER BROCHEN DAM

FOURTH DAM SAFETY EVALUATION REPORT

1 INTRODUCTION

In terms of the National Water Act, (Act 36 of 1998), Der Brochen Dam has been categorized as a Category III dam, by the Dam Safety Office of the Department of Water Affairs. The dam was designed by Mitchell and Greyling Consulting Engineers and was constructed by Terasit. The dam is operated and maintained by the Mpumalanga Region of the Department of Water Affairs (DWA) and the Groot Dwars River Irrigation Board.

In terms of the Dam Safety Legislation, Der Brochen Dam is due for a Dam Safety Inspection and report in 2010.

The Chief Directorate Engineering Services (CD: ES) was approached during the month of April 2010 by the Directorate: Strategic Asset Management (D: SAM) requesting assistance to with the dam safety evaluation inspections and reports.

Mr. JP van Zyl (Pr. Eng.) of the Department of Water Affairs was approved as the Approved Professional Person (APP) as required in terms of the Government Notice R.1560 of July 1986 for this the 4th dam safety inspection of the ***DER BROCHEN DAM.*** He was assisted by Mr. HJ Wright, who is the author of this report, as well as the various members of the professional team as listed in **Table 1**.

Table 1: Professional Team

Dam Component	Member of Team	Employer of Team Member
Fill dam (rockfill)	Mr. FHWM Druyts	DWA
Geology	Prof. A van Schalkwyk	Knight Hall Hendry
Hydrology	Mr. D van der Spuy	DWA
Spillway	Mr. NJ van Deventer	DWA
Structural Analysis	Mr. JH Durieux	DWA
Mechanical Equipment	Mr. VW Kohlmeyer	DWA
Risk and Impact Assessment	Dr. C Oosthuizen	DWA

Table 2: History of Dam Safety Inspections

Dam Safety Inspection	Date	APP	Report
1	1993	Mr. DB Badenhorst of BKS Consulting Engineers	Veiligheidsinspeksieverslag: Der Brochen Dam
2	2002	Mr. SS Kramer of the Department of Water Affairs and Forestry [1]	Der Brochen: Second Dam Safety Inspection Report
3	2005	Mr. IC Segers of the Department of Water Affairs and Forestry [2]	Der Brochen: Third Dam Safety Inspection Report
4	2010	Mr. JP van Zyl of the Department of Water Affairs [3]	Der Brochen Dam : Fourth Dam Safety Inspection Report

[1]: Assisted by Mr. Elges and Dr. Oosthuizen.
[2]: Assisted by Mr. Elges and Dr. Oosthuizen.
[3]: Assisted by Messrs. Druyts, Wright and Dr Oosthuizen

2 SUMMARY OF PERTINENT INFORMATION

Important information regarding the dam is summarised in this section of the report.

2.1 Owner

The owner of the dam is the Department of Water Affairs (DWA).

The person(s) in control of the dam:

Mr. VA Msimango
Buffelskloof Dam
Tel No: 013 235 4051
Cellphone: 082 325 1202

Mr. K Pretorius
DWA Groblersdal
Tel No: 013 262 6800
Cellphone: 082 807 5614

2.2 Classification

The dam, being 30,5 m above the lowest foundation level, is a Large dam with a High Hazard Potential Rating and has accordingly been classified as a Category III dam. It is therefore subject to five-yearly dam safety inspections by an Approved Professional Person (APP), assisted by a professional team, approved in terms of the regulations of the Water Act.. The registration information regarding the position of the dam is to be updated.

2.3 Main Function

The dam is used to store water for mostly mining and to a lesser extent for irrigation purposes. Water is supplied to the Dwars River Irrigation Board and to mines situated downstream of the dam.

2.4 Location

The dam is located in the Groot Dwars River, near the town of Lydenburg in the Mpumalanga Province. The applicable 1:50 000 topocadastral map is 2530AA Draaikraal.

Position:

Latitude 25^{0} 03' 20"

Longitude 30^{0} 07' 12"

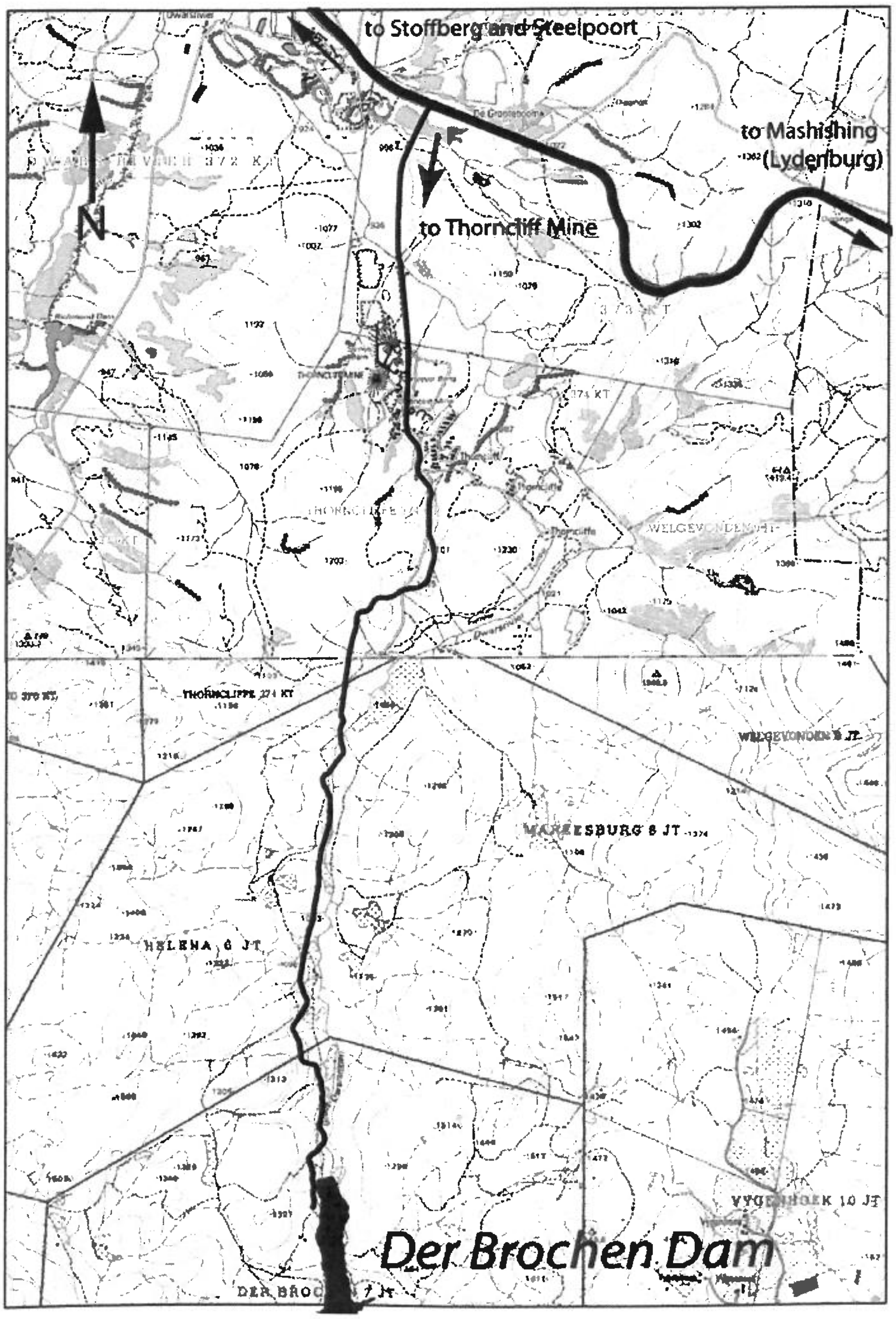


Figure 2.1: Locality map of Der Brochen Dam

2.5 Dam Statistics

General:

Name of the dam	**DER BROCHEN DAM**
Name of the river	**Groot Dwars River**
Nearest town	**Lydenburg**
Province	**Mpumalanga**
Purpose	**Store water for mining and irrigation**
Completion date	**1989**
Owner	**Department of Water Affairs**
Designed by	**Mitchell and Greyling Consulting Engineers**
Constructed by	**Terasit**

Hydrological Data:

Effective catchment area	**149 km^2**
Mean annual rainfall	**709 mm**
Design flood recurrence interval	**200 years**
RDD (1:200 year)	**210 m^3/s**
RMF (K-value = 4,6)	**715 m^3/s**
SEF	**1 000 m^3/s (See discussion in report)**
Spillway capacity (NOC level: RL 1 116,50 m)	**886 m^3/s (Design NOC level)**
Spillway capacity (NOC level: RL 1 116,06 m)	**764 m^3/s (2010 surveyed NOC level)**

Dam description:

Type of dam	**Earthfill Dam**
Type of spillway	**Uncontrolled Side-channel Spillway**
Maximum height above lowest foundation	**30,5 m**
Height above riverbed	**30,5 m**
Length of spillway	**130 m**
Length of embankment crest	**236 m**
Storage capacity	**7,3 million m^3**
Freeboard	**3,06 m (Design value = 3,5 m)**
Non-overspill Crest level (RL) - Design	**1 116,50 m (See note below)**
Full Supply Level (RL)	**1 113,00 m**
Lowest Foundation level (RL)	**1 086,00 m**
U/S slope	**3,5 : 1**
D/S slope	**2,6 : 1**

Note: Actual lowest level on crest as surveyed in 2010 is RL 1 116,06 m

2.6 Description of the dam

Der Brochen Dam, is situated approximately 35 km west of Lydenburg on the Groot Dwars River, in the Mpumalanga Province. This dam consist of an earthfill embankment, stand-alone intake tower and a side-channel spillway. The dam has a maximum height of 30,5 m. The dam is classified as Large and was completed in 1989.

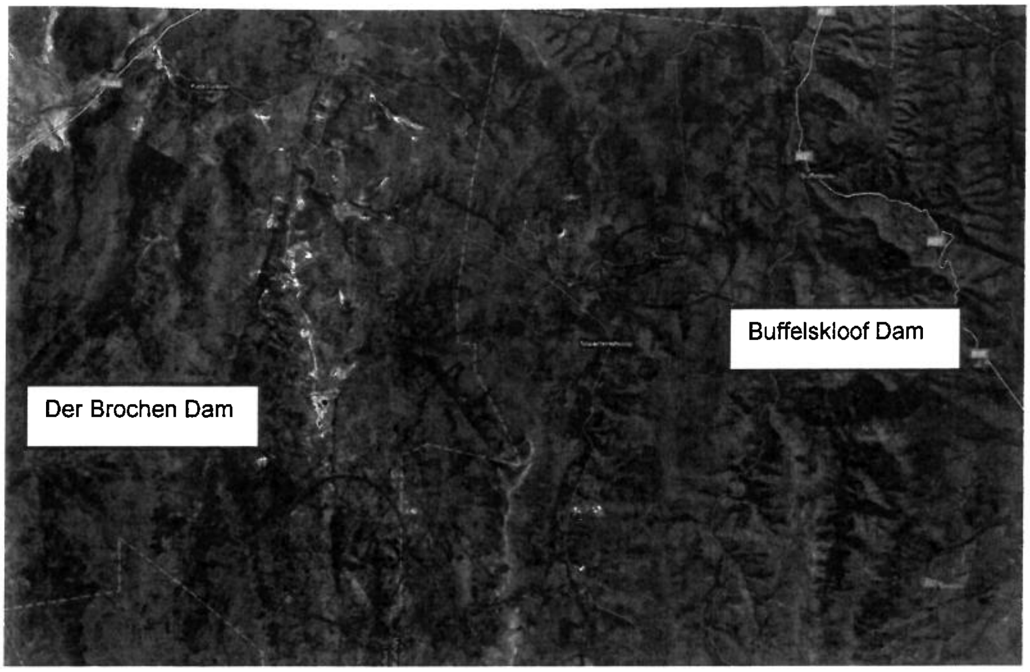


Figure 2.2: Aerial photograph of Der Brochen Dam

2.7 Design and Construction

The dam was designed by Mitchell and Greyling Consulting Engineers and was constructed by Terasit. The dam was completed in 1989.

