TCTA

MOKOLO AND CROCODILE WATER AUGMENTATION PROJECT (MCWAP)

CONTRACT № TCTA 07-041

CONSULTING SERVICES FOR MCWAP

PHASE 2: GEOTECHNICAL INVESTIGATIONS
STAGE 3: Operational Reservoir - Steenbokpan

VOLUME 1: GEOTECHNICAL DATA REPORT

July 2012

MOKOLO CROCODILE CONSULTANTS

Report No: 2A-R-111E-54 (Rev A)

MOKOLO AND CROCODILE WATER AUGMENTATION PROJECT

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Volume 1: Geotechnical Data Report

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MOKOLO AND CROCODILE WATER AUGMENTATION PROJECT

CONTRACT № TCTA 07-041

PHASE 2: GEOTECHNICAL INVESTIGATIONS
STAGE 3: Operational Reservoir - Steenbokpan

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Volume 3	Phase 2, Stage 3: Geotechnical Interpretive Report

MOKOLO AND CROCODILE WATER AUGMENTATION PROJECT

CONTRACT № TCTA 07-041

PHASE 2: GEOTECHNICAL INVESTIGATIONS STAGE 3: Operational Reservoir - Steenbokpan

VOLUME 1: GEOTECHNICAL DATA REPORT

EXECUTIVE SUMMARY

1 INTRODUCTION

Mokolo Crocodile Consultants (MCC) has been appointed by the Trans-Caledon Tunnel Authority (TCTA), the implementing agency, to undertake the detailed design of the Mokolo and Crocodile Water Augmentation Project (MCWAP).

The MCWAP is implemented using a phased approach. Phase 2 has, for practical reasons, been split into 4 stages. This Report deals with Phase 2: Stage 3 of the Project, extending from the Operational Reservoir in the south to Steenbokpan in the north, a distance of approximately 27.8 km. Similar and separate reports have been generated for the other 3 stages.

In partial fulfilment of Sub-Task 1.1.1E – Field Investigation Report of Appendix A of the Scope of Services for the MCWAP, further geotechnical investigations were undertaken. Following an evaluation of available geotechnical information obtained from feasibility stage investigations, this task comprised the planning and execution of geotechnical field investigations. The feasibility investigation work comprised a few (at 5 km spacing) test pits along the centreline.

Report "Phase 2 Stage 3: Geotechnical Investigations" comprises three volumes, of which this is Volume 1:

- Volume 1: Geotechnical Data Report (**This Volume**);
- Volume 2: Annexures supporting Volume 1; and
- Volume 3: Geotechnical Interpretive Report.

This Volume contains the narrative, factual data, whilst Volume 2 contains the Annexures supporting the Report. Volume 3 interprets the data contained in Volumes 1 and 2 and should be read in conjunction with them.

2 BACKGROUND

The Department of Water Affairs (DWA) commissioned the Mokolo and CrocodileRiver (West) Water Augmentation Project (MCWAP) Feasibility Study to analyse the options for transferring water from the Mokolo Dam and Crocodile River (West). In April 2008 the Technical Module of this study was awarded to Africon (now incorporated in Aurecon) in association with Kwezi V3, VelaVKE and specialists. The focus of the Technical Module was to investigate the feasibility of options to:

- Augment the supply to the Lephalale area from Mokolo Dam to supply the growing water requirement for the interim period until a transfer pipeline from the Crocodile River (West) can be implemented (Phase 1); and
- Transfer water from the Crocodile River (West) to the Lephalale area (Phase 2).

The Technical Module had been programmed to be executed at a Pre-feasibility level of investigation to identify different options and recommend the preferred schemes. This was followed by a feasibility level investigation of the preferred water schemes. Recommendations on the preferred options for Phase 1 and Phase 2 were presented to DWA during October 2008 and draft reports were submitted during December 2008. The Feasibility Stage of the project commenced in January 2009 and considered numerous water requirement scenarios, project phasing and optimisation of pipeline routes. The study team submitted draft Feasibility Reports during October 2009 to the MCWAP Main Report in November 2009.

As part of the Tender Design stage for Phase 1, detailed geotechnical investigations have been performed for Phase 2 Stage 3 of the MCWAP. Components investigated include the pipeline route and borrow pits.

