DJ HAGEN (Pr Eng M Eng)

Reference No: DJH059-R01

3 December 2019

Sappi Paper and Paper Packaging
Private Bag X1001
Ngodwana
1209

Attention: Mr Errol von Berg

Dear Sir

REVIEW OF DAM SAFETY RISK AND PROPOSED REMEDIAL WORK ASSOCIATED WITH CATEGORY 3 NGODWANA DAM, MBOMBELA

1 Introduction and background

Ngodwana Dam is a 41 m high zoned earthfill Category III Dam. The dam is located on a tributary of the Elands River, Mpumalanga Province, directly upstream from the N4 highway and the Ngodwana Paper Mill, 40 km from Mbombela. The layout of the dam is shown in **Figure 1**.

Figure 1: Existing dams, rivers and pipelines

Since 1987, six dam safety evaluations (dse's)of the dam have been completed with the last one in September 2016. Annual dam safety reports (dsr's) are also presently conducted with the last one completed in September 2019 by Altus de Beer Consulting Engineer, who is also presently the Approved Professional Person responsible for the dam.

The 2016 dse report recommended further analyses and monitoring of the suspect downstream slope stability of the dam. These investigations were concluded in the 2019 dsr. The main conclusion from this report is quoted below for ease of reference:

"The principal safety risk for Ngodwana Dam is the precarious stability conditions of the downstream slope, as was determined as part and parcel of the 2018 dam safety report."

In this review report it is concluded that a downstream slope failure of the dam is a very likely potential failure mode, but that internal erosion of the poorly protected embankment core, internal erosion of the complex embankment foundation, specifically the embankment left flank, or internal erosion along the outlet conduit are other potential failure modes to be considered.

2 Site inspection

Preceding a project team meeting, a site inspection of the dam was completed on 19 November 2019. The dam was visited again on 20 November 2019 accompanied by Messrs Altus de Beer, Hennie Viviers and Hendry Nkosi. A photographic record of the site inspections is included in **Appendix A** with comments and items which should be addressed. The dam level at the time of the inspections were only a few metres below Full Supply Level.

3 Review of previous investigations

3.1 Dam safety evaluations (7 yearly)

The latest dse was completed in September 2016 and recommended further analyses and monitoring of the suspect downstream slope stability of the dam.

3.2 Annual dam safety reports

The investigations recommended by the 2016 dse were concluded in the 2019 dsr. These investigations are discussed in Section 3.4 and 3.5 below.

3.3 Embankment zoning

The embankment zoning is shown in **Figure 2** below. Areas of concern in this zoning are:

- The natural gravel inclined chimney drain may not comply with all filter criteria such as permeability (free-draining), collapsibility (cohesionless) and adequate protection of the base core material.
- The gravel strip drains are only for conveying seepage water from the chimney to the toe drain and do not provide continues protection to the foundation and shell zone as a filter blanket drain would have done.

1 FOUNDATION
2 DOWNSTREAM SHELL
3 NATURAL GRAVEL
4 IMPERVIOUS ZONE
5 GRAVEL STRIP

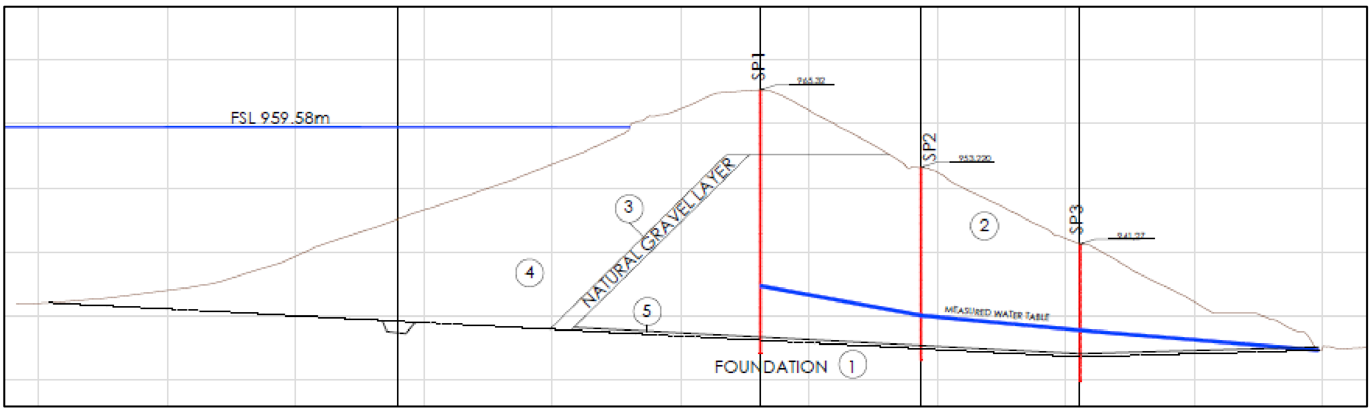

Figure 2: Embankment internal zoning

An original construction photo of the dam zoning is shown in **Figure 3**. The darker red colour impervious zone, light colour gravel layer and light red coloured downstream shell zone can be seen from upstream to downstream.

Figure 3: Embankment zoning during construction

3.4 Geological investigations

Mr A VAN SCHALKWYK is the team member responsible for geotechnical aspects. The regional geology map of the area is shown in **Figure 4**. The foundation geology is summarised in Drawing No SAPPI 2018-03 in **Appendix B**.

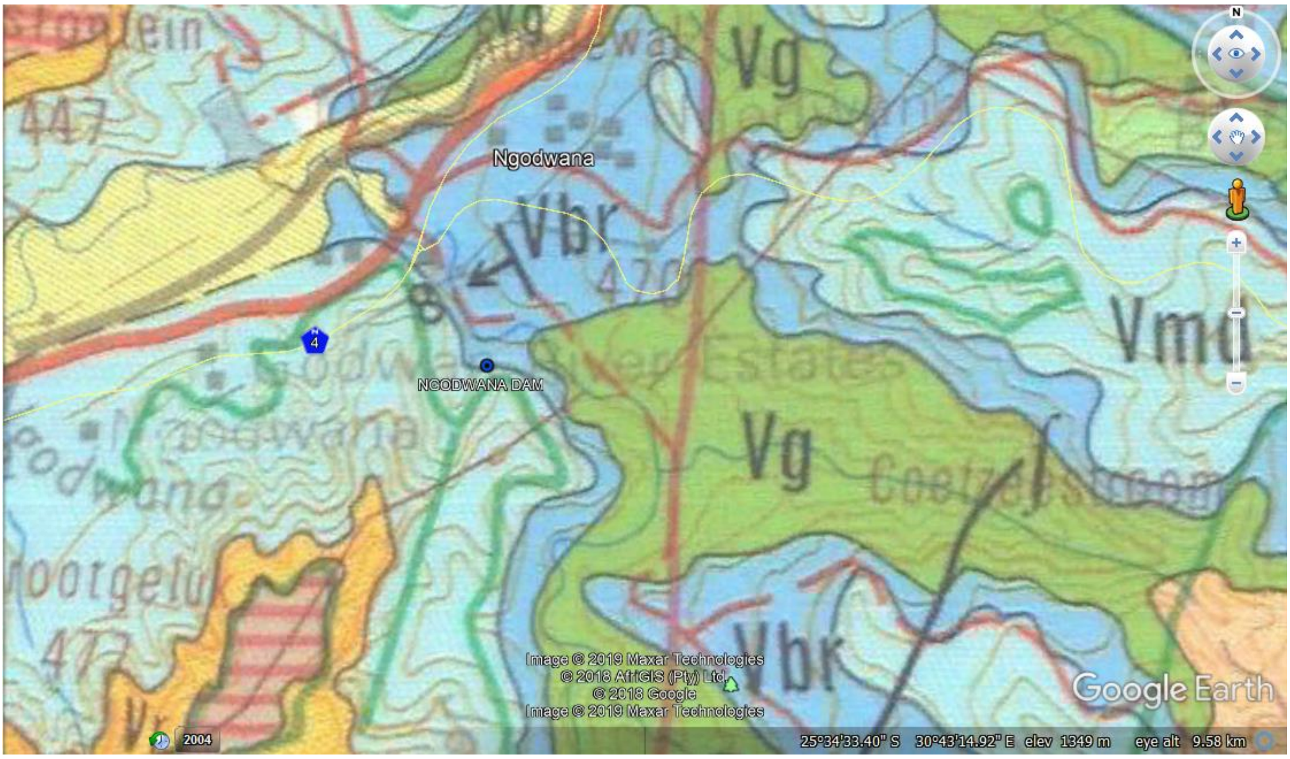

Figure 4: Regional geology map (Vbr: Quartzite & Vmd is dolomite & limestone)

The site geology is extremely complex due to the occurrence of a variety of sedimentary, volcanic and metamorphic rocks, unconformities in the sedimentary succession, faulting, variable weathering, thick alluvium in the river section, colluvium on the left flank and large dislodged quartzite blocks on the right flank. Although the embankment flanks are founded on some of these low strength materials, most of the embankment core cut-off trench was founded on the underlying quartzite bedrock. The upper part of the left flank core trench was extended upstream and was founded on weak tuff and partly cemented colluvium. Parts of the right flank was founded on weak tuff, tuffaceous shale and agglomerate.