The following personnel were involved with the design of the dam:

- Mr. T Mitchell (Approved Professional Engineer);
- Prof. A van Schalkwyk (Geology, geotechnical aspects and materials);
- Dr. BV van Wyk (Geotechnical aspects and materials);
- Prof. A Rooseboom (Hydraulics); and
- Mr. BCD Greyling (Civil Engineering aspects).

2.8 Available reports and Drawings

The following reports are available at the Head Office of the DWA in Pretoria:

1. Mitchell, TC: Groot Dwarsrivierbesproeiingsraad: Voorgestelde Der Brochen Dam: Ontwerpverslag. May 1988.

2. Van Wyk, BC: Groot Dwarsrivier: Der Brochen Dam: Geotegniese Verslag. May 1988.

3. Sigma Beta Consulting Engineers: Der Brochen Dam: Hydraulic Redesign of Spillway. Revision 1. October 1989.

4. Mitchell, TC: Der Brochen Dam: Handleiding. Hersiende Uitgawe. Mei 1991.

5. Badenhorst, DB: Groot Dwarsrivier-besproeiingsraad: Veiligheidsinspeksie-verslag: Der Brochen, BKS Consulting Engineers. November 1993.

6. Davis, GN: Der Brochen Dam, Groot Dwarsrivier: First Engineering Geological Maintenance Report for Dam Safety Purposes. Council for Geoscience. August 1999.

7. Kotze, A: Der Brochen Dam: Flood Frequency Analysis. Department of Water Affairs and Forestry. February 2006.

8. Kramer, SS: Der Brochen Dam Second Dam Safety Inspection Report. Department of Water Affairs and Forestry. March 2002.

9. Segers, IC: Der Brochen Dam Third Dam Safety Inspection Report. Department of Water Affairs and Forestry. July 2005.

3 GEOLOGY

The dam was founded on Dwars River Subgroup anorthosites of the Rustenburg Layered Group, Bushveld Complex. Numerous younger dolerite dykes intrude the Bushveld Complex. The flanks were deeply weathered, with the river section unweathered to slightly weathered at shallow depths.

Grouting was done, but no records are available showing the extent of the grouting.

Davis (1999 and 2005) reported that the soil and rock adjacent to the spillway cut is potentially dispersive. Seepage was also noted via joints in the rock within the spillway chute and beneath the concrete slabs lining the spillway chute. No part of the dam revealed any form of past slope instability. The crest of the embankment is not horizontal, and this could indicate settlement of the embankment.

Prof A van Schalkwyk is a member of the professional team for the 2010 visit. His findings are presented in **Appendix E**. Some extracts from his report is listed as follows:

- Geotechnical investigations for design of the Der Brochen Dam were conducted according to accepted standards and were adequately documented. Construction records are limited to a set of "as-built" cross-sections through the embankment and the spillway channel.

- The shells of the embankment dam were founded on colluvial/alluvial materials after the layer of organic-rich material had been removed. The core trench excavation was founded on bedrock along the left flank and river section, while it was taken about 1 m deep into the residual anorthosite on the right flank.

- Materials for the embankment were obtained from four borrow areas located within the dam basin. Badenhorst (1993) indicated that the material is weathered norite.

- The shear strength of the founding materials was shown to be higher than that of the embankment, while the compressibility and permeability of the foundations were lower than for the embankment. The bedrock was found to be highly permeable in places and was treated by means of a grout curtain.

- The site inspection showed the embankment to be in a reasonably good condition, but there are signs of settlement and minor cracking. It is recommended that an accurate topographical survey of the dam wall be done.

- It is recommended that the dam crest be rehabilitated to its original height (or higher if needed for improved spillway capacity). The drain outlets must also be cleaned and maintained.

- Although extensive laboratory tests showed the embankment soils to be non-dispersive to marginally dispersive, a few small "sinkholes" indicative of highly erodible material developed on the dam crest and were subsequently repaired. It is recommended that dispersion tests be conducted on material to be used for rehabilitation.

- The spillway is in a reasonable condition, considering the liberal use of shotcrete and the large areas of unlined soil and rock. The soil slope above the concrete/shotcrete lining of the sides is prone to erosion from surface run-off and from possible high water levels in the spillway channel. It is recommended that this slope be protected by means of shotcrete on wire mesh.

- Concrete cladding on the spillway crest has cracked due to settlement of the supporting soilcrete wall, and it is possible that the cladding could be lifted off during flood events. It is recommended that the cladding be repaired.

- Horizontal seismic acceleration of 0,09 g, 0,10 g and 0,18 g are associated with recurrence intervals of 50 year, 100 year and the Probable Maximum Intensity respectively.

- The spillway channel is in a reasonable condition considering its design and age.

It can be concluded that from a geological point of view there is no serious concerns.

4 HYDROLOGY

A review of the hydrology of Der Brochen Dam was done in 2010 by Van der Spuy. The report is attached as **Appendix F1**. Previous reports are dated 2006 (Kotze, et al) and 1999 (Rademeyer).

Van Deventer (2010) commented on the flood determinations and recommended a value for the Safety Evaluation Flood (SEF).
The report is attached as **Appendix F2** and discusses the methodology in detail. Deterministic, empirical and extreme value methods were used for the calculations.

The recommended flood peaks is shown in **Table 4.1** and the flood volumes in **Table 4.2**.

Table 4.1: Recommended flood peaks (m^3/s) for Der Brochen Dam (Van Deventer, 2010)

DURATION (HOURS)	EXCEEDANCE PROBABILITY (%)							SEF
	50	20	10	5	2	1	0,5	
1,5	26	64	107	165	263	344	431	895
3	**30**	**71**	**119**	**184**	**293**	**385**	**481**	**1 000**
6	24	57	94	145	232	306	380	792

Table 4.2: Recommended flood volumes (million m^3) for Der Brochen Dam (Van Deventer, 2010)

DURATION (HOURS)	EXCEEDANCE PROBABILITY (%)							SEF
	50	20	10	5	2	1	0,5	
1,5	0,330	0,790	1,320	2,040	3,250	4,280	5,330	11,08
3	**0,460**	**1,110**	**1,840**	**2,840**	**4,530**	**5,950**	**7,430**	**15,440**
6	0,530	1,270	2,110	3,280	5,200	6,860	8,540	17,750

The South African National Committee on Large Dams (SANCOLD) Guidelines on safety in Relation to Floods (1991) states that for a large size dam with a high hazard rating the 200 year flood is to be used for the Recommended Design Discharge (RDD). The guidelines also states that for a large size dam with a high hazard potential the Safety Evaluation Discharge (SED) equal to the Regional Maximum Flood (RMF) + Δ (the adjacent region numerically one step higher) is to be used.

The dam lies in the region with a K-value of 4,6 (TR137). The adjacent region numerically one step higher is 5,0. Using this value, a SEF of 1 221 m^3/s is obtained. Dam Safety Inspection Reports No's 2 and 3 (dated 2001 and 2005 respectively) used a K'-value of 4,817 (K' = K + 1/K), and obtained a value for the SEF of 955 m^3/s. Van Deventer (2010) recommended the value for the SEF as 1 000 m^3/s. Refer to **Appendix F2**. The probability of exceedance of the recommended SEF is 1×10^{-4}.

5 SPILLWAY CAPACITY

5.1 Capacity

The dam has a 130 m long uncontrolled side channel spillway. The Full Supply Level (FSL) is at RL 1 113,00 m, whilst the design Non-overspill Crest (NOC) level is at RL 1 116,50 m. This results in a design total freeboard of 3,5 m above the spillway's lowest notch. The side channel spillway is situated on the left bank and discharges directly into the natural river section.

The design report stated that the spillway was formed in rock in places, and on a soil cement stabilised fill in other places. Refer to **Photograph 1** and **2**. Concrete was used for the construction of the upstream potion of the spillway crest. For the downstream section a thin concrete slab of 75 mm was cast on top of the soil cement fill. A proper rock foundation was apparently too deep which would have resulted in excessive cost. Shotcrete was used to protect rock against possible erosion from the water. The level of overflow varies, with the upstream concrete section overflowing first, followed by the downstream stabilised fill sections.

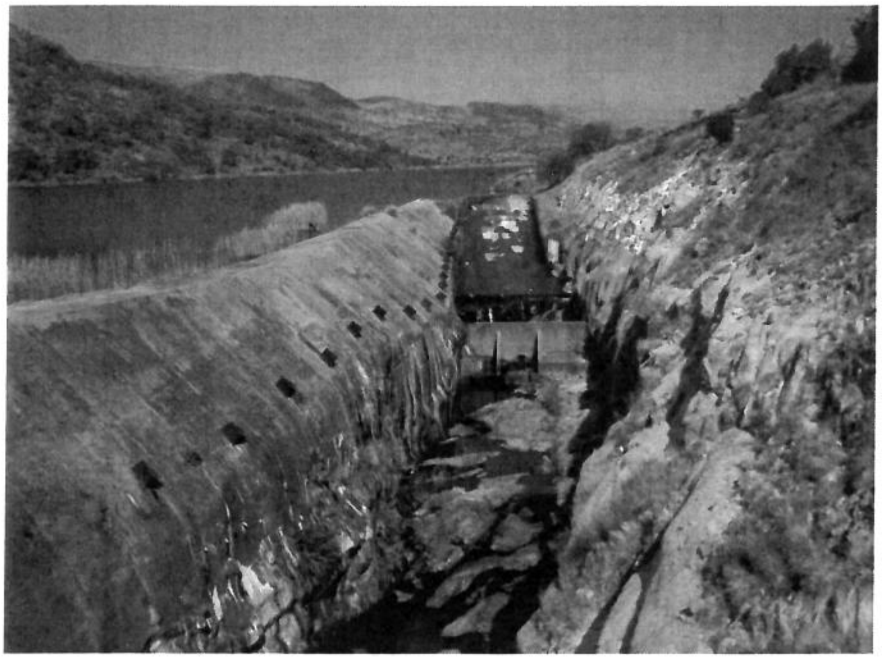


Photo 1: Upstream section of side channel spillway (2010/07/27)

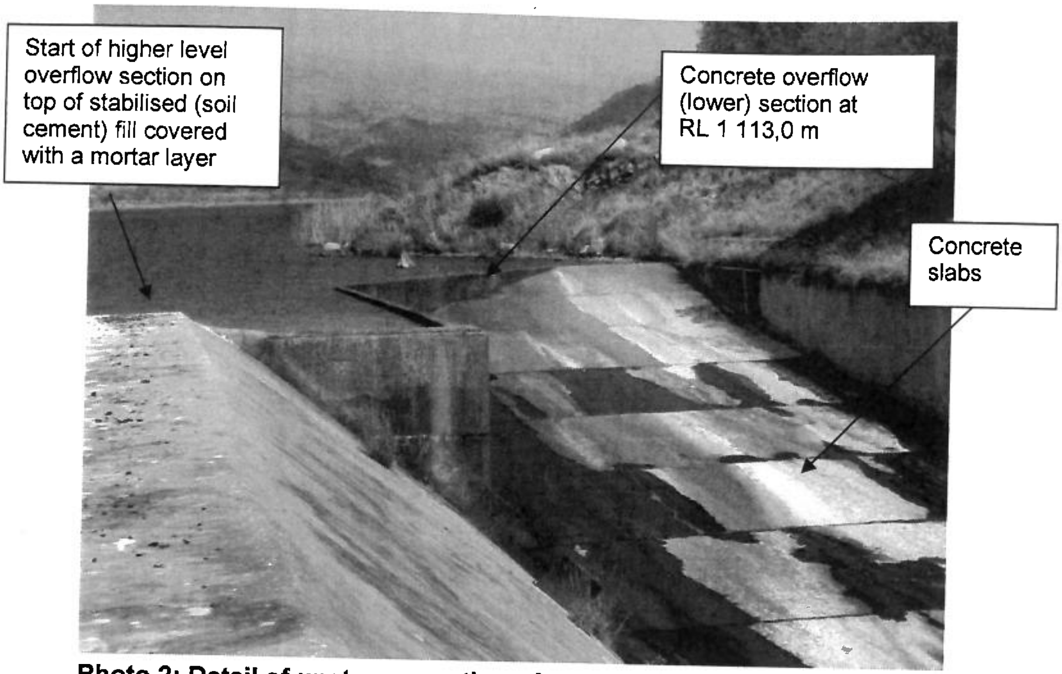


Photo 2: Detail of upstream section of spillway (2010/07/27)