The Chainage reference system used increases from south to north (Operational Reservoir to Steenbokpan). Test pits were not numbered in any specific order.

The diameter of the pipeline has not yet been established. Interpretations given in the report assume a diameter of 2,000 mm and will have to be amended once the actual pipe diameter is known.

3 PIPELINE ROUTE INVESTIGATIONS

The pipeline route investigation comprised test pitting at a nominal spacing of 200 m (using a TLB[2]) along the centreline of the pipeline route. The pits were dug to a depth of 4 m (or to refusal of the TLB) and were profiled in accordance with standard procedures and profiles of each test pit have been compiled. The soils encountered were sampled and tested to assess their suitability for use as bedding and selected backfill to the pipe. Laboratory tests (Indicator, compactability tests, etc) were carried out on representative samples. Occasional pH, conductivity tests and chemical (SRB) tests were carried out on different soil types in order to assess the aggressiveness of the soils towards the steel pipeline.

[2] Minimum characteristics: Backhoe depth not less than 4 m; gross power not less than 70 kW; and bucket breakout force not less than 60 kN.

Geotechnical tests (triaxial, shearbox, Constrained Soil Modulus and Hydrostatic Compression) were carried out in order to quantify the characteristics of the soils when used as bedding or selected backfill to the pipeline.

The topsoil and subsoil (at borrow pit sites and along the centreline) were tested to establish their fertility and to provide baseline data when rehabilitating borrow pits and over the backfilled pipeline.

Dynamic penetrometer tests (DPLs, commonly incorrectly referred to as DCPs) were conducted in and adjacent to selected test pits in order to provide a quantitative assessment of the consistency of the soils encountered. These soundings were reduced to equivalent Standard Penetration Tests (SPT) N-values (blows per 300 mm penetrated) and are presented graphically (as SPT N-values versus depth) on the soil profiles.

Access was not permitted onto the farms Rooipan 357LQ and its Remainder. Test pitting was according carried out along the Road D175 from the Operational Reservoir to where the pipeline rejoins the road.

4 BORROW PITS

Four borrow pits were located, providing suitable bedding and selected backfill material, generally at an economic spacing for haulage purposes during construction. In places the targeted spacing of 5 km has not been achieved. A borrow source should have been identified on Rooipan 357LQ, but access was denied. This has resulted in an approximately 8 km gap between BP43 (on Stage 1) and BP52. Once access problems have been resolved, further investigation will be necessary to resolve this shortcoming. The results of the borrow pit investigation are presented in Annexure B and include locality plans, test pit profiles and results of laboratory testing. The main characteristics are summarised hereunder in Table 5.

Table 5: Borrow pit summary

BP no.	Location (WGS84 Lo27)		Chainage (m)	Offset to pipeline (m)	Est. volume bed soft backfill (m^3)	Compactability Factor (range)
	Y	X				
43#	-041 362	2 658 260	-2,000	on Stage 1	≈100,000	0.32 – 0.39
53+	-040 487	2 641 428	2 300	50 L	50,000	0.30 – 0.34
52	-037 097	2 640 453	6 000	50 L	≈100,000	0.32 – 0.41
50	-035 600	2 633 400	12,800	100 R	≈100,000	0.36 – 0.41
48	-032 678	2 632 164	16,500	200 R	≈100,000	0.31 – 0.46
49	-029 600	2 629 600	20,700	50 R	≈100,000	0.20 – 0.38
15$	-028 890	2 622 230	25,500	500 R (on Stage 4)	≈100,000	0.34 – 0.39

+ BP only partially investigated
# Closest BP to south, on Stage 1
$ BP on Stage 4
L = Left/south or west of pipeline
R= Right/east of pipeline

5 FINDINGS

The geology of the area comprises Waterberg sandstone, which occurs over the whole of the route. Extensive deposits of Quaternary sand are present, blanketing the sandstone. Calcrete and ferricrete (with occasional silcrete) occur at the base of the sand.

The investigation was carried out between June and September, prior to the rainy season. In none of the test pits was any groundwater encountered.

In addition to the bedding material from the borrow pits, gravel (present below the sand) was identified and sampled for use in gravelling haul roads and regravelling of existing roads that may be damaged during hauling operations.