3.5 Instrumentation monitoring

Fortunately, good instrumentation monitoring results are available for the embankment including standpipe piezometers (7 No), embankment movement surveys and embankment seepage v-notches (4 No). The instrumentation layout is shown in Drawing No SAPPI 2018-01 & 02 in **Appendix B**.

The most significant observations that can be made from the dam safety instrumentation monitoring are repeated below with additional comments provided in italics:

- *The 3 No piezometers at the "culvert" section show a lower phreatic surface within the embankment, but this could be due to the drains provided along this outlet conduit. The 4 No piezometers at the "riverbed" section towards the left flank show a concerning high phreatic* *surface within the embankment. This is also the area where the wet area on the lower downstream face had been observed. The high observed phreatic surface indicate that the natural gravel layer does not effectively draw-down the phreatic surface. Saturated conditions exist below the phreatic surface leading to lower shear strength for embankment materials.*

- The portion of the embankment between the riverbed and the left flank foundation contact showed significant erratic movements over the past 5 years, e.g. beacon SB15 on the crest near the foundation contact show vertical settlement of 22 mm and horizontal (downstream) movement of 12 mm.
- However, during 2017 there was a vertical rise (upwards) of 11 mm. The precision survey of 5-9 August 2019 revealed that the entire extreme left portion of the embankment settled vertically by 7 mm and horizontally (downstream) by between 7-14 mm.
- Ngodwana Dam wall displayed large initial vertical and horizontal settlement, but settlements have now stabilised. Maximum vertical settlement (Beacon 7) of 200 mm occurred within the first year (1983-1984) after completion, then another 200 mm settlement during the next 15 years (1984-1999) and only 38 mm during the past 20 years (1999-2019). Total current vertical settlement is 439 mm.
- Horizontal movement of the dam crest (downstream) under the hydrostatic water load, followed the vertical settlement pattern. Total maximum horizontal movement (Beacon 6) is currently 246 mm, having stabilised to only 20 mm horizontal movement over the past 15 years (2004-2019).
- Seepage declined to less than 0.5 l/s. Measured seepage has steadily decreased from 3 l/s in 1997/1998 to less than 1 l/s in 2008/2009. Over the period 2008/2009-2012/2013 the measured seepage has again increased from under 1 l/s to about 1.5 l/s in 2015, but these “increases” could have been due to the measurement of “non-seepage” runoff at monitoring weir “Seepage 1 – internal drains”, which is no longer used in the calculation of total seepage. *The seepage decline might also be attributed to blocked toe drains.*

3.6 Slope stability analyses

In 2017/2018 seepage and slope stability analyses of two sections of the embankment were performed.

Material properties were obtained from extensive laboratory testing done on samples retrieved from the piezometer boreholes. The test results for the material in the downstream shell zone is shown in **Table 1**. Noticeable is the high clay content of average 27% and very low gravel content of 4% average. The material is clearly of low strength for a “shell” zone where normally coarser material is placed.

Table 1: Material properties of downstream "random" zone

SAMPLE DETAILS			TEST RESULTS												
BH No	Depth (m-m)	Sample No.	Clay (%)	Silt (%)	Sand (%)	Grav. (%)	PI (whole sample) (%)	GM	UCSC	Double H. Dispersion (%)	MDD (kg/m³)	OMC (%)	k (m/s)	c' (kPa)	Φ' (degrees)
SP1	14.04 – 21.00	A7/1720	29.2	15.1	48.3	7.4	13	0.81	SC	62					
SP1	21.00 – 30.04	A7/1721	20.4	11.7	60.0	7.8	10	1.01	SC		1877	12.4	6.5×10^{-7}	32.8	19.5
SP2	4.05 – 7. 53	A7/1722	24.0	11.3	63.6	1.2	10	0.83	SC	23.2					
SP2	8.08 – 14.14	A7/1723	24.0	11.5	63.5	1.1	9	0.86	SC		1827	10	1.4×10^{-7}	32.0	18.3
SP3	1.90 - 5.92	A7/1724	24.9	22.0	50.5	2.6	13	0.68	CL	26.4					
SP3	11.80 – 17.06	A7/1725	34.1	47.6	16.5	1.8	24	0.24	OH		1478	22.9	1.1×10^{-8}	0.4	29.0
SP4	13.00 – 19.15	A7/1726	28.9	13.9	47.7	9.6	14	0.88	SC	13.0					
SP4	19.15 – 26.15	A7/1727	23.7	9.8	65.0	1.5	9	0.91	SC		1864	11.0	2.2×10^{-7}	39.6	16.8
SP5	9.70 – 15.36	A7/1728	26.3	11.9	58.6	3.2	1	0.90	SC	13.7					
SP5	17.46 – 25.52	A7/1729	26.5	15.9	55.4	2.2	13	0.80	SC		1834	15.1	3.1×10^{-9}	15.9	25.7
SP6	1.84 – 6.55	A7/1730	27.8	15.1	54.1	2.9	13	0.81	SC	0					
SP6	7.55 – 16.00	A7/1731	26.5	12.2	55.9	5.4	11	0.89	SC		1609	15.	5.6×10^{-7}	13.4	20.3
SP7	2.20 – 6, 54	A7/1732	30.0	17.9	49.4	2.8	13	0.74	SC	10.5					
SP7	7.00 – 12.00	A7/1733	26.2	11.9	58.9	2.9	12	0.83	SC		1857	13.7	4.7×10^{-9}	33.0	24.4
AVERAGES			**26.61**	**16.27**	**53.39**	**3.74**	**11.79**	**0.8**		**21.3**	**1764**	**14.3**	$\mathbf{2.3 \times 10^{-7}}$	**23.9**	**22.0**

The safety factors achieved for the "steady state" loading case is shown in **Table 2**. The required safety factor for this loading case according to the United States Bureau of Reclamation is 1.5 and the achieved safety factors for the downstream slope are lower than this for Scenarios 1 & 4. Lower shear strength parameters were assumed for these scenarios.

Table 2: Slope stability analyses safety factors achieved

Scenario	Downstream Slope Stability		Upstream Slope Stability	
	Riverbed Section	Culvert Section	Riverbed Section	Culvert Section
1	1.672	1.606	2.228	2.248
2	1.326	1.289	2.228	2.248
3	1.629	1.539	2.228	2.248
4	1.175	1.193	2.228	2.248

Further slope stability analyses are recommended during design stage of the proposed remedial works to include:

- Further triaxial shear strength testing of representative embankment material samples, under both drained and undrained conditions
- Deeper slope failures of the downstream face to include a section of the embankment crest, which will result in an overall dam failure.
- Modelling the various zones in the embankment foundation to check for foundation failure contribution.
- Modelling a section of the right flank of the embankment and its foundation.
- Rapid draw-down loading case for the upstream face.
- Seismic loading cases.

3.7 Conclusions

Seepage and slope stability analyses show lower than normally accepted safety factors against slope failures of the embankment downstream face. The material in the large downstream shell zone of the embankment is of low strength and erodible.

The standpipe piezometers show a high phreatic surface within the embankment at its highest section where a wet area on the lower downstream face had also been observed.

The portion of the embankment between the riverbed and the left flank foundation contact showed significant erratic movements.

The effectiveness of the embankment internal drainage system and toe drain is suspect.

4 Potential failure modes

The following is considered likely potential failure modes of Ngodwana Dam with items contributing to concern noted.