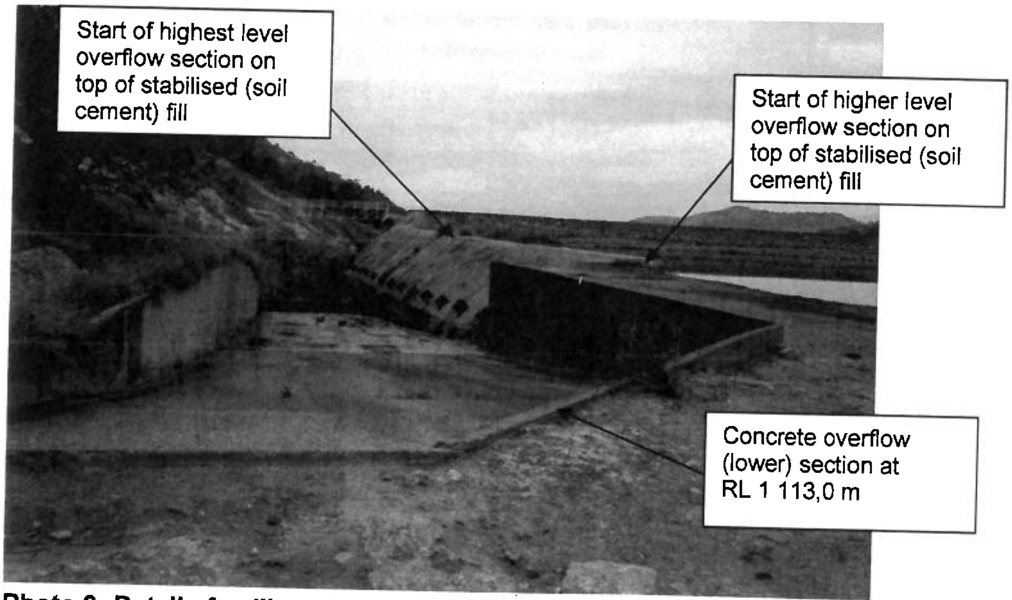


Photo 3: Detail of spillway levels (2010/11/17)

It was noted during the second and third dam safety inspection reports (2001 and 2005) that the original spillway capacity as calculated during the design phase was not entirely correct as only one of the two cross walls were actually constructed. The discharge capacity was recalculated in 2001 and resulted in a capacity marginally higher than in the original design. The maximum discharge capacity at RL 1 116,5 m is stated to be 799 m^3/s. Routing of the flow was also done and it was stated that the maximum incoming flood with zero freeboard is 972 m^3/s (resulting in a capacity of 799 m^3/s). **Table 5.1** shows the figures that were calculated from the 2001 report (Kramer).

Table 5.1: Capacity of spillway (including routing 2001)

Description	RMF	MEF
Inflow (m^3/s)	715	955
Outflow (m^3/s)	616,3	790
Outflow / Inflow (%)	86,2	82,7
Maximum level (m)	1 115,65	1 116,44
Maximum depth over spillway (m)	2,65	3,44
Maximum level below NOC (m)	0,85	0,06

Note: MEF = Maximum Expected Flood

A survey of the dam was done during 2010 by Directorate: Spatial and Land Information Management (D: SLIM). The survey shows deviations from the original design slopes and levels. The minimum NOC level of the embankment is RL 1 116,06 m, whilst the design value is RL 1 116,50 m.

5.2 Model Study (2010)

The geometry of the side channel spillway was obtained by a survey done in 1994 by Directorate: Spatial and Land Information Management (D: SLIM). From this geometry a model at a scale of 1:30 was constructed in the DWA Hydraulic Laboratory in Pretoria West. The purpose of the model was to determine the capacity of the spillway at NOC level. A separate report on the study is compiled. Refer to **Appendix K**..

Photo 4: Hydraulic model in Pretoria West

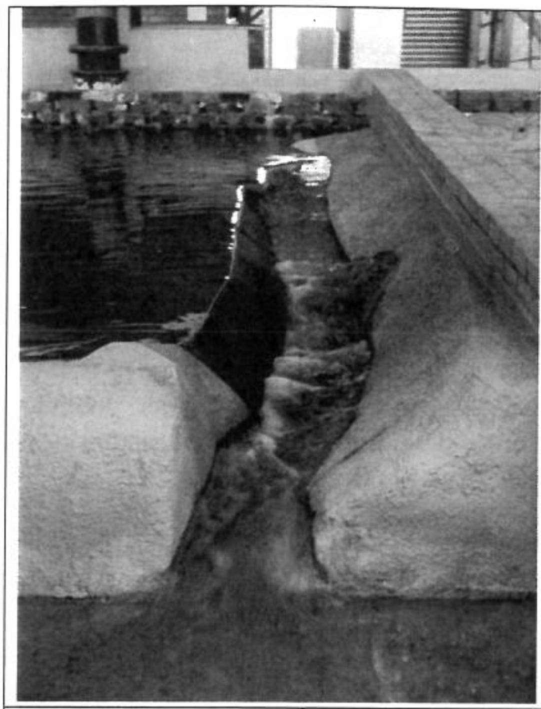


Photo 5: Flow of 300 m^3/s

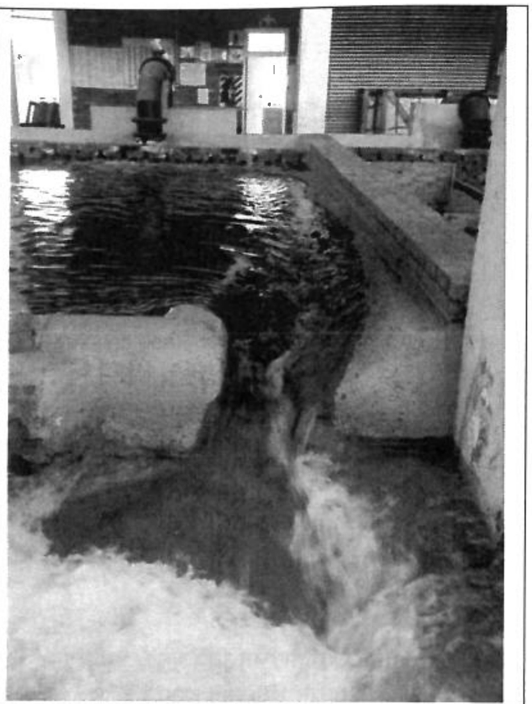


Photo 6: Flow of 700 m^3/s

Figure 5.1 shows the maximum spillway capacity. The maximum capacity at the design NOC at RL 1 116,5 m was calculated at 886 m^3/s. The discharge capacity at the surveyed (2010) crest level of RL 1 116,0 m is 764 m^3/s.

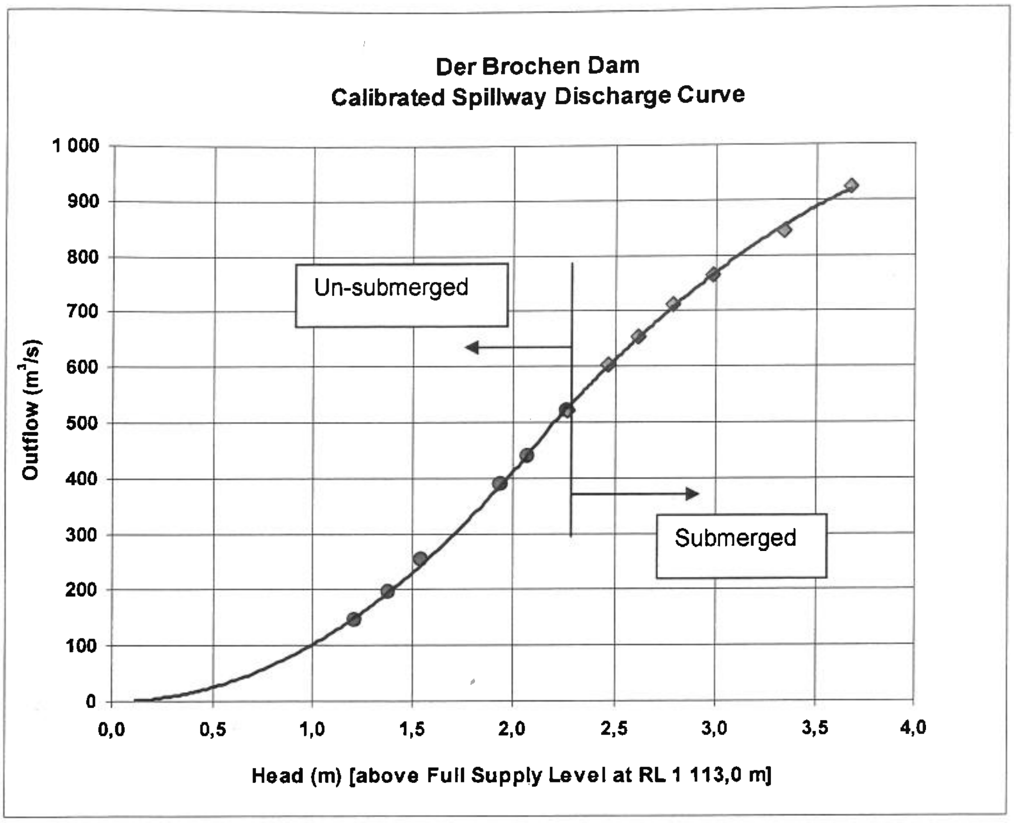


Figure 5.1: Spillway discharge curve

5.3 Flood Routing

Routing of the inflowing peak of 1 000 m^3/s was done. The out flowing peak was determined as 793 m^3/s. This is less than the spillway capacity if the NOC would be at RL 1 116,50 m. **Figure 5.2** shows the flood routing.

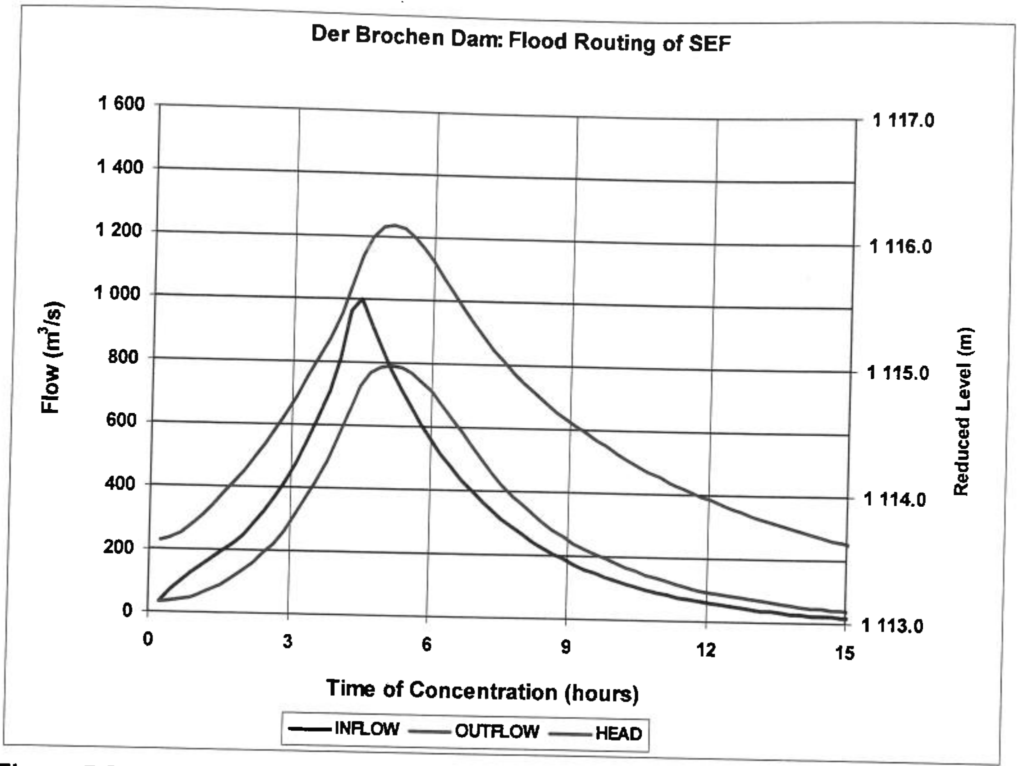


Figure 5.2: Routed flows (Van Deventer 2010)

5.4 Conclusion

The spillway cannot accommodate the routed SEF. It can however accommodate a routed flood peak with a probability of exceedance $6{,}66 \times 10^{-4}$.