The nearest known commercial sources of crushed stone and crusher dust are located about 50 km east of Steenbokpan, in the vicinity of Lephalale. These sources have been discussed in detail in the Stage 1 report on this project.

This Report outlines and summarises the results and findings of the geotechnical investigations.

At time of writing, not all laboratory test results have necessarily been supplied by the testing laboratory and the following cut-off dates apply:

- Received by 30 July 2011: bound into Annexures (Volume 2) and have been interpreted in Volume 3; and
- Received after 1 August 2011: are neither bound into Volume 2, nor interpreted in Volume 3 and are only stored in electronic format in the Project Files.

On the first page to each Annexure in Volume 2 a summary is included detailing any outstanding test results.

MOKOLO AND CROCODILE WATER AUGMENTATION PROJECT

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PHASE 2: GEOTECHNICAL INVESTIGATIONS STAGE 3: Operational Reservoir– Steenbokpan

VOLUME 1: GEOTECHNICAL DATA REPORT

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PHASE 2: GEOTECHNICAL INVESTIGATIONS
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GLOSSARY

ARC	Agricultural Research Council of South Africa
BH	Borehole
BP	Borrow pit
CBR	California Bearing Ratio
DCP	Dynamic Cone Penetrometer
DPL	Dynamic Probe – Light
DWA	Department of Water Affairs
MCC	Mokolo Crocodile Consultants
MCWAP	Mokolo and Crocodile Water Augmentation Project
PI	Plasticity Index
Ptn	Portion
SANAS	South African National Accreditation System
SPT	Standard Penetration Test
SRB	Sulphate Reducing Bacteria
TCTA	Trans-Caledon Tunnel Authority
TLB	Tractor-loader-backhoe
WGS84	World Geodetic System (dated 1984)

1 INTRODUCTION

Mokolo Crocodile Consultants (MCC) has been appointed by the Trans-Caledon Tunnel Authority (TCTA), the implementing agency, to undertake the detailed design of the Mokolo and Crocodile Water Augmentation Project (MCWAP).

The MCWAP is implemented using a phased approach. In partial fulfilment of Sub-Task 1.1.1E – Field Investigation Report of Appendix A of the Scope of Services for the MCWAP, further geotechnical investigations were undertaken. Following an evaluation of existing available geotechnical information obtained from Feasibility Stage investigations, this task comprised the planning and execution of further geotechnical field investigations which had been identified as being necessary. The earlier work comprised investigations of the sub-surface materials along the pipeline route.

The results of the geotechnical investigations conducted during the Feasibility Stage, and forming part of Sub-Task 1.1.1E, are presented and interpreted by MCC as baseline information on the engineering properties, the corrosion properties and the agricultural properties during the design, tender and construction stages.

For practical purposes Phase 2 is reported on in 4 separate Stages as follows:

- Stage 1: Tarantaalpan to Operational Reservoir (along Transnet rail line) (55.5 km);
- Stage 2: Crocodile River to Trans net Rail Line (Tarantaalpan) (42.0 km);
- Stage 3: Operational Reservoir to Steenbokpan (approximately 27.8 km); and
- Stage 4: Steenbokpan to Matimba (approximately 37.9 km).

This Report deals only with Phase 2 Stage 3 of the Project. Similar reports are compiled for the other three Stages making up Phase 2. The location of the different Stages is shown on the Locality Plan (Figure 1: Phase 2 Stage 3 Locality Plan (Drawing no. 2A-G3-020).

The Chainage reference system used increases from south to north (Operational Reservoir to Steenbokpan). Test pits were not numbered in any specific sequence..

At time of writing, not all laboratory test results have necessarily been supplied by the testing laboratory and the following cut-off dates apply:

- Received by 30 July 2011: bound into Annexures (Volume 2) and have been interpreted in Volume 3; and
- Received after 1 August 2011: are neither bound into Volume 2, nor interpreted in Volume 3 and are only stored in electronic format in the Project Files.

On the first page to each Annexure in Volume 2 a summary is included detailing any outstanding test results.

The diameter of the pipeline has not yet been established. Interpretation given in the report assumes a diameter of 2,000 mm and will have to be amended once the actual pipe diameter is known.