Table 3: Potential failure modes

Failure mode	Items contributing to concern
1. Downstream slope failure	• Low strength and erodible downstream shell zone material • No blanket drain • Effectiveness of toe drain uncertain
2. Piping through the foundation due to weak layers in the foundation	• Complex foundation layers • No blanket drain • Effectiveness of toe drain uncertain
3. Piping through the embankment core	• Chimney drain may not comply with all filter criteria
4. Piping along the outlet conduit/ embankment core contact surface	• Effectiveness of protection filters uncertain as seepage water contains clayey material

5 Hazard potential of dam

A dam break analysis conducted in 1987 indicated that the dam break flood peak could be as much as 11 000 m^3/s compared to the 1 in 200 year flood of the catchment of the dam of 832 m^3/s. A dam failure will cause significant damage to the N4 and SAPPI Mill immediately downstream of the dam, and also further downstream of the dam.

6 Risk to Sappi

Observations, analyses, original design shortfalls and instrumentation monitoring have identified likely potential failure modes of Ngodwana Dam. The present probability of failure of this Category III is considered too high.

7 Proposed remedial works

The proposed remedial work to construct a downstream stabilizing berm with an adequate internal drainage filter system and toe drain is supported. The proposed layout of the berm is shown in **Figure 5**. The extent and size of the berm should be optimized by further slope stability analyses. A new toe drain for the embankment flanks above the berm should also be considered. The berm toe drain should have manholes at regular intervals for maintenance and monitoring.

Figure 5: Proposed stabilizing berm on downstream face

8 Other items requiring attention

As part of this review investigation the following other items were identified and could be included in the remedial work scope of works (photographs in **Appendix A** are referred to in brackets):

- Remedial work to the breaching section downstream face local slip (Photos 18 & 19) and possible raising of the breaching section as it is no longer considered a necessary emergency spillway.
- Repair of outlet conduit joints where water with muddy material is leaking out.
- Spillway joint sealant replacement (Photos 15 & 16).
- Removal of trees along spillway discharge channel training walls and repair of joint (Photo 17).
- Provide safety handrails alongside the spillway retaining walls (Photo 11).
- Reservoir rim stability assessment.

Yours faithfully

DJ Hagen
Pr Eng

Appendix A: Photos

Photo 1: General view of spillway and dam embankment from right flank (19 November 2019).

Photo 2: Spillway discharge channel looking downstream from right flank (19 November 2019).

Photo 3: Embankment crest from end of right flank (19 November 2019). Note survey fixed station for movement monitoring.

Photo 4: Lower upstream face of embankment showing good rip-rap upstream slope protection (19 November 2019).

Photo 5: Lower downstream face from end of left flank (19 November 2019). Note survey fixed station for movement monitoring.

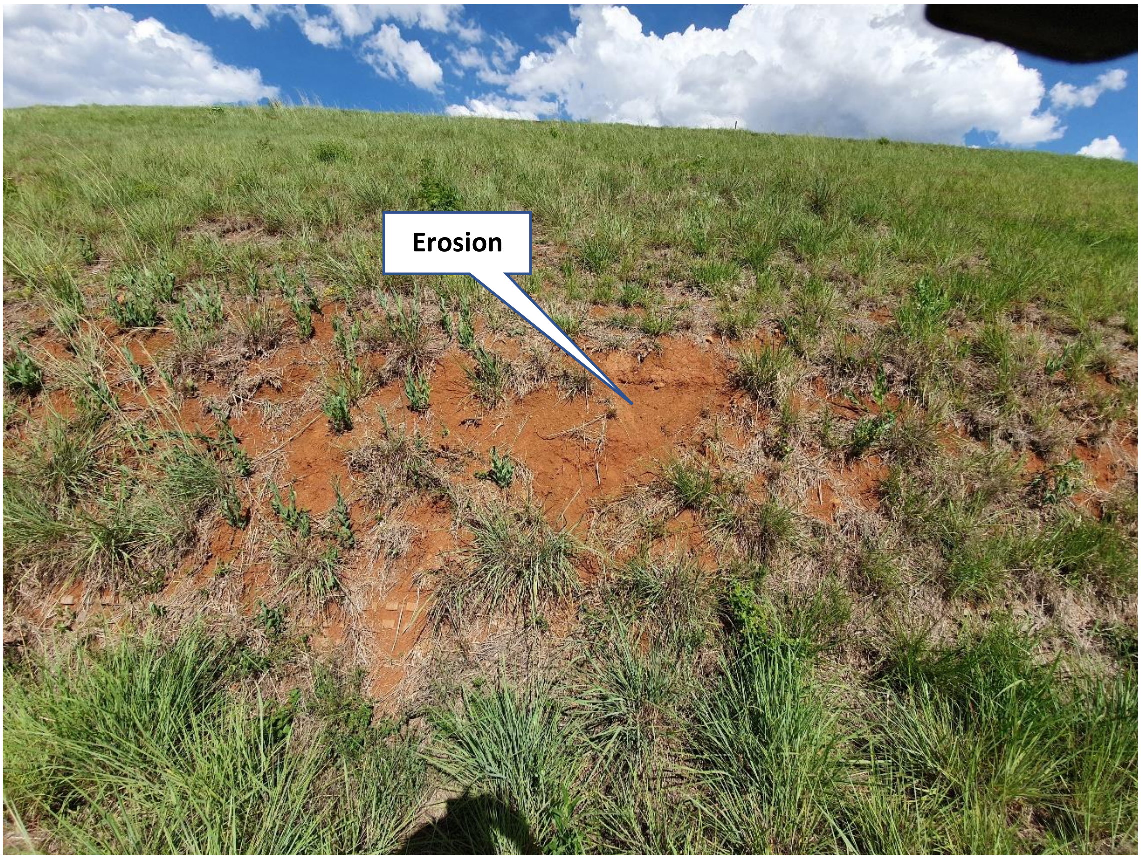

Photo 6: Downstream face erosion on steeper slope section typically above berm drain (19 November 2019). Note reddish clayey sand embankment material exposed.

Photo 7: Downstream toe on lower left flank (19 November 2019). Note wet conditions which could be attributed to high phreatic surface within embankment.

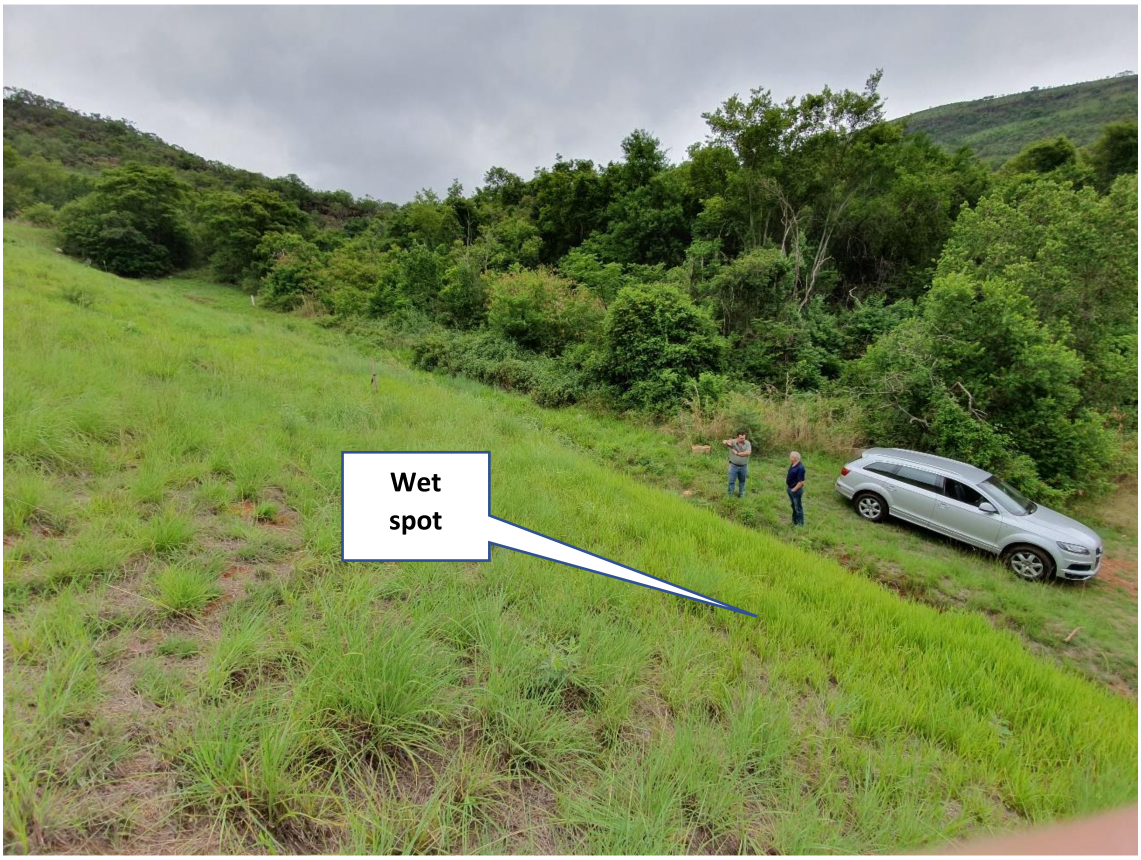

Photo 8: Downstream toe on lower left flank (20 November 2019). Note wet spot referred to in previous reports.