6 EMBANKMENT

The earthfill dam is 236 m long and has a maximum height of 30,5 m. A total freeboard of 3,5 m has been designed for. The dam comprises a homogeneous embankment, with a chimney and strip drains which divide the internal blanket filter into compartments. The dam has an upstream slope of 1: 3,5 (vertical: horizontal) and a downstream slope of 1: 2,6 (vertical: horizontal). It was reported during the design stage that the material to be used was not dispersive.

It was previously indicated that level discrepancies occur between the as-built drawings and a survey that was done of the dam during the first dam safety inspection (1993). A new survey was requested (2000), but was not provided. A section with different upstream and downstream slopes than the design were analysed in the first dam safety inspection report (1993). It was stated by Badenhorst (1993) that the correlation between the as built information and the 1993 survey is questioned as the dam apparently settled by up to 950 mm, where as the design stated that settlement in the order of 200 to 300 mm was predicted..The access bridge abutment reflect the settlement that has occurred.

A survey of the dam was done during 2010 by Directorate: Spatial and Land Information Management (D: SLIM). The survey shows deviations from the original design slopes and levels. The minimum NOC level of the embankment is
RL 1 116,06 m, whilst the design value is RL 1 116,50 m. This is discussed in **Section 6.2**.

Photo 7: Downstream slope of embankment after recent burning of the grass cover (2010/11/17)

6.1 Stability Analysis

Stability analysis of the dam was presented in all of the three previous dam safety inspection reports. The dam was found to be stable for the set criteria.

Unfortunately no results of actual material properties used in the construction of the embankment is available. A geotechnical report on materials and the foundation was compiled during the design stage by Dr. BC van Wyk and Prof. A van Schalkwyk. This properties used in the design analyses are shown in **Table 6.1**. An horizontal earthquake loading of 0,1 g for the design earthquake and 0,18 g as the maximum earthquake was used to determine the cross section. The designers concluded that the dam will be stable for slopes the provided, but that careful monitoring during construction of the material properties was required.

Material properties were obtained by Badenhorst (1993) for calculation of the stability of the dam wall for the first dam safety inspection report by using results of material tests obtained during the design stage. The properties used in that analysis as well as those in 2002 and 2005 are shown in **Table 6.2**.

The results of the previous stability analyses are shown in **Table 6.3**.

Table 6.1: Material properties used during design stage for stability analysis of Der Brochen Dam

Zone	Density (kg/m^3)	Cohesion (kPa)	Friction angle
Impervious material	2 000	10	28,0
Foundation	2 100	20	35,5

Table 6.2: Material properties for stability analysis in 1993

Zone	Density (kg/m^3)	Cohesion (kPa)	Friction angle
Impervious material	2 060	10	28
Sand Filter	1 500	0	32

Table 6.3: Results of the previous stability analyses

Load Case	Earthquake Loading	Date of Analysis			
		1988 (Design) (Mitchell & Greyling)	1993 (Badenhorst)	2002 (Kramer)	2005 (Segers)
Rapid drawdown	No	1,22	1,22	1,40	1,40
	Yes	1,10	-	-	-
Steady State Seepage FSL Filter operational	No	1,65	1,40	1,80	1,80
	Yes	1,25	-	1,40	1,40
Steady State Seepage FSL Filter blocked	No	1,20	-	1,30	1,30
	Yes	-	-	1,10	1,10

Notes:
1. 1988 analyses used earthquake acceleration of 0,1 g (horizontal).
2. 2002 analyses used earthquake acceleration of 0,065 g (horizontal) and 0,045 (vertical).

A stability analysis of the embankment was done using the Slide (RocScience) computer program. The software can compute the factor of safety using various methods. For this study, the Simplified Method of Slices by Bishop was used. The program converts the total unit weight of the materials to the required unit weight (either wet state, dry state or submerged state) for each load case. The load cases used and acceptable criteria are shown in **Table 6.4** and the results are shown in **Table 6.5**. The material properties in **Table 6.1** and **Table 6.2** were used as the properties are still considered valid.

Table 6.4: Load Cases for Stability Analysis for dam (2010)

Condition	Earthquake Loading	Applicable Slope	Minimum Factor of Safety
Steady Seepage (working filter)	No Yes	Downstream Downstream	1,5 1,2
Rapid Drawdown	No See Note 2 below	Upstream See Note 2 below	1,2 See Note 2 below
Rapid Drawdown (from half full dam to empty)	No Yes	Upstream Upstream	1,3 1,0

Table 6.5: Results of Stability Analysis for dam (2010)

Condition	Earthquake Loading	Applicable Slope	Factor of Safety
Steady Seepage (working filter)	No Yes	Downstream Downstream	1,754 1,339
Rapid Drawdown	No	Upstream	1,225
Rapid Drawdown (from half full dam to empty)	No Yes	Upstream Upstream	1,540 1,045

Notes:
1. 2010 analyses used earthquake acceleration of 0,1 g (horizontal) and 0,067 g (vertical).
2. Too severe load case (personal communication with Dam Safety Office).

It is concluded that the embankment complies with the above stability criteria.

6.2 Monitoring

Instrumentation

No instrumentation, such as piezometers or temperature gauges were installed during the construction of the dam. Also, no instrumentation has been added since completion of the dam.

Settlement

The first DSI report stated that settlement of 950 mm occurred during the first five (5) years of the dam's lifespan. The 2010 survey has shown the minimum NOC level of the embankment is RL 1 116,06 m, whilst the design value was RL 1 116,50 m. From the 2010 survey is it evident that only about 440 mm of settlement occurred, which is closed to the predicted 200 mm to 300 mm envisaged during design stage. Settlement should however still be closely monitored.

The settlement that has occurred reflects under the abutment of the bridge leading to the intake tower.

Seepage

The previous reports reported no signs of seepage on the downstream face of the dam. During the inspection held on 27 July 2010, no signs of wet spots on the downstream slope could be seen.

Seven (7) shallow manholes without lids collect and monitor seepage water from the internal chimney and blanket drain by means of strip drains. Refer to
Figure 6.1.

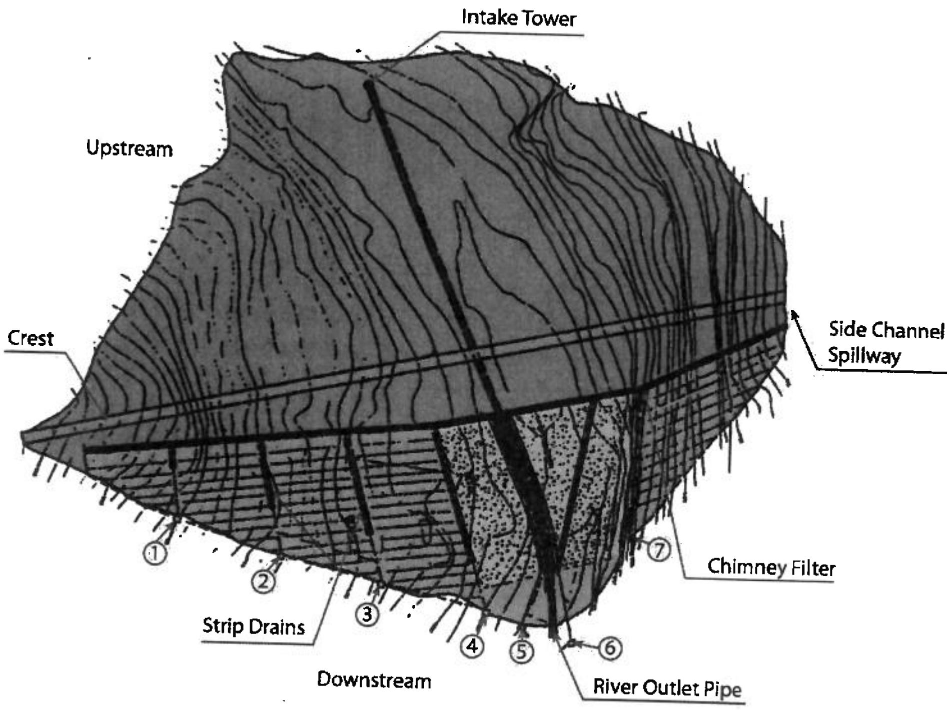


Figure 6.1: Manholes and collector strip drain layout

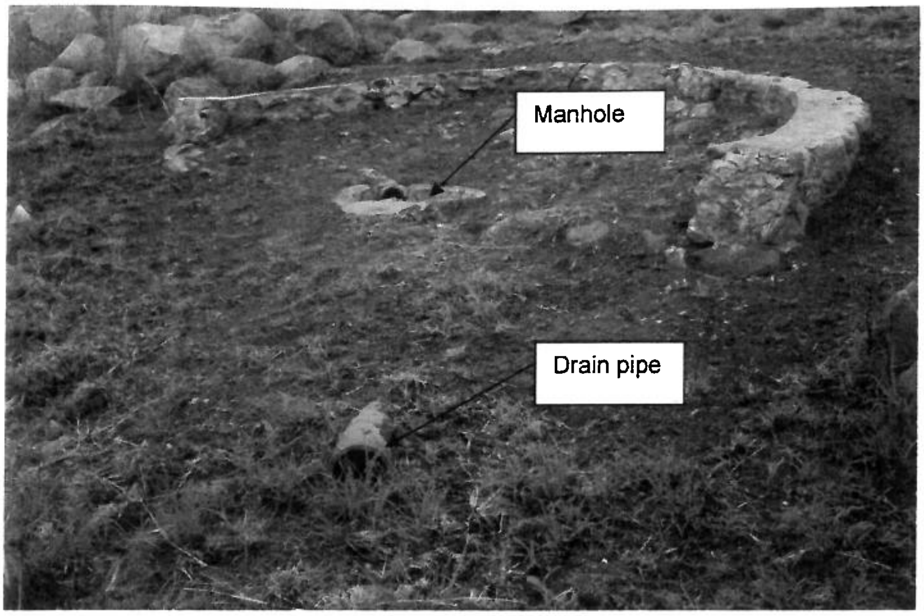


Photo 8: Typical manhole layout (2010/11/17)

Photo 9: Detail of a manhole (2010/11/17)

The following was observed during the inspection held on 17 November 2010:

- Manhole 1: Manhole was cleaned. No silt is present. No seepage.
- Manhole 2: Manhole was cleaned. Pipes from strip drain were silted up. No seepage.
- Manhole 3: Manhole was cleaned. No silt is present. A snake trail was visible on the silt inside one of the pipes. No seepage.
- Manhole 4: Manhole was cleaned. A wet spot was seen downstream of the manhole. No pipes could be seen coming into the manhole, or draining from it.
- Manhole 5: Manhole is silted up. Slightly moist.

- Manhole 6: Manhole is silted up. Reeds are present. Stormwater ponds around the manhole.
- Manhole 7: Standing water is present in manhole with slight in-flow. The outlet drainage pipe is blocked.