1.1 Background

1.1.1 Feasibility Investigations

The Department of Water Affairs (DWA) commissioned the Mokolo and Crocodile River (West) Water Augmentation Project (MCWAP) Feasibility Study to analyse the options for transferring water from the Mokolo Dam and Crocodile River (West). In April 2008 the Technical Module of this study was awarded to Africon (now incorporated in Aurecon) in association with Kwezi V3 (now incorporated in WorleyParsons), VelaVKE and specialists. The focus of the Technical Module was to investigate the feasibility of options to:

- Augment the supply to the Lephalale area from Mokolo Dam to supply the growing water requirement for the interim period until a transfer pipeline from the Crocodile River (West) could be implemented (Phase 1); and
- Transfer water from the Crocodile River (West) to the Lephalale area (Phase 2).

The Technical Module had been programmed to be executed at a Pre-Feasibility level of investigation to identify different options and recommend the preferred schemes. This was followed by a Feasibility level investigation of the preferred water schemes. Recommendations on the preferred options for Phase 1 and Phase 2 were presented to DWA during October 2008 and draft and final reports were submitted during December 2008. The Feasibility Stage of the project commenced in January 2009 and considered numerous water requirement scenarios, project phasing and optimisation of pipeline routes. The study team submitted draft Feasibility Reports during October 2009 to the MCWAP Main Report in November 2009.

As part of the Feasibility investigations, geotechnical investigations were performed for Phase 2 of the MCWAP. These included the following:

a) Pipeline Route Investigations

The pipeline route investigation carried out during the Feasibility Stage comprised test pitting (using a TLB[3]) along the centreline of the pipeline route at a nominal spacing of 5 km. The pits were dug to a depth of 4 m (or to refusal of the TLB), were profiled in accordance with standard procedures and logs of each test pit compiled. The soils encountered were visually evaluated to provide a preliminary assessment of their suitability for use as bedding and selected backfill to the pipe. No borrow sources were identified, nor was any laboratory testing carried out on any samples.

Dynamic penetrometer tests (DPLs, commonly incorrectly referred to as DCPs) were conducted adjacent to and in selected test pits in order to provide a quantitative assessment of the consistency of the soils encountered. These soundings were reduced to equivalent Standard Penetration Tests (SPT) N-values (blows per 300 mm penetrated) and are presented graphically (as SPT N-values versus depth) on the soil profiles.

[3] Minimum characteristics: Backhoe depth not less than 4 m; gross power not less than 70 kW; and bucket breakout force not less than 60 kN

Applicable data from these investigations has been extracted from the reports on this work and is integrated into the current report.

The fieldwork was carried out under competitive tender by the soils testing laboratory, Civilab.

b) Potential Borrow Pits

No borrow pit investigation was carried out.

c) Feasibility Study Report

Supporting Report 8b – Detailed Geotechnical Investigations (Report Number P RSA A000/00/8409) prepared by the lead Consultant, Africon, in association with other consultants, covers the results obtained from these investigations undertaken during Feasibility Stage.

1.1.2 Current Investigations

Following selection of the final alignment, a detailed geotechnical investigation was carried out to characterise the material conditions along the pipeline and to define borrow sources along the route. As the diameter of the pipeline has not been fixed, the depth of test pits and the target volume of material in borrow pits was based on an assumed diameter of 2,000 mm. The investigation comprised the following aspects:

a) Excavation of test pits at nominal 200 m centres along the pipeline;
b) The proving of sources of borrow material for bedding and backfill material at a nominal spacing of 5 km. Test pits were dug at a nominal spacing of 30 m to prove a nominal 100,000 m^3 of suitable material at each borrow site;
c) Laboratory testing (Indicators, pH, conductivity, compactibility, triaxial, shearbox, Constrained Soil Modulus, Hydrostatic Compression) was carried out to characterise the materials encountered;
d) Additionally, fertility tests were carried out to provide baseline data for rehabilitation along the pipeline and at borrow pits; and
e) A desk-top seismic hazard assessment.

The fieldwork and laboratory testing was carried out by Geostrada, under competitive tender.