Photo 9: Downstream face from left flank (20 November 2019). Note longitudinal crack likely caused by surface slip movement.

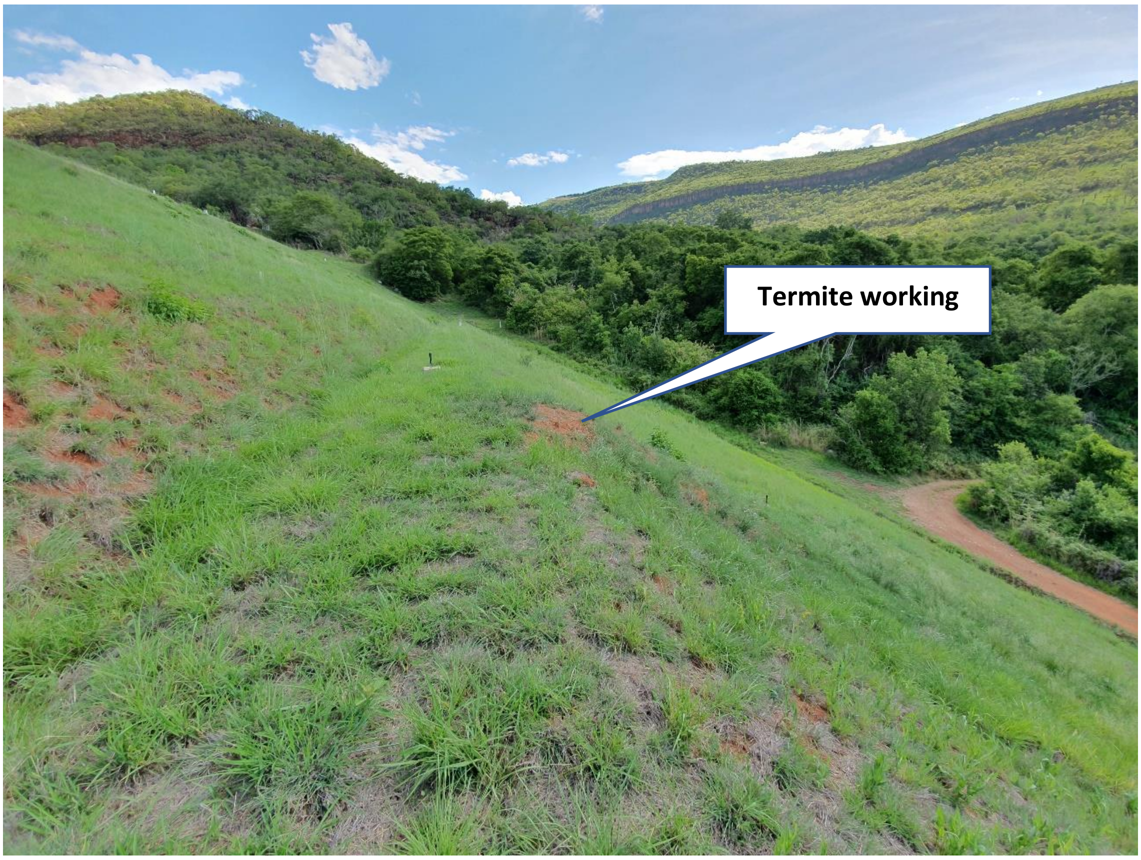

Photo 10: Lower berm on downstream face towards left flank (19 November 2019). Note dormant termite working.

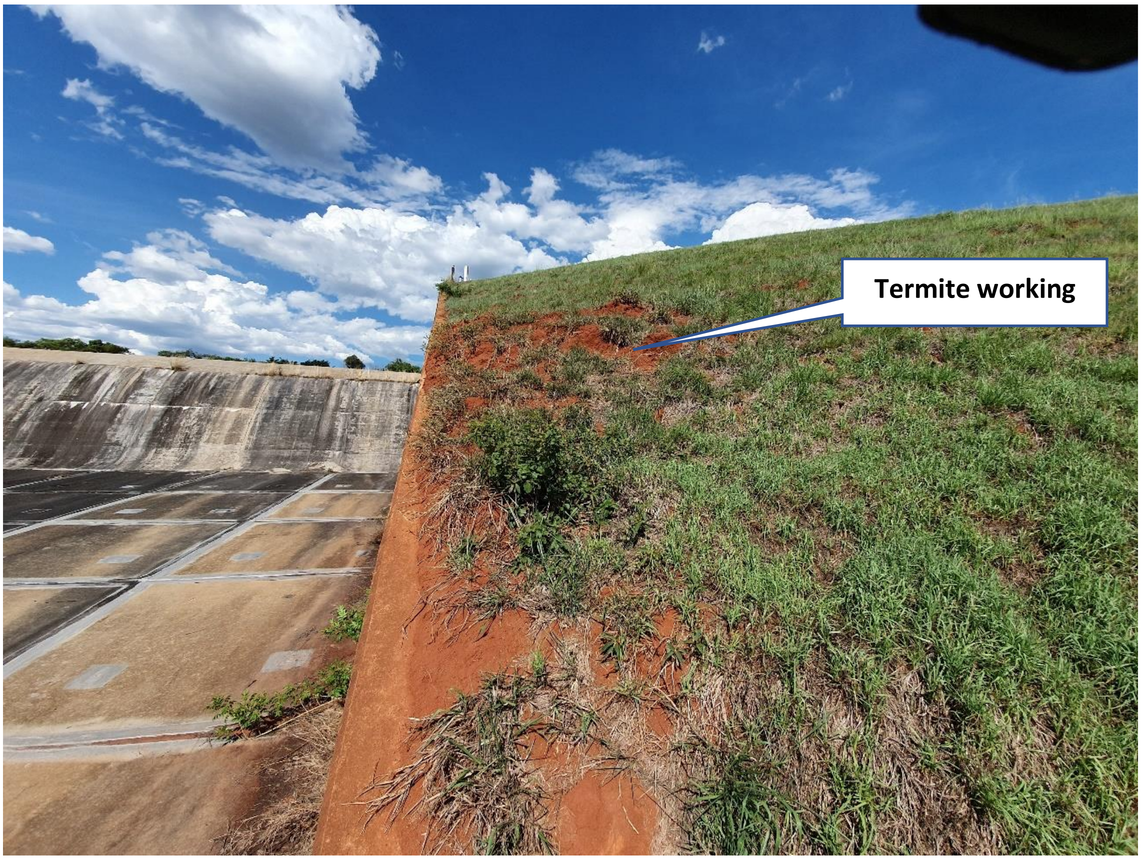

Photo 11: Spillway left retaining wall contact with embankment (19 November 2019). Note dormant termite working. Also note no safety handrail.

Photo 12: V-notch weirs in chamber at embankment toe to measure seepage flow from sub-soil drains (19 November 2019). Note overgrown state and sediment which will influence accuracy of readings.