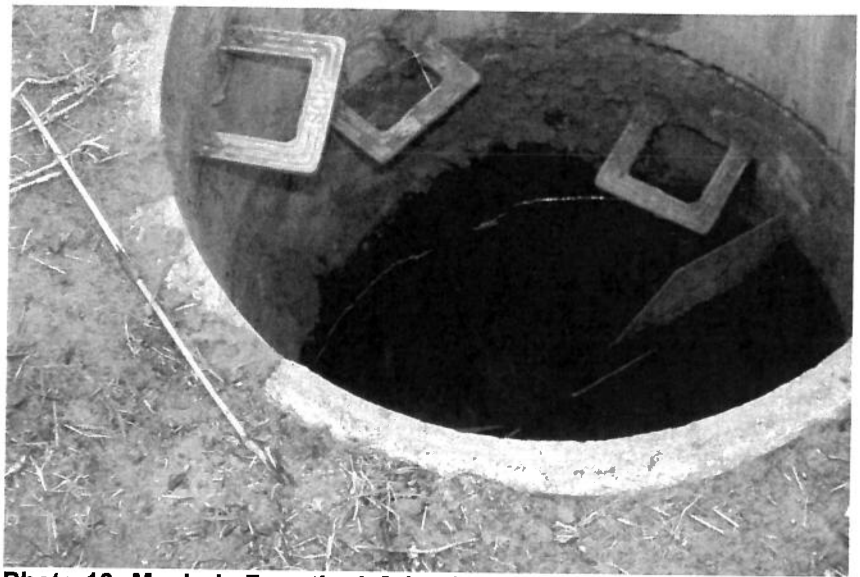


Photo 10: Manhole 7 on the left bank with seepage water ponding on the inside due to a blocked outlet pipe (2010/11/17)

7 INTAKE TOWER AND OUTLET WORKS

The outlet works comprises an upstream free standing cylindrical wet tower 28,5 m high (Appendix H), 3 m in diameter (OD) having cylindrical walls 300 mm thick with one 1 050 mm diameter bottom outlet pipe leading downstream. No downstream control is provided. Access to the inlet tower is gained from the centre of the embankment crest across a two span steel truss bridge and walkway.

Four intakes are located on opposite sides of the circular wet tower at two levels. The intakes situated on the outside are fitted with gate valves of the same size as the pipe. The valves are controlled from the top of the tower.

The sizes and levels are shown below:

Reduced Level (m)	Pipe size (mm)	Number Off
1093,70	300	2
	200	2
1095,80	300	2
	200	2

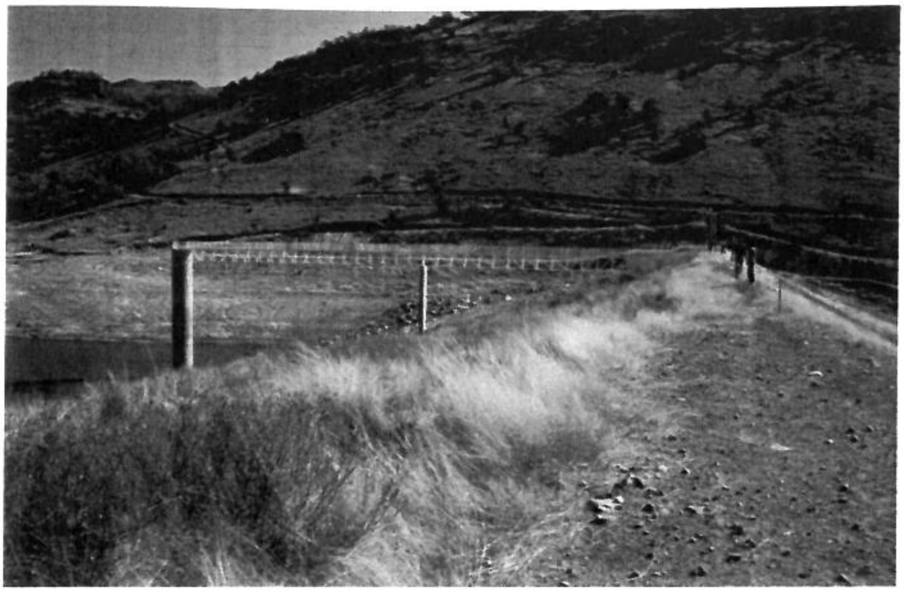


Photo 11: Intake tower and access bridge (August 1994)

Only one valve was operational at the time of the inspection. The alignment of the vertical access ladder with that of the steel hoods discharging the water to the bottom outlet pipe is not safe. During the inspection on 17 November 2010 sulpherous fumes were smelled at the level just before the steel hoods start.

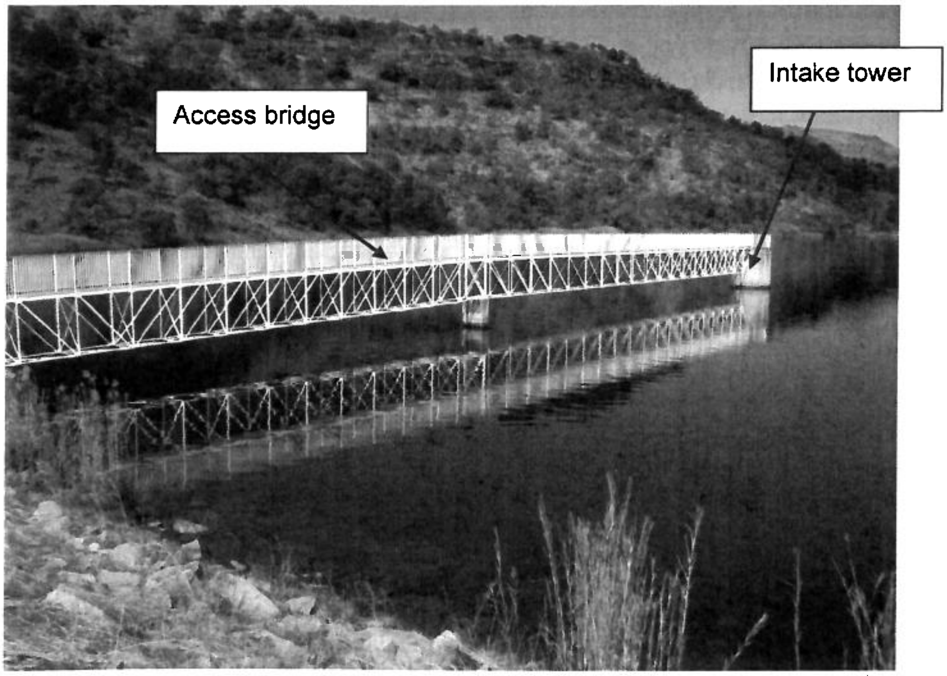


Photo 12: Intake tower and access bridge. Note kink in bridge girder at the pier sloping towards the embankment (2010/07/27)

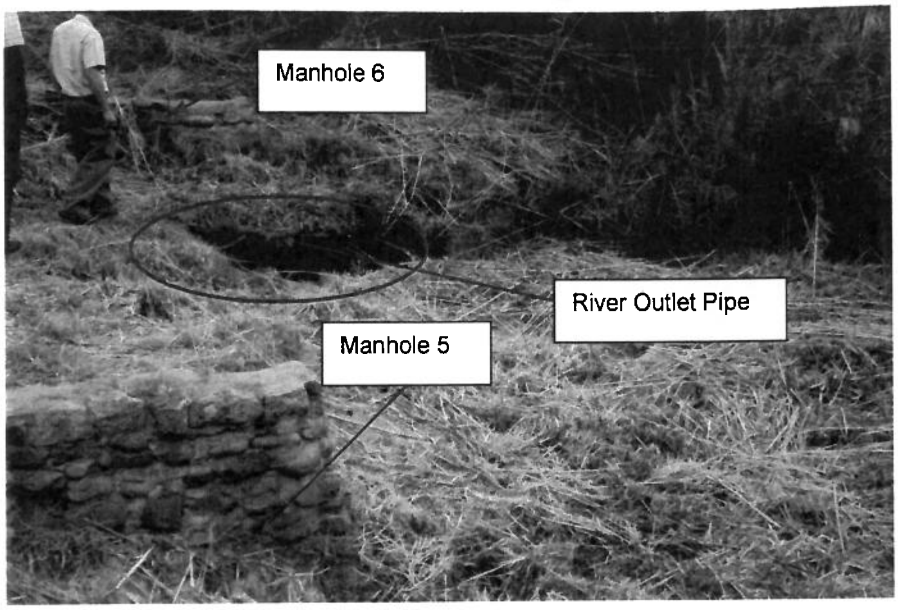


Photo 13: Outlet pipe to river (2010/11/17)

It was previously calculated that it will take between 30 (2001 report) and 45 days (2005 report) to draw down the dam from FSL to the lowest drawdown level (RL 1 093,7 m). An accurate area-capacity table is not available, thus the drawdown time could not be calculated.

Although the design of the tower is for a wet well, due to only one valve currently operational, the tower is for all practical purposes operated as a dry well, since the bottom outlet pipe takes the water away quicker than what is being supplied by the operation of a single valve.

7.1 Stability

In this evaluation a pseudo-static earthquake stability analyses (hand calculation) was done of the structure. Stresses at the heel and toe of the base were calculated, as well as a sliding Factor of Safety. The tower was analysed as a dry well.

The following load combination was used in the stability analyses of the Intake Tower:

- Load Case A: Dam at Full Supply Level with Earthquake loading.

A case with the dam at Safety Evaluation Flood level was not considered to be more critical as the earthquake loading.

Full uplift was assumed over the base of the Intake Tower. The Westergaard formula for earthquake loading was used to account for the force on the structure due to the inertia of the reservoir water. An acceleration of 01, g was used in the calculations.

The results are shown in **Table 7.1**.

Table 7.1: Results of Stability Analysis for Tower

Load Case	Permissible stress (MPa)	Permissible Factor of Safety	Stress at heel (MPa)	Stress at toe (MPa)	Factor of Safety (Sliding)	Factor of Safety (Overturning)
A	0,5	1,0	- 0,425	+ 0,561	2,20	0,55

Notes:
- \- = tension
- \+ = compression

The results of the preliminary hand stability check have shown the tower to be <u>not stable</u> under earthquake loading. It is recommended that a rigorous dynamic analysis be conducted to confirm the stability of the tower.

8 RISK AND IMPACT

The risk level as well as impact as a result of a failure was determined by using the procedures described by Oosthuizen (2000).

A level 0 risk analysis was performed. This entails performing a dambreak analysis and routing the dambreak flood downstream using NWS SMPDBK (Fread et al: 1987). The results of the routing was then plotted on 1: 50 000 topographical maps and used to determine the population at risk, direct and indirect monetary losses as well as the socio-economic, social and environmental impacts in the case of failure. These results are presented in **Table 8.1**. **Appendix L** shows the risk and impact calculations as well as the maps showing the inundated areas.

Table 8.1: Results from dambreak analysis to be used in the impact determination

Item	Result
Population at risk	1900 to 2000
Monetary loss: Direct	R 140 to 180 million
Indirect	R 280 to 360 million
Socio-economic impact	Moderate to high
Social impact	Low to moderate
Present ecological state	Class D

The different impacts resulting from a dam failure were determined using graphs (Oosthuizen: 2000). The results are presented in **Figures 9.1** to **9.6**. From these graphs it is determined that the population at risk is *unacceptable,* the financial impact, approached unacceptable, and the the socio-economic impact, the social impact as well as the ecological impact are all relatively *acceptable*.

The above however did not establish the dependency of the mines on the water for their processes, which is unknown.

Using the methodology described by Oosthuizen (2000), it was determined that 20 to 30 persons could lose their lives as a result of a dam failure (refer to **Appendix L**). According to the slope stability analysis as well as the visual inspection there was no apparent deficiency, the probability of failure of the dam was assumed to be between 1×10^{-3} and 1×10^{-4}. Using this, the annual risk of fatalities per exposed hour was calculated to be between $3{,}3 \times 10^{-9}$ and $1{,}7 \times 10^{-10}$ and the risk of monetary losses to be between R 54 000/annum and R 420 000/annum. These values were used to determine the risk level (see **Figure 9.6**). According to **Figure 9.6** the risk level of the dam is approaching un*acceptable*.