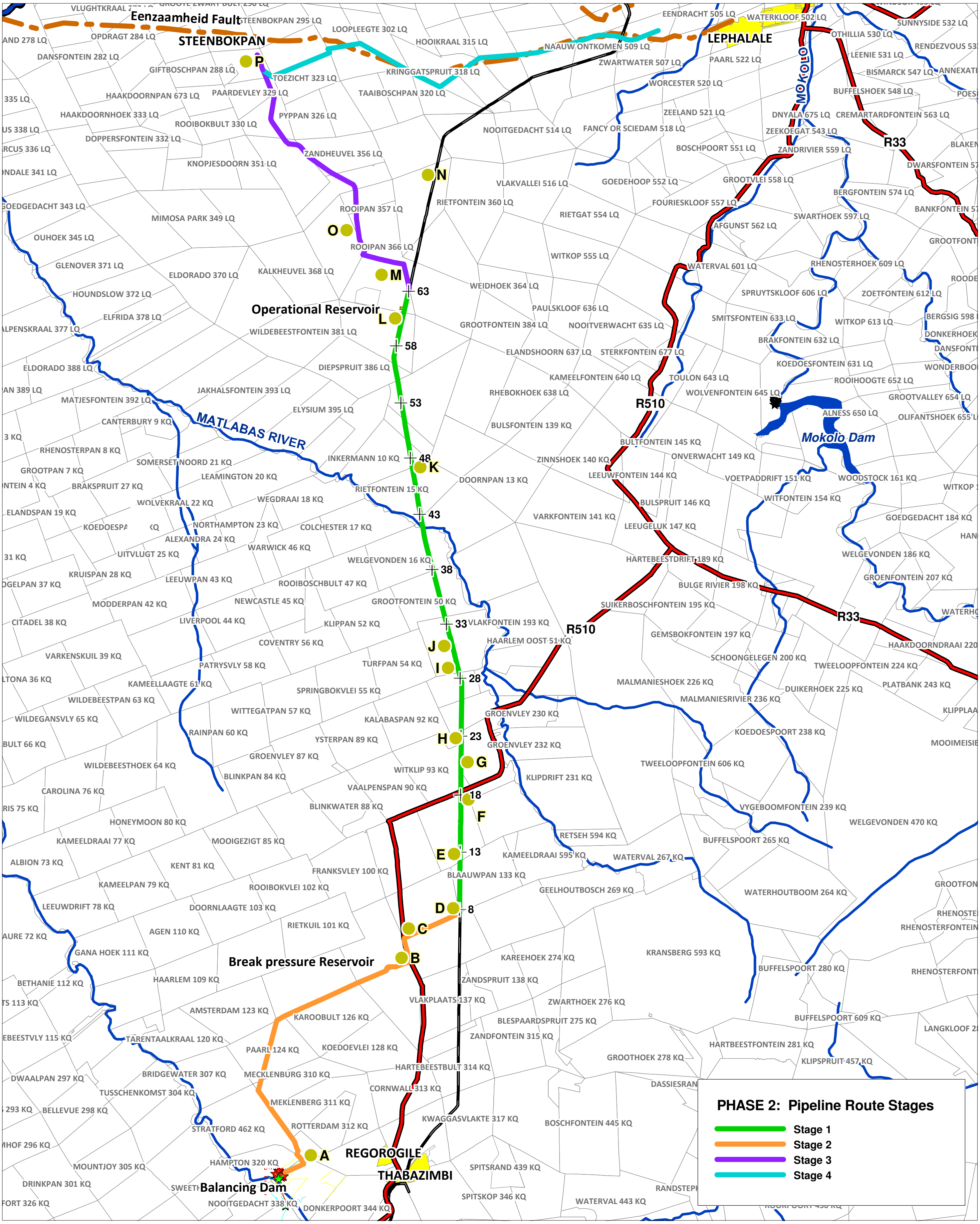
2 SCOPE OF REPORT

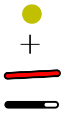
2.1 Scope of Geotechnical Investigations

This Report covers and summarises the results of the detailed geotechnical investigations conducted during the Tender Design Stage for Phase 1 along the pipeline route from the Operational Reservoir to Steenbokpan, a distance of approximately 27.8 km. Over much of this length, the pipeline parallels the D175 road.

In the south, access was denied to part of the pipeline route where this cuts north-westward across farmland from the Operational Reservoir to link up with Road D175 on the southern boundary of the farm Rooipan 355LQ. In an attempt to provide information that could be extrapolated onto the pipeline route of this 2.7 km gap and to cater for the possibility that an alternative alignment of the pipeline could be to follow Road D175, test pits were dug along the alignment of Road D175 from the Operational Reservoir to the southern boundary of Rooipan 355LQ (Chainage 8,600 m on the "preferred/original" route).