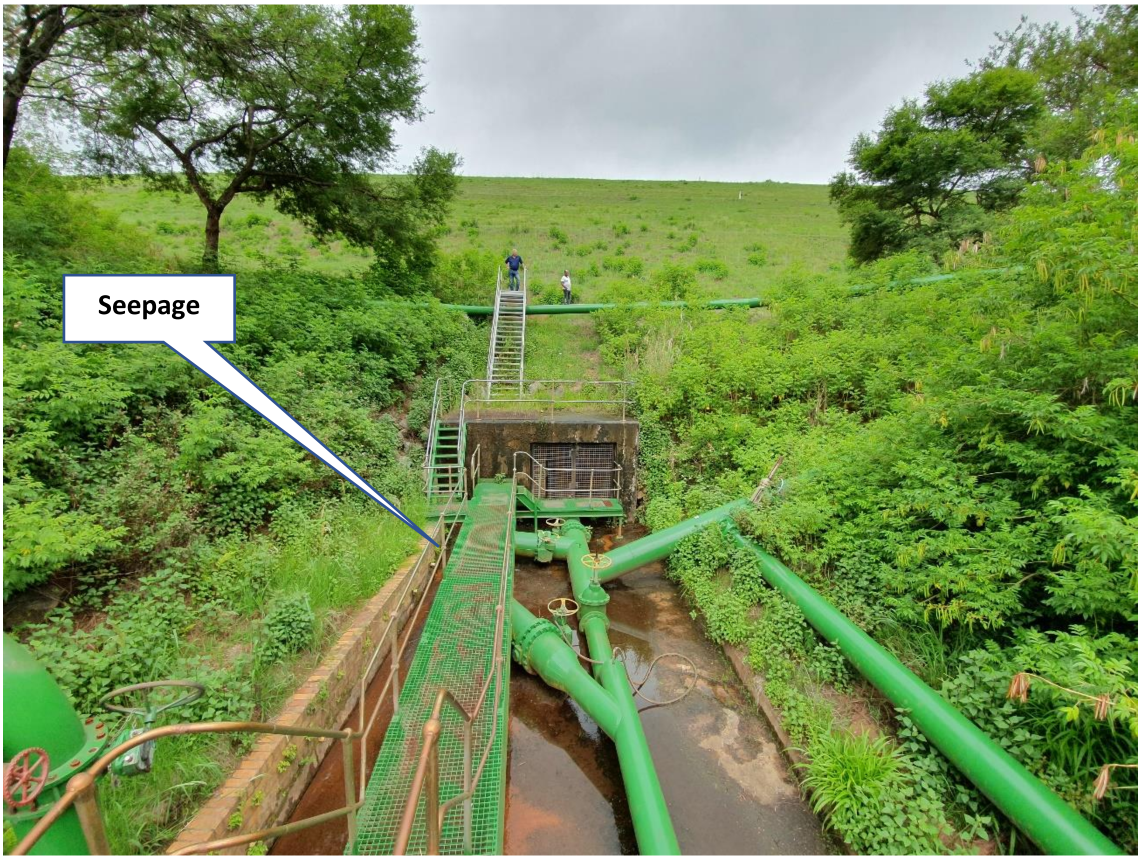

Photo 13: Outlet conduit exit at embankment toe (20 November 2019). Seepage was noted emanating from sides of conduit monitored at v-notch weirs.

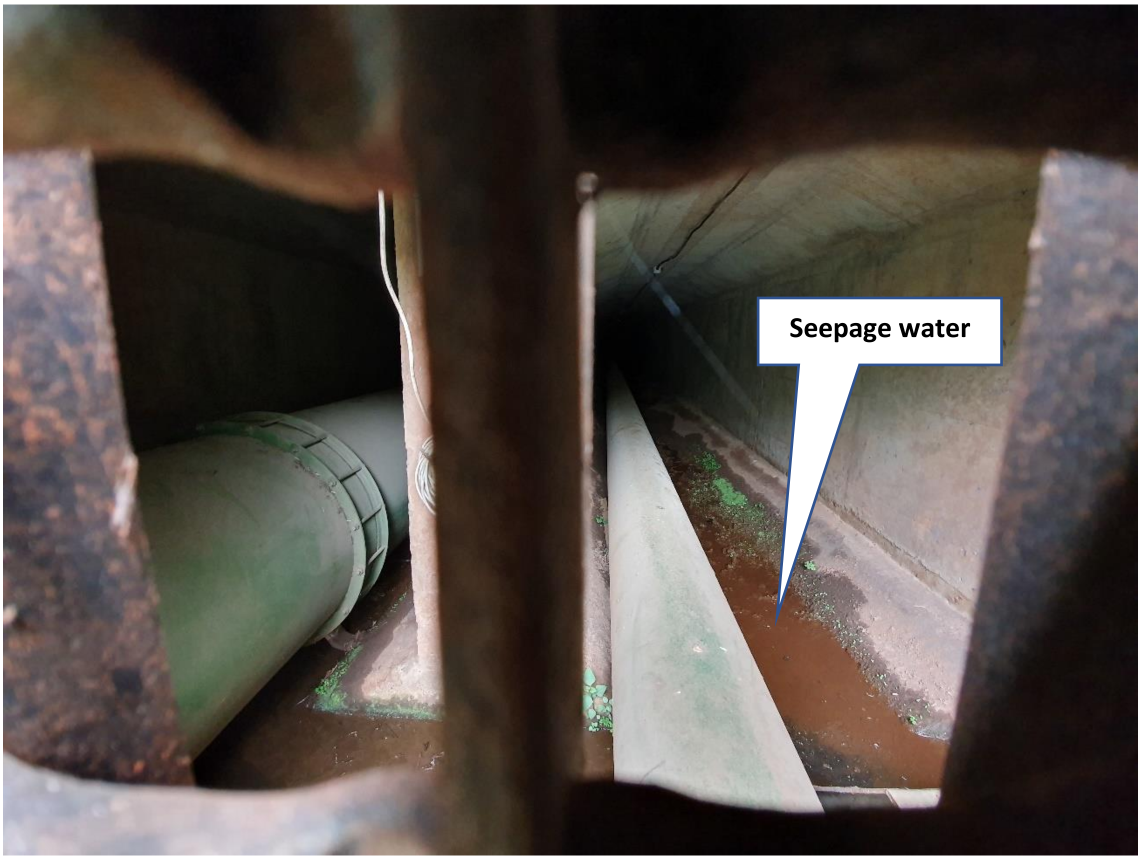

Photo 14: Double barrel outlet conduit (20 November 2019). Note seepage water with clayey deposits.

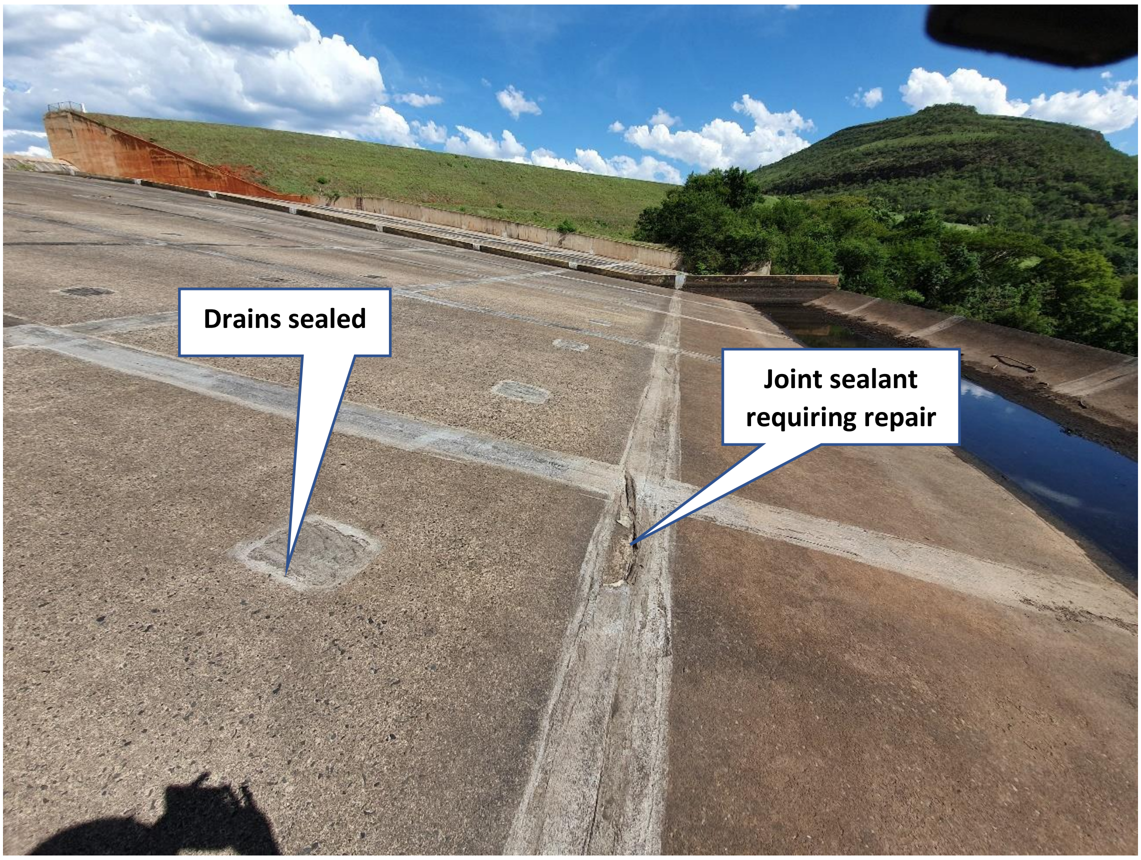

Photo 15: Spillway lining joint sealant requiring repair (19 November 2019). Note lining drains also sealed.