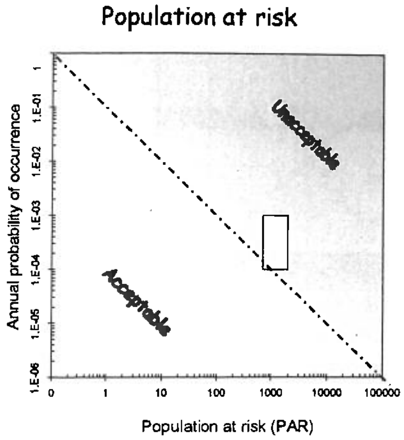


Figure 9.1: Population at risk

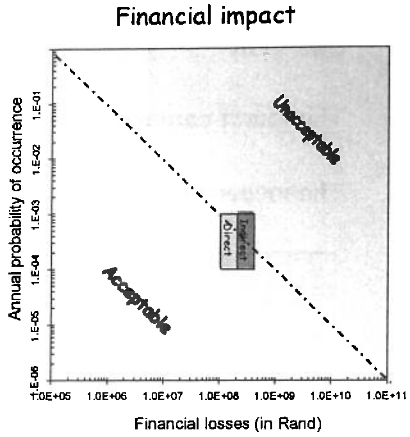


Figure 9.2: Financial impact

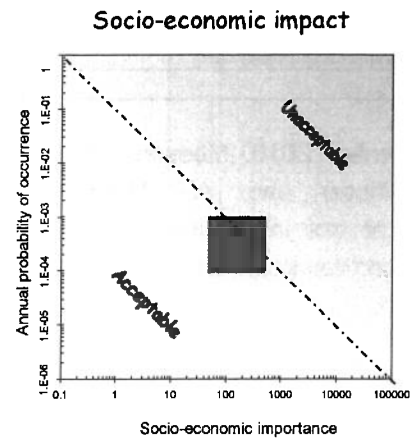


Figure 9.3: Socio-economic impact

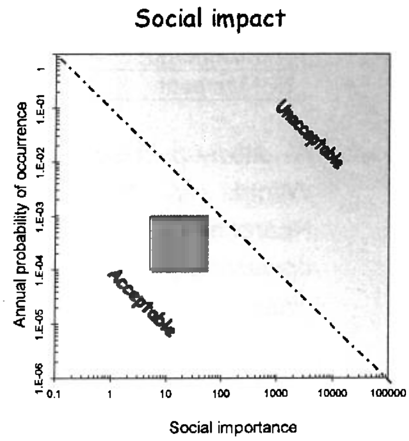


Figure 9.4: Social impact

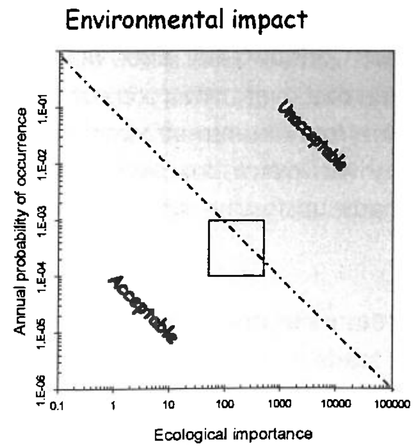


Figure 9.5: Ecological impact

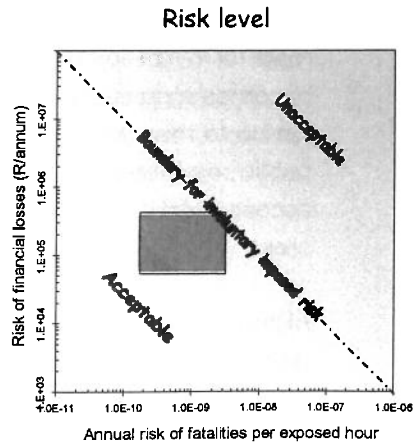


Figure 9.6: Risk level

9 SAFETY INSPECTION

9.1 Site Visit

The fourth dam safety inspection was carried out on 27 July 2010.

The following persons were present:

Name	Office
P. Barnard	DWA: Pretoria: Dam Design
F. Druyts	DWA: Pretoria: Dam Design
P. Duminy	DWA: Pretoria: Dam Design
K. Matjila	DWA: Pretoria: Dam Design
S. Mthethwa	DWA: Pretoria: Dam Design
J. van Zyl	DWA: Pretoria: Dam Design
HJ. Wright	DWA: Pretoria: Dam Design
A. van Schalkwyk	KHH: Engineering Geologist
K. Pretorius	DWA: Groblersdal: Operations (Limpopo)
M. Hendriks	DWA: Groblersdal: Operations (Limpopo)
A. Msimango	Buffelskloof Dam (Water Control Officer)
B. Mameshi	Mapoch's Mine

A follow-up inspection was held on 17 November 2010. Messrs. JP van Zyl , HJ Wright, A Msimango (Water Control Officer) and W Matsabe (Regional Representative) were present. The purpose of this inspection was to inspect the downstream slope for seepage after the grass on the slope was cut and burned, and to inspect the manholes after it was cleaned open.

9.2 Access

The dam is approximately 35 km west of Lydenburg. About 310 km from Pretoria past the De Hoop Dam towards the town of Steelpoort, turn off from the R555 at the first turn off towards Lydenburg (Mashishing). Carry on with the tar road for about 14 km up to the Thorncliff Mine, turn-off to the right. Carry on with the newly tarred mine access road for 8 km to the Der Brochen Mine Project Control Gate, after which the roads becomes a gravel road. Carry on with this gravel road over mine property for another 7 km up to the dam, for a total distance of 15 km from the turn-off from the Lydenburg public road towards Thorncliff Mine. Cross the river over a low level crossing and an access road on the downstream right bank leads up to the right bank embankment crest.

Alternatively a steel foot bridge crosses from the mine gravel haulage road along the left bank over the side channel spillway, which leads to the earthfill crest. Access to the intake tower is reached by a second steel bridge. The tower cannot be reached by vehicle.

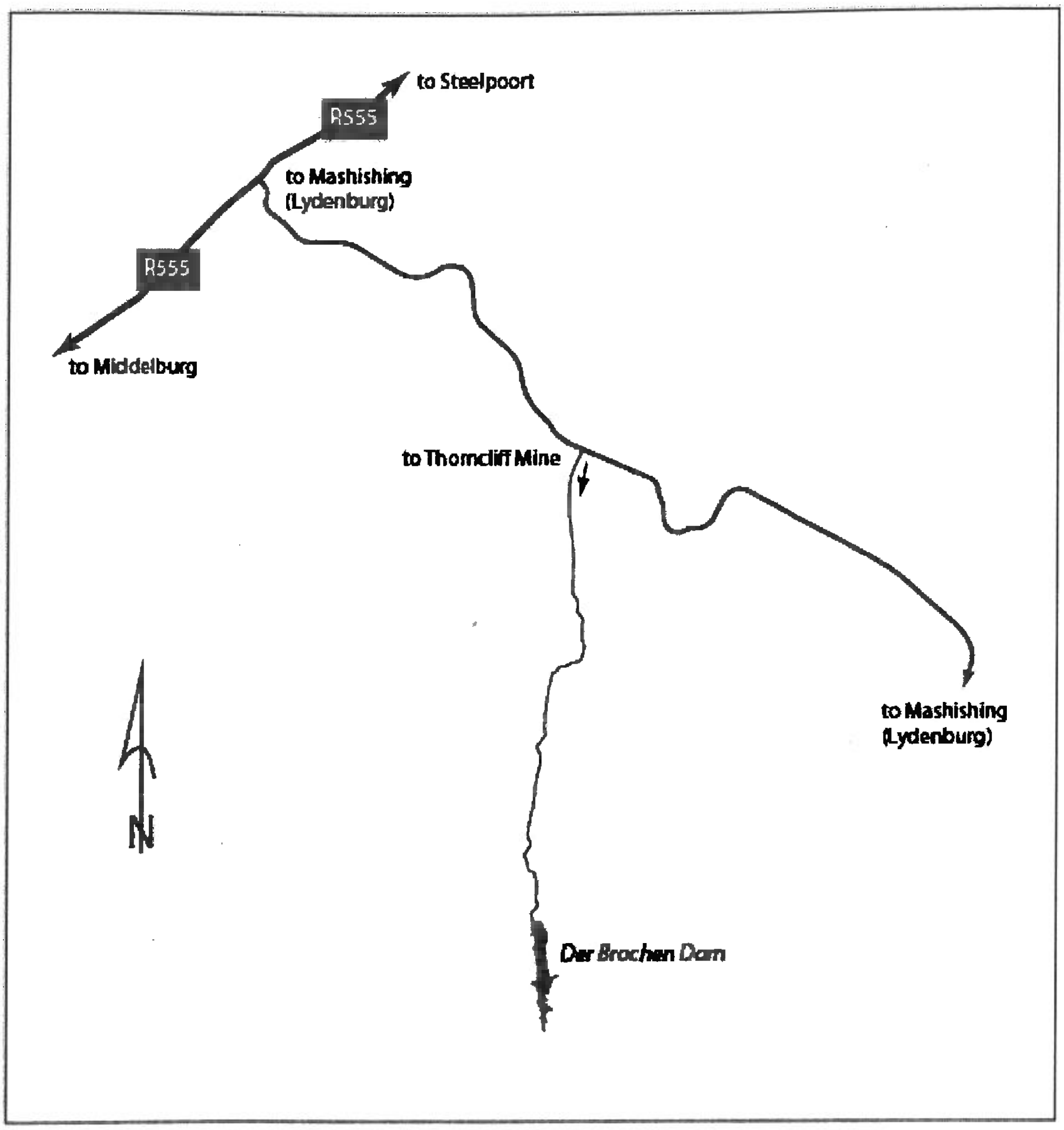


Figure 9.1: Access to Der Brochen Dam

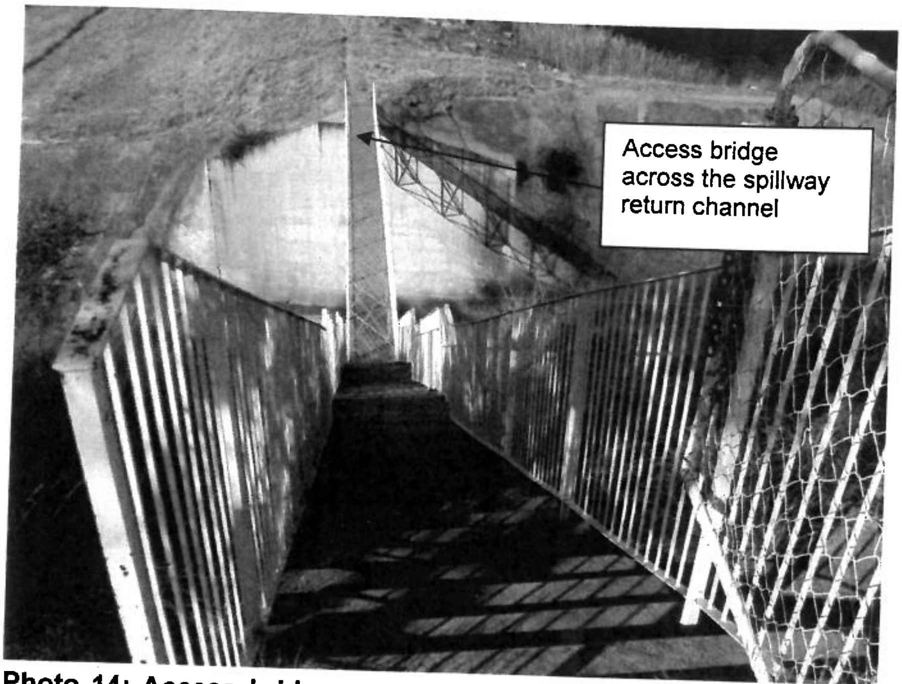


Photo 14: Access bridge over side channel spillway for access to the earthfill embankment

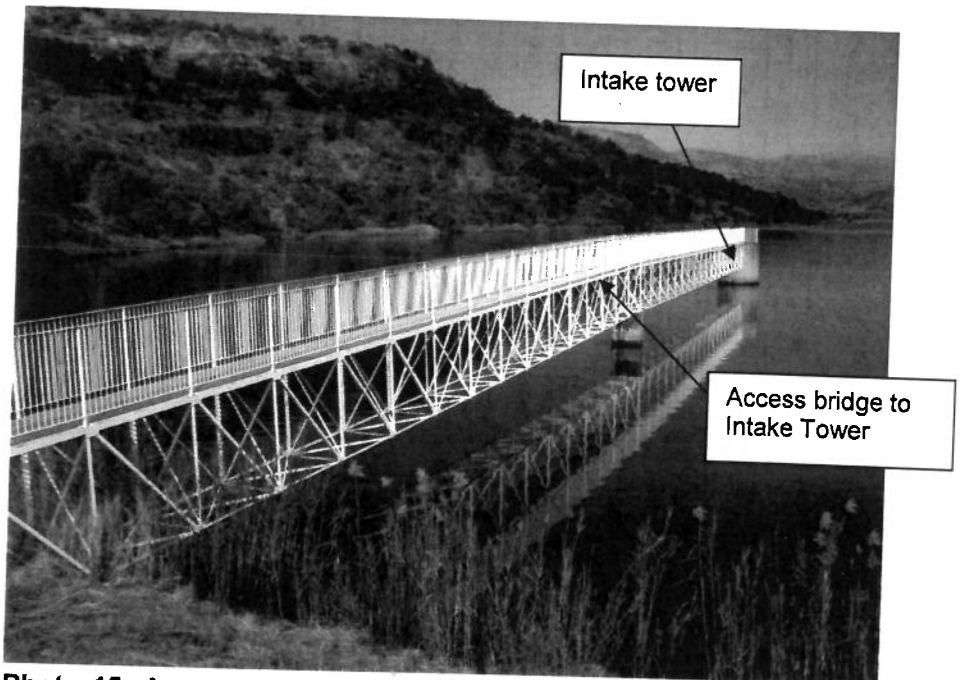


Photo 15: Access bridge to the Intake Tower from the earthfill crest. Note the kink in the vertical alignment at the pier due to settlement of the bridge abutment of approximately 600 mm. The lateral stability of the bridge is a concern.