A Locality Plan for Phase 2 is included as Figure 1: Phase 2 Stage 3 Locality Plan (Drawing no. 2A-G3-020).





Legend

- Spoil Sites
- km
- Main Roads
- Railway Line
- Rivers
- Farm Boundaries
- Towns

Scale: 1:440,000

5 0 5 10

Kilometers

N

Project: Mokolo and Crocodile (West) Water Augmentation Project

Drawing Title: Phase 2 Locality Plan (Stage 3)

Drawing Number: 2A-G3-020

Rev: FIG 1

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3 AVAILABLE GEOTECHNICAL INFORMATION

3.1 Desk Study

The investigations commenced with a desk study of available information, the findings of which are summarised hereunder:

- Feasibility Report as detailed in 1.1.1 (c) above; and
- Researching documented geology on published geological maps.

3.2 Published Information

Available geological information including the published 1:250 000 scale geological maps (Council for Geoscience). The sheets relevant to this report are:

- Sheet 2326 Ellisras.

3.3 Feasibility Study Investigations

During the Feasibility Study for the MCWAP, test pitting was carried out along the centreline of the pipeline route, at a nominal spacing of 5 km. Test pits were profiled, but no laboratory testing was carried out, nor were borrow sources identified. The investigation was reported to the (then) Department of Water Affairs and Forestry as the report "Mokolo and Crocodile River (West) Water Augmentation Project (MCWAP) Feasibility Study: Technical Module: Supporting Report No. 8b: Detail Geotechnical Investigations: Phase 2".

The data from the earlier report has been extracted and is incorporated into this Report.

4 INVESTIGATION METHODOLOGY

This section describes the investigation methodology followed during the Tender Design investigations.

4.1 Outline

A broad outline of the geotechnical investigations is as follows:

- Assessment of climate and weathering;
- Desk study of available information;
- Field verification of the geology;
- Test pitting along the pipeline;
- Test pitting in potential borrow pits;
- Dynamic Penetrometer Light (DPL) tests (commonly referred to as DCP tests);
- Laboratory testing of material samples taken in the field; and
- Desk-top seismic hazard assessment.

As the pipeline diameter had not been fixed at the time of the investigations, these were based on an assumed diameter of 2,000 mm.

4.2 Desk Study

Available geological and geotechnical data was assessed in order to obtain background information relating to the expected geotechnical conditions on the site. On a broad level, the published geological maps (Council for Geoscience) were studied, as well as published orthophotos (Chief Directorate: Surveys and Mapping) and images from Google Earth®

The available sources of information are listed in Section 3.2 above.

4.3 Field Verification of the Geology

During the field investigations the geology of the site was confirmed by occasional test pits that encountered bedrock.

The co-ordinates of test pits excavated along the pipeline were recorded using a hand-held GPS instrument. Coordinates comply with the WGS84 coordinate system, utilising the Hartbeeshoek94 Datum (South African Grid, Lo 27).

4.4 Centreline Test Pitting (see Annexure A)

Test pits were dug along the pipeline route in order to assess the thicknesses and nature of the in-situ material. The test pits were dug using a New Holland B90B tractor-loader-backhoe (TLB). Excavation with a TLB gives a direct assessment of the excavatability of the materials present and allows their inspection in an undisturbed state.

The characteristics of the TLB are given below:

Table 1: Characteristics of TLB

Specification	New Holland B90B
Overall power (kW)	72
Max. Torque (Nm/rpm)	400/1400
Bucket width (mm)	610
Maximum reach (mm)	4270

Holes were generally dug to refusal of the TLB, or to a maximum depth of 4 m (based on an assumed 2,000 mm diameter pipeline). A summary of all the test pits dug is given in Annexure A1.

The profiles encountered were logged by a geospecialist and samples were taken of representative horizons. Test pit profiles appear in Annexure A2. Profiles were logged in accordance with Brink and Bruin, 2002.

After logging and sampling the holes were immediately backfilled using the TLB. Where the nature of the in-situ materials permitted it, DPL tests were