Photo 16: Spillway lower lining steep section (19 November 2019). Joint sealant also requiring repair.

Photo 17: Spillway right training wall joint movement likely caused by tree roots (19 November 2019).

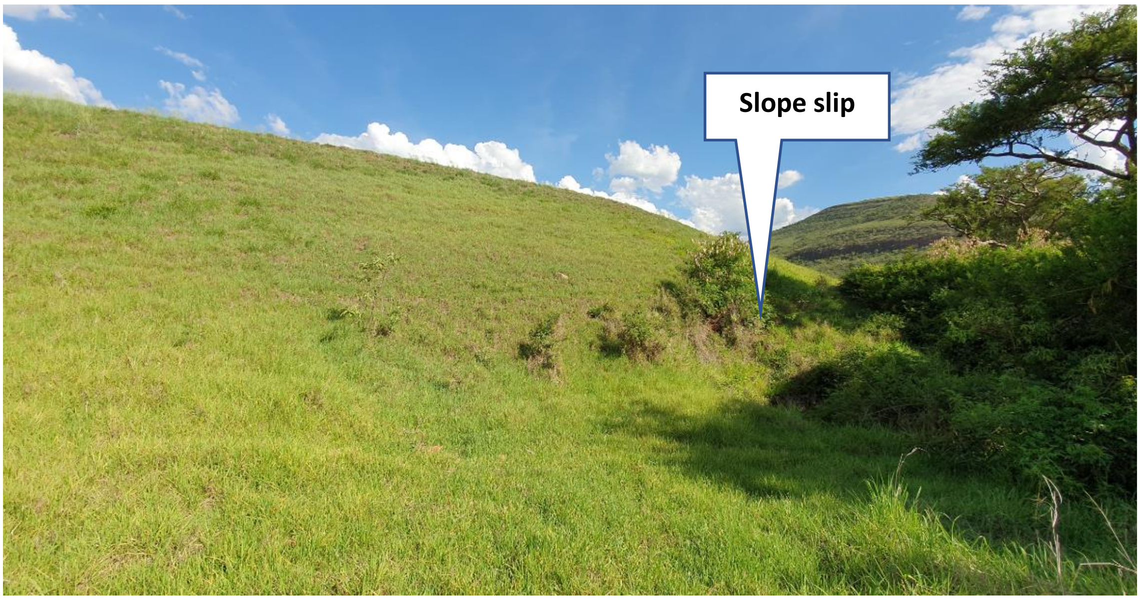

Photo 18: Downstream face of breaching section (fuseplug embankment) on right flank showing local slip (19 November 2019).

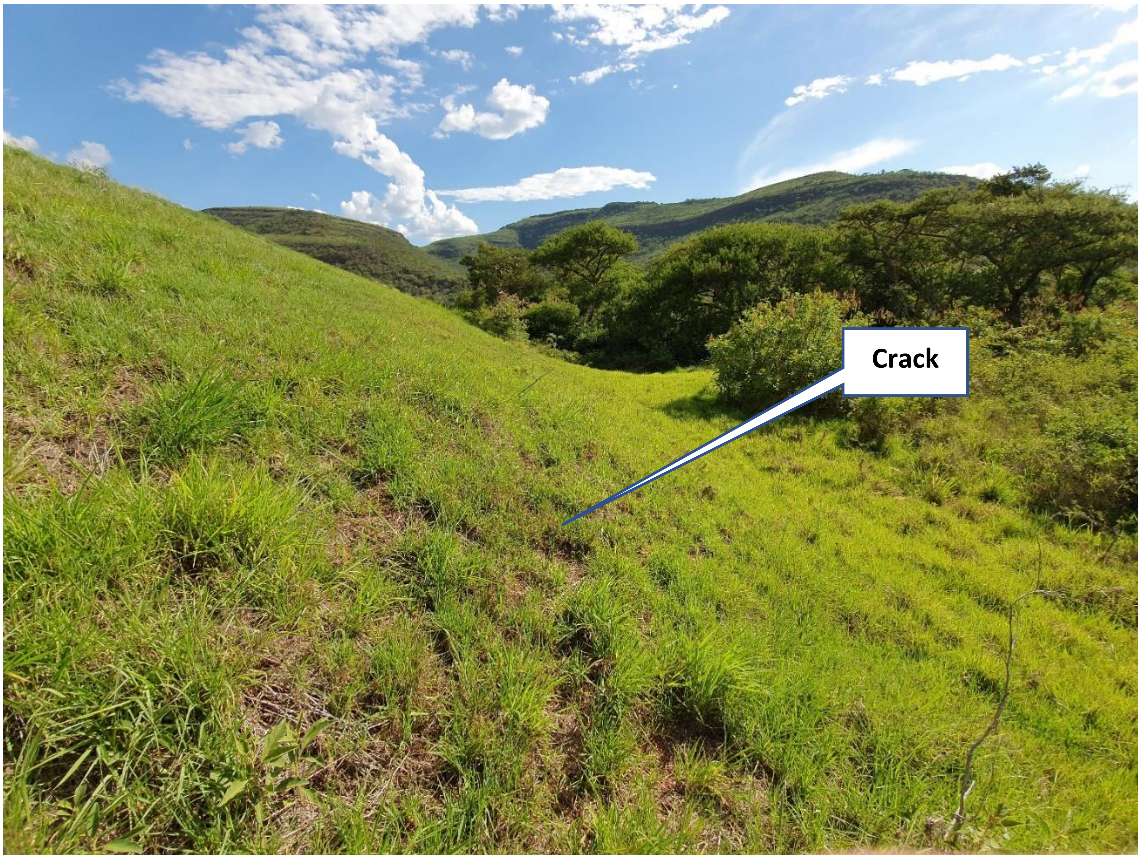

Photo 19: Breaching section downstream face towards left flank (19 November 2019). Note longitudinal crack likely caused by surface slip movement.

Appendix B: Drawings

DAM WALL AND SPILLWAY PLAN WITH AERIAL PHOTOGRAPHIC FEATURES

SCALE 1 : 1000

AMENDMENTS

NR.	DATE	APPROVED	DESCRIPTION	PAR.
A	SEPT 2017		FOR APPROVAL	TEL

DESIGNED J STANDER	DRAWN J STANDER
DESIGN CHECKED BY A. DE BEER SIGNATURE:............ DATE:.........	INFRASTRUCTURE TECHNICAL INFORMATION MANAGEMENT NAME: SIGNATURE:............DATE:............

PROJECT STATUS

CONCEPT DRAWING | TENDER DRAWING | APPROVED FOR CONSTRUCTION | AS BUILT DRAWING

PROJECT ENGINEER (CONSULTANT) DATE

INITIALS AND SURNAME SIGNATURE AND Pr. No.