9.3 Visual Dam Inspection

The water level was 50 mm below the Full Supply Level on 27 July 2010 and 1,2 m below FSL on 17 November 2010.

The dam is on the property of Anglo Platinum. A high level of security is maintained at the entrance of the mine's property, which could result in delays should the dam have to be reached in case of an emergency. Access to the dam must be arranged via the mine management.

There is no Water Control Officer or related personnel stationed at the dam. The operating personnel are resident at the nearby Buffelskloof Dam. An Operation and Maintenance Manual and Emergency Preparedness Plan exist, both in Afrikaans. These reports should be updated as well as translated.

9.3.1 Earthfill embankment

Non-overspill Crest

The NOC is covered with thin grass cover. Minor signs of local settlement are present on the crest, but no animal burrows, cracks or holes are present. Settlement has occurred under the support of the inlet tower bridge, as well as on the right abutment of the bridge across the spillway. The crest is uneven causing, downstream erosion due to surface water not being drained upstream. It is recommended that the crest be shaped to ensure proper surface run-off, as part of reinstating the design freeboard. This will also prevent ponding of water. Trees close to the toe of the wall should be removed.

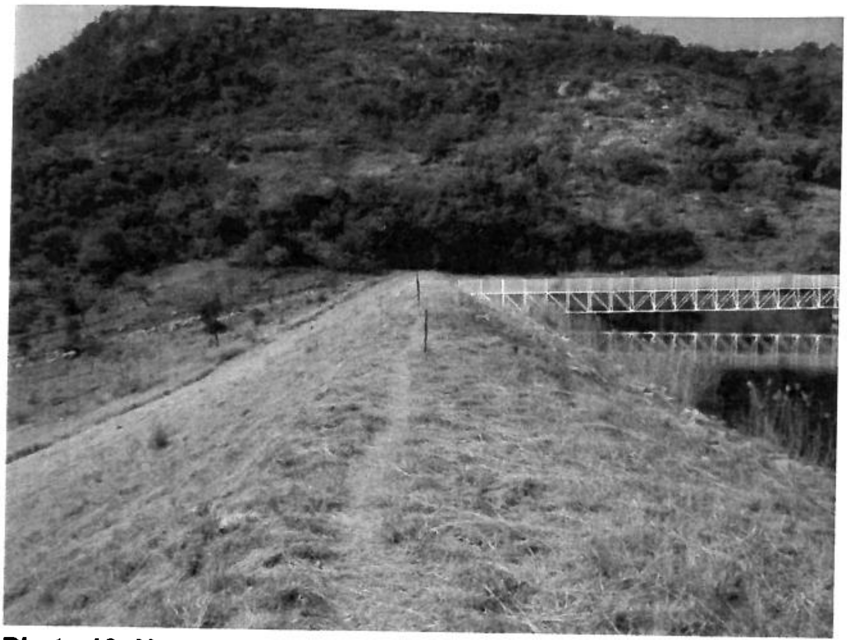


Photo 16: Non-overspill crest of the earthfill embankment on the left hand side of the Intake Tower access bridge seen on this photo. The grass on the upper portions of the dam was cut.

Photo 17: Signs of settlement on the embankment crest.

Upstream Slope

The slope protection consists of rip rap, but grass is present between the rock. Due to the high water level the upstream slope could not be inspected. No erosion, termite activity, big holes or slope failure is visible. It is recommended that the grass and reeds be regularly cut

Photo 18: Non-overspill crest of the earthfill embankment on the right hand side of the access bridge towards the Intake Tower. The grass on the upper portions of the dam was cut.

Downstream Slope

The downstream slope protection consists of grass cover. The grass was partially cut during the first inspection, and burned during the second inspection, enabling inspection of the slope for seepage and the manholes. No animal/termite activity was noticed. Grass and reeds in the proximity of the gauging weir should be removed. Erosion on the downstream slope close to the downstream toe is evident due to stormwater run-off over a large downstream surface.

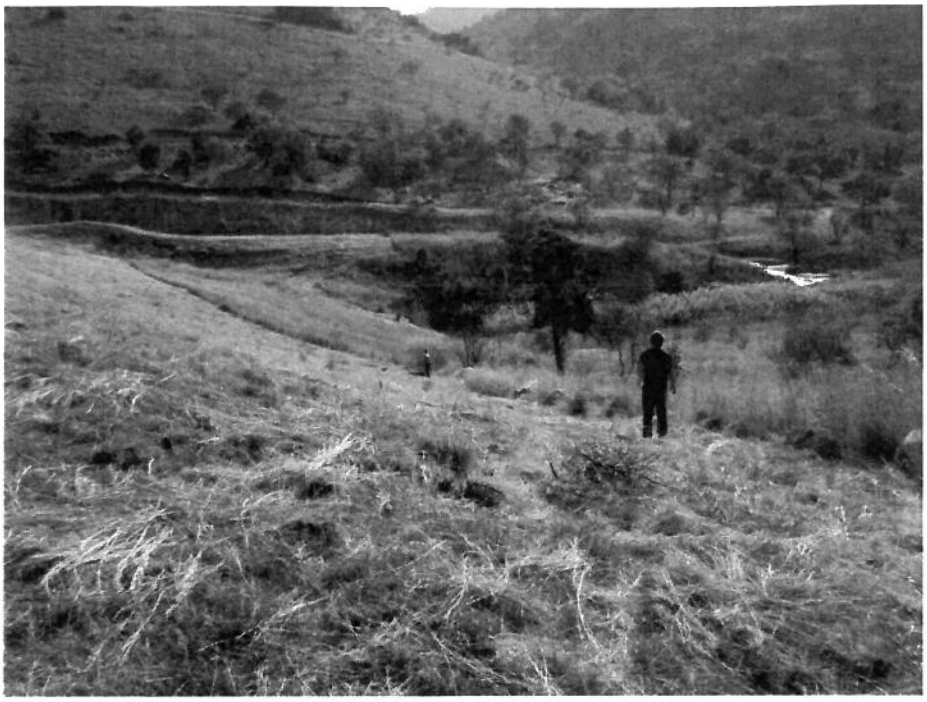


Photo 19: Downstream slope of the embankment seen from the right bank NOC. Cutting of grass took place for only the top half of the dam wall in July 2010. Subsequently, the cutting was completed and the slope burned.

Photo 20: Downstream slope of embankment seen from the downstream toe. Cutting and burning of grass took place during the period from August to October 2010.

Photo 21: One of the toe drain manholes that was previously overgrown with grass. Refer to Section 6 for details. Manhole covers are to be provided.

Photo 22: Pipes in manholes previously covered with sediment.

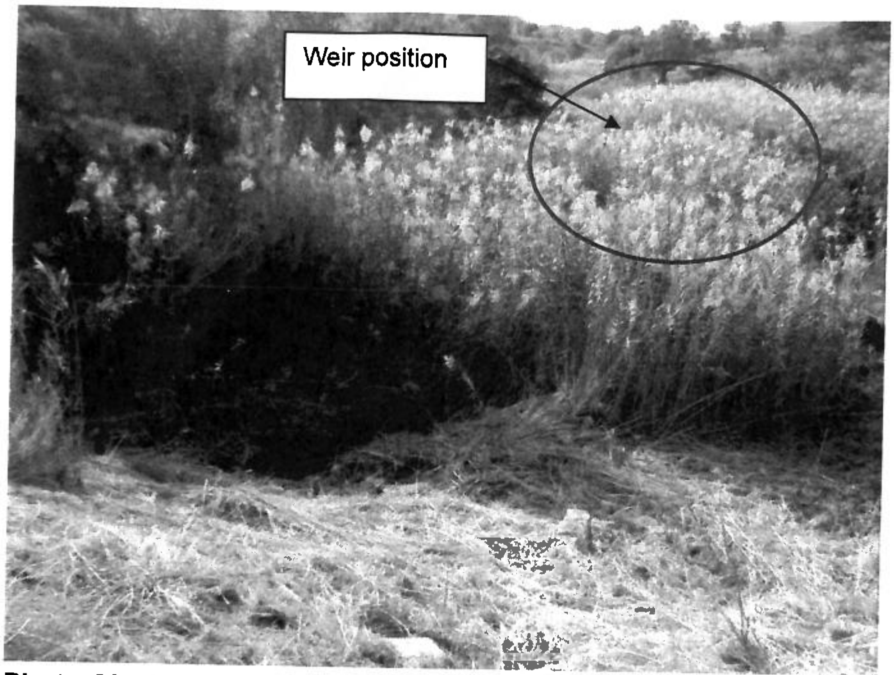


Photo 23: Gauging weir to monitor river releases and leakage from toe drains somewhere hidden in the reeds. Long grass in the area makes reading difficult. No signs of seepage could be found, but it is recommended that the grass and reeds in this area be cut and signs of seepage identified.

Note:

Burning of the grass was well planned and executed by Mr. Msimango. This procedure should actually be recorded in the Operation and Maintenance Manual. Burning was done from the Left Bank towards the Right Bank, in order to give animal and snakes a chance to escape into the natural veld on the Right Bank. The access road on the right Bank was widened and graded beforehand to act as a barrier to prevent the fire from going into the natural veld. The fire fighting teams of the mine was present to assist with controlling the burning.

9.3.2 Side channel spillway

The side channel spillway is located on the left hand side of the dam wall. Concrete was used for the construction of the upstream potion of the spillway crest. For the downstream section a thin concrete/mortar slab of 75 mm was cast on top of the soil cement fill. A proper rock foundation was apparently too deep which would have resulted in excessive cost. Shotcrete was used to protect rock against possible erosion from the water. The level of overflow varies, with the upstream concrete section overflowing first, followed by the downstream stabilised fill sections. A control structure to dissipate low flows is present.

The condition of the spillway appears to be similar to what was reported before.

Grass growing in the cracks of the spillway crest is to be removed. The loose spillway cladding will wash away during a flood event. The mortar cap sounds hollow below when tapped. It is recommended that cladding be redone. It is recommended that a safety barrier be provided to prevent personnel or members of the public who gain unrestricted access, from falling into the spillway.

Minor cracks in chute floor slabs are present, but are not a cause of concern. Erosion gulleys are present on the left bank, due to concentrated storm water form the left bank drainage berm not being maintained.

No major erosion in the spillway channel or downstream is witnessed.