INSPECTOR OF WORKS (EKURHULENI):

INITIALS AND SURNAME SIGNATURE AND Pr. No. DATE

CLIENT

SAPPI Paper and Paper Packaging
SAPPI Southern Africa Ltd
Reg No 1951/003180/06
Ngodwana

APPROVED PROFESSIONAL PERSON

A de Beer Pr Eng
Reg No. 820410

CONSULTING ENGINEER

ALTUS DE BEER
CONSULTING ENGINEERS

LOCATION OF PROJECT:

NGODWANA DAM

DESCRIPTION OF PROJECT

DAM WALL AND SPILLWAY PLAN
WITH AERIAL PHOTOGRAPYHIC FEATURES

CONTRACT No. : 1734		PROJECT No. : 1734
DATE : SEPT 2018	SCALE : AS SHOWN	ORIGINAL PAPER SIZE: A1
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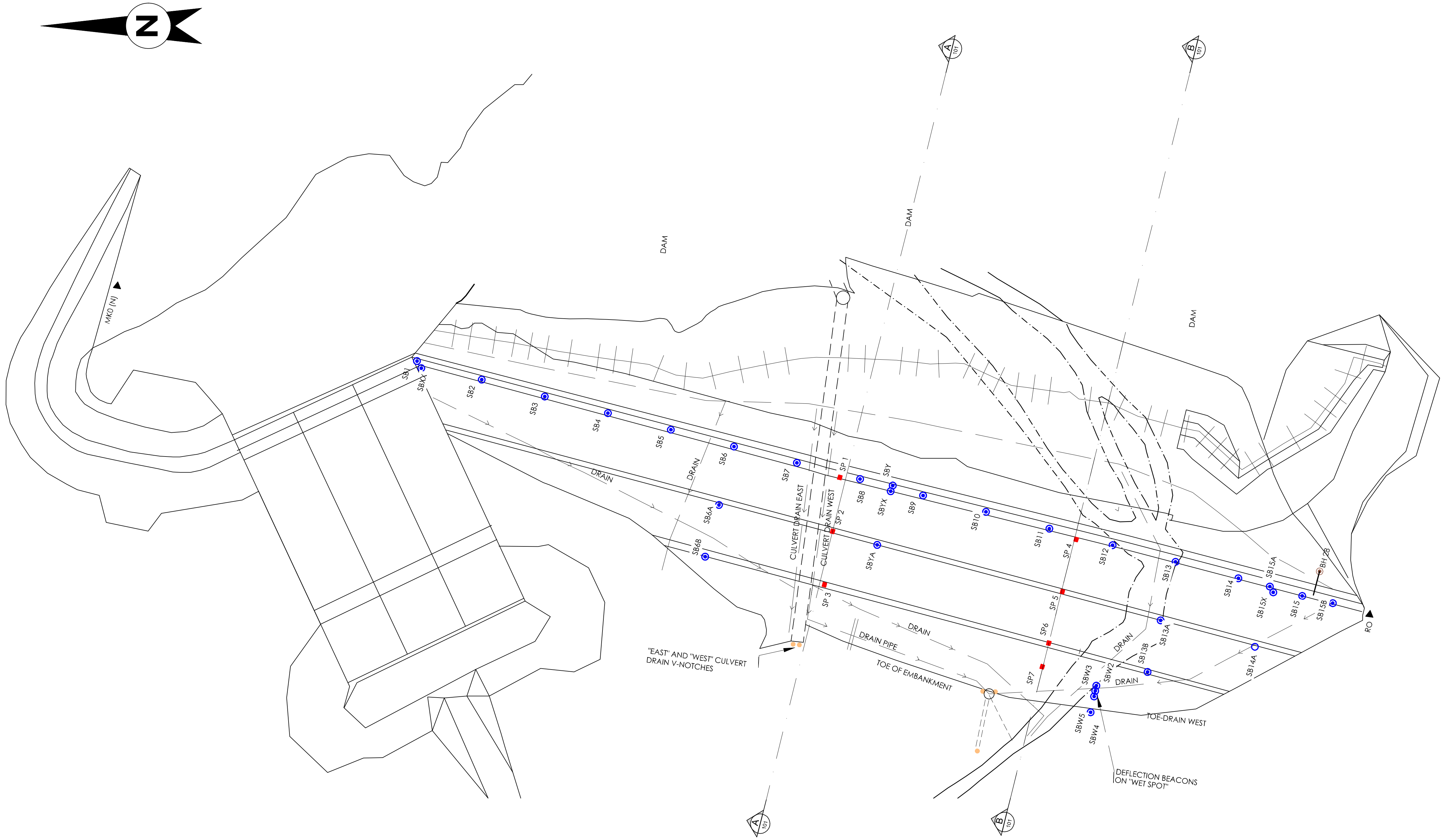

DAM WALL AND SPILLWAY PLAN

SCALE 1 : 1000

SETTLEMENT MONITORING BEACON SURVEY DATA - August 2018						
Station	Horisontal (Y) Deflection (mm)	ORIGINAL BEACON MASL	CURRENT BEACON MASL	Vertical Deflection (mm)	ORIGINAL GROUND MASL	CURRENT GROUND MASL
SP2	-28	965,933	965,869	-64	965,635	965,571
SP3	-88	965,973	965,741	-232	965,665	965,433
SP4	-186	965,915	965,628	-287	965,603	965,316
SP5	-216	965,944	965,612	-332	965,681	965,349
SP6	-245	965,948	965,546	-402	965,634	965,232
SP7	-177	965,900	965,462	-438	965,636	965,198
SP8	-129	965,863	965,545	-318	965,553	965,235
SP9	-90	965,861	965,579	-282	965,560	965,278
SP10	-75	965,861	965,651	-210	965,582	965,372
SP11	-71	965,880	965,674	-206	965,589	965,383
SP12	-57	965,865	965,665	-200	965,578	965,378
SP13	-66	965,747	965,527	-220	965,434	965,214
SP14	-75	965,835	965,582	-253	965,568	965,315
SP15A #	-34	965,675	965,636	-39	965,425	965,386
SP15B #	-10	965,651	965,594	-57	965,400	965,343

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A	SEPT 2017		FOR APPROVAL	TEL

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ALTUS DE BEER
CONSULTING ENGINEERS

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SHEET NO: 2 OF 4
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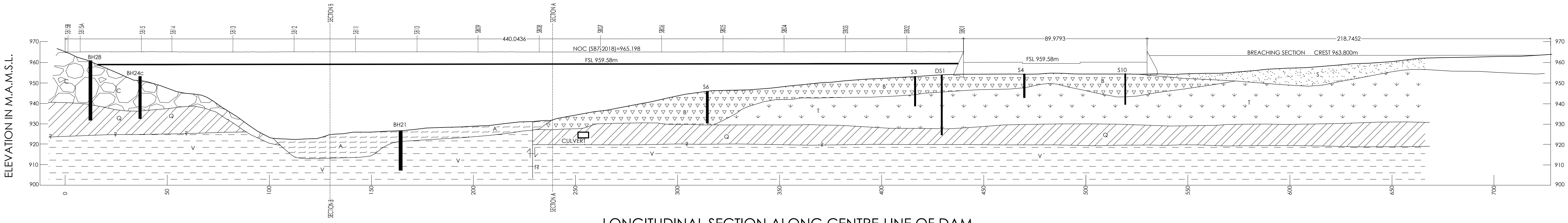