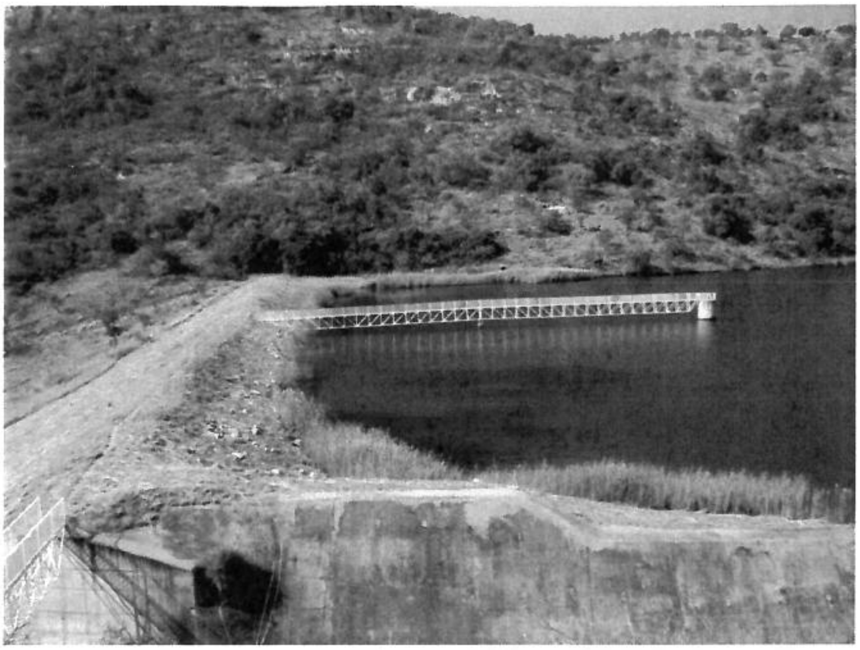


Photo 24: General view from the left hand of the side channel spillway. Note the kink at the pier of the access pedestrian bridge from the dam crest towards the intake tower.

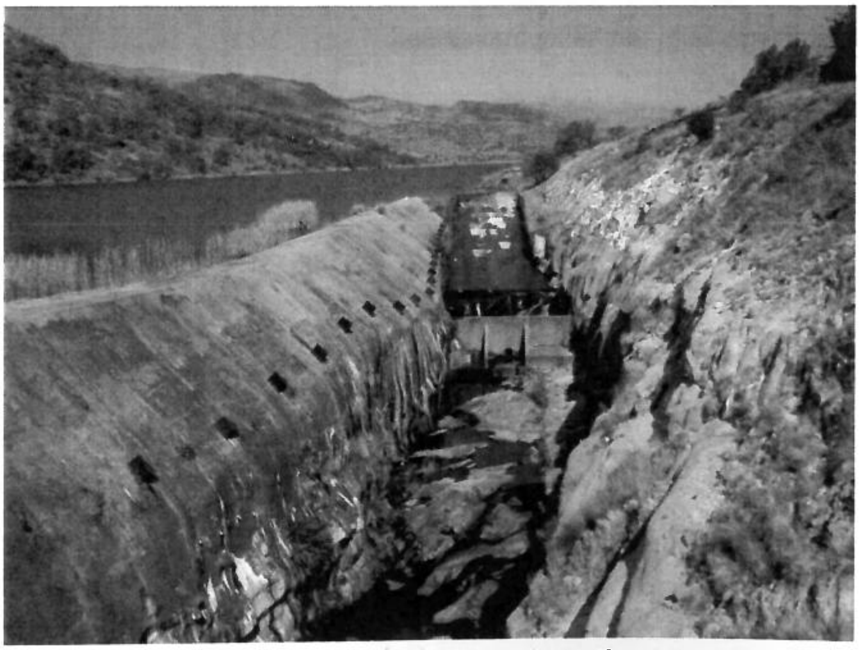


Photo 25: View of side channel spillway from the pedestrian foot bridge.

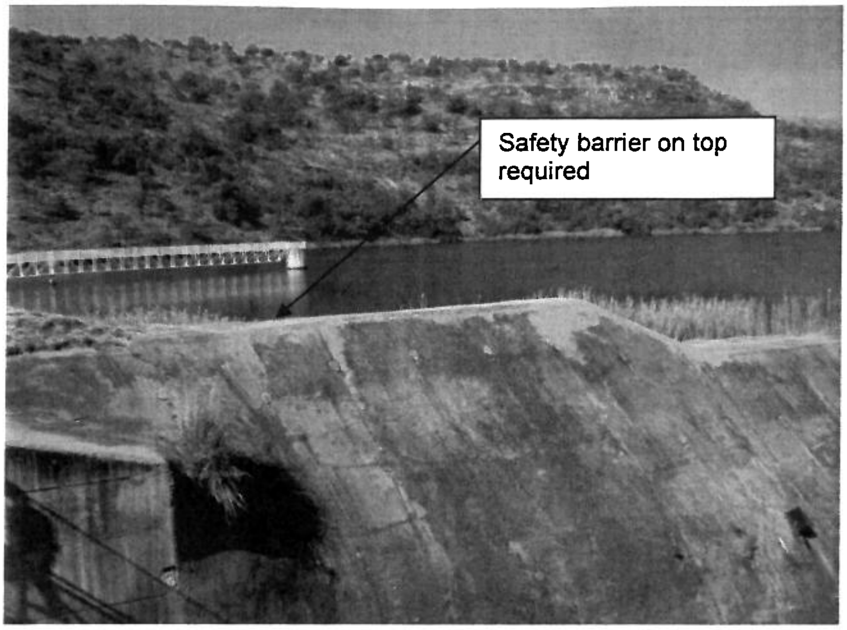


Photo 26: Side channel spillway and retaining wall at the connection between the spillway and earthfill embankment. It is recommended that a safety barrier be provided to prevent personnel from falling into the spillway.

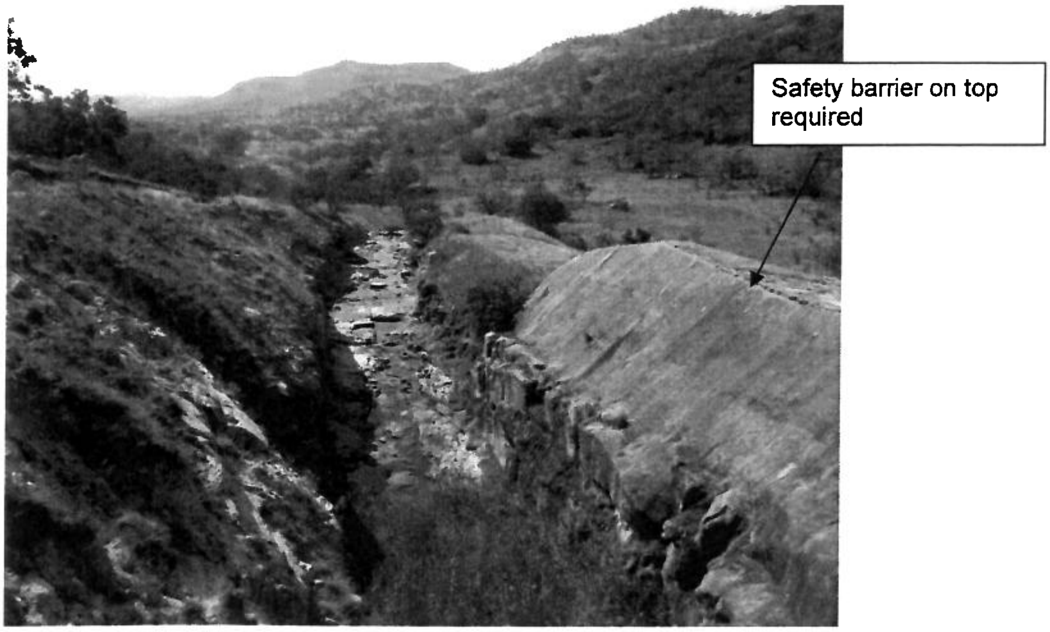


Photo 27: Downstream view of side channel spillway (photo taken from pedestrian foot bridge). Note shotcrete on right hand side.

9.3.4 General

The embankment dam does not appear to be in distress. However, major damage to the side-channel spillway may occur in the event of an extreme flood.

9.3.5 Mechanical and Electrical

The poor condition of the mechanical items at especially the intake tower is a cause for concern. The drawdown time of the dam in case of an emergency will be considerably longer than designed for, as it was reported during the site visit that only one of the valves are operational.

A separate mechanical and electrical inspection was done by Directorate: Strategic Asset Management. Refer to **Appendix J**. The following extract is taken from the inspection report:

- No safe access ladders to reach the bottom level of the tower is available;
- Ventilation in the tower is poor;
- No isolating facilities have been provided upstream of the valves to ensure service or repair;
- The outlet pipe system could not be inspected as no isolating upstream is possible;
- All valves must be isolated and tested; and
- The installation of a suitable discharge valve with a double isolating system must be investigated.

10 CONCLUSIONS

The following conclusions can be made:

- Due to the operating personnel not being stationed at the dam, as well as difficulty of access, operation and maintenance become extremely difficult, which is unfair to the dam operator.

- The embankment is in a reasonably good condition and does not show signs of distress.

- Erosion on the downstream slope close to the toe is evident due to stormwater run-off over a large downstream surface.

- Manholes for the toe drain system were cleaned open. Manholes are not covered.

- Grass on the downstream slope was cut and burned.

- Settlement of the dam crest has occurred.
- The embankment complies with stability criteria.
- No signs of leakage is visible on the downstream slope.
- The spillway capacity is not adequate.
- Grass growing in the cracks of the spillway crest is to be removed. The loose spillway cladding will wash away during a flood event.
- No safety barrier of any kind as fall protection is present along the top of the side channel spillway return channel. Personnel working at the dam are endangered.
- There is no safety boom present.
- The pedestrian access bridge from the left bank to the non-overspill crest is flimsy.
- The pedestrian access bridge to the outlet tower requires attention.
- A hand-check of the stability of the intake tower during a pseudo static earthquake analyses loading has shown the tower to be not stable.
- Due to the malfunction of valves the capacity of the outlet works is less than during design stage.
- Maintenance of the mechanical equipment is not done on a continuous basis.
- The poor condition of the mechanical items at and especially the intake tower is a cause for concern.

11 RECOMMENDATIONS

It is important to note that the purpose of the following table is not to duplicate recommendations and actions listed in the O&M manual. Personnel from the regional office should ensure that the Water Control Officer understands his responsibilities as required in the O&M manual. His duties and the detail check-list as per the O+M Manual should form part of their respective Performance Agreements.

Various recommendations made in the previous DSI reports have not received the required attention. This is unacceptable.

The letter by the Dam Safety Office (DSO) dated 02 November 2006 (Appendix B) expressed concern that almost none of the various recommendations made in the previous DSI reports have received the required attention . The comments of the DSO in the above letter that have not been taken into account during the past 5 years, includes:

- Recommendations such as the urgent compilation of an EPP, grouting of cavities beneath the spillway crest, reinstatement/checking of the available freeboard and rehabilitation of the outlet works;
- Arrangement for continuous monitoring of seepage/leakage and settlement.
- Although a risk and impact assessment was done as part of this report, it is recommended that the recommendation by the DSO for a detailed re-assessment of the loss of mining establishments downstream be done as part of the preparation of the EPP.

Routine maintenance:

Routine maintenance is to be done as per the approved Operation and Maintenance Manual. The following as per the site inspections requires attention:

Number	Ongoing Recommendations	2nd DSI	3rd DSI	4th DSI	Responsibility
1	Manholes of the toe drain system to be cleared of silt and grass and provided with covers	✓	✓	✓	Northern Operations
2	Reeds in vicinity of the bottom river outlet pipe to be removed to ensure free drainage	✓	✓	✓	Northern Operations
3	Trees and bushes within 30 m of the downstream toe of dam to be removed	✓	✓	✓	Northern Operations

Number	Recommendation within next 2 years	2nd DSI	3rd DSI	4th DSI	Responsibility
5	A formal EPP is to be drawn up	✓	✓	✓	Northern Operations
6	The Operation and Maintenance Manual and Emergency Preparedness Plan is to be updated and translated into English			✓	Northern Operations
7	Missing bolts to be provided for access bridge to Inlet Tower and structural stability to be checked			✓	Northern Operations
8	Appropriate warning signs to be erected at the various entrances where the public has access			✓	Northern Operations

Number	Recommendation within next 5 years	2nd DSI	3rd DSI	4th DSI	Responsibility
9	Recommendations made as per the mechanical inspection report to be implemented	✓	✓	✓	Northern Operations

A study is currently underway where the possible rehabilitation of the dam is being investigated. The following recommendations to be investigated as part of the study:

- All hollow areas below the spillway crest addressed;
- The embankment crest is to be re-instated to it's original level or higher and sloped to ensure that surface run-off occurs upstream;
- Access pedestrian bridge over spillway to be upgraded;
- Intake Tower dynamic stability analysis to be done;
- Safe access ladders are to reach the bottom of the intake tower is be provided; and
- Handrails at the spillway retaining wall.