LONGITUDINAL SECTION ALONG CENTRE-LINE OF DAM
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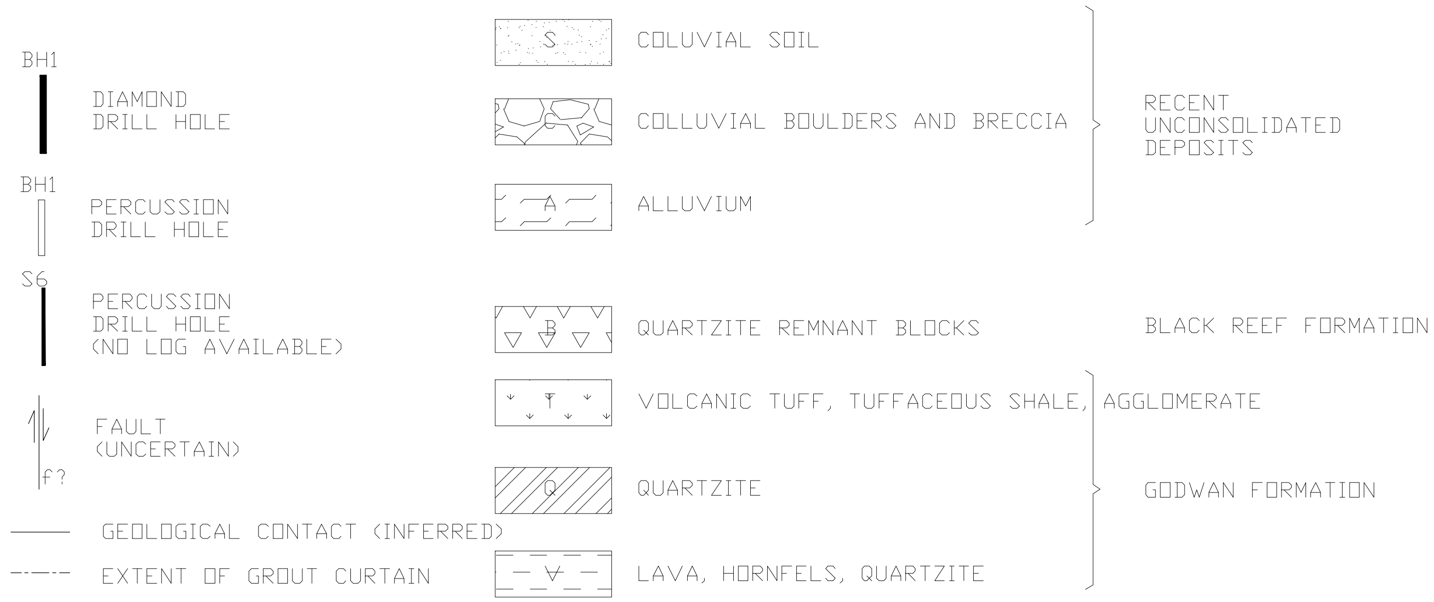

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ALTUS DE BEER
CONSULTING ENGINEERS

LOCATION OF PROJECT:

NGODWANA DAM

DESCRIPTION OF PROJECT

LONG SECTION

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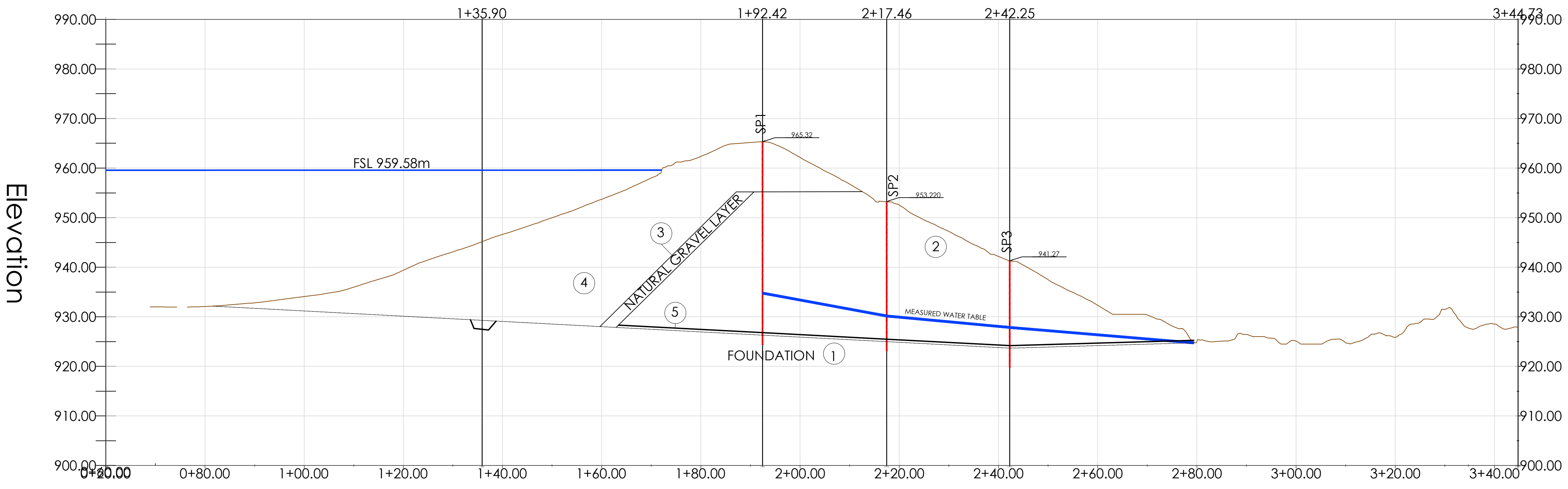

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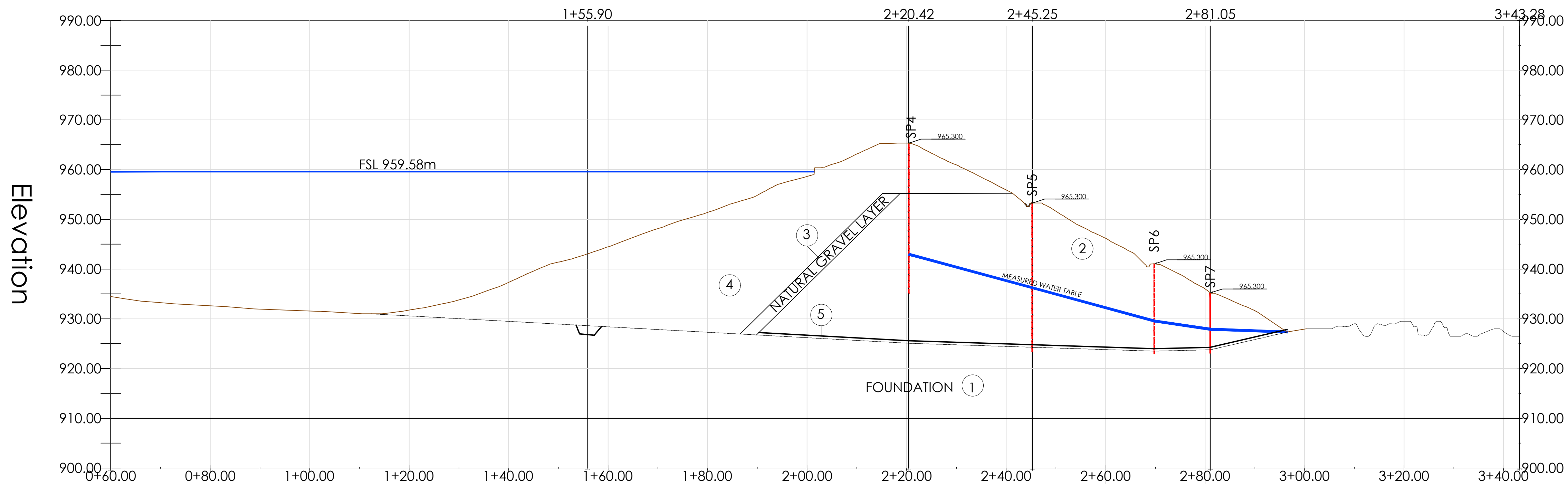

SECTION B-B 'RIVERBED"
Scale 1:500

LEGEND:

1 FOUNDATION
2 DOWNSTREAM SHELL
3 NATURAL GRAVEL
4 IMPERVIOUS ZONE
5 GRAVEL STRIP

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SIGNATURE:............. DATE:..........

INFRASTRUCTURE TECHNICAL INFORMATION MANAGEMENT
NAME:........
SIGNATURE:.............DATE:..............

PROJECT STATUS

CONCEPT DRAWING | TENDER DRAWING | APPROVED FOR CONSTRUCTION | AS BUILT DRAWING

PROJECT ENGINEER (CONSULTANT)
INITIALS AND SURNAME | SIGNATURE AND Pr. No. | DATE

INSPECTOR OF WORKS (EKURHULENI):
INITIALS AND SURNAME | SIGNATURE AND Pr. No. | DATE

CLIENT
SAPPI Paper and Paper Packaging
SAPPI Southern Africa Ltd
Reg No 1951/003180/06
Ngodwana

APPROVED PROFESSIONAL PERSON
A de Beer Pr Eng
Reg No. 820410

CONSULTING ENGINEER
ALTUS DE BEER
CONSULTING ENGINEERS

LOCATION OF PROJECT:
NGODWANA DAM

DESCRIPTION OF PROJECT
CROSS SECTIONS

CONTRACT No. : 1734		PROJECT No. : 1734
DATE : SEPT 2018	SCALE : AS SHOWN	ORIGINAL PAPER SIZE: A1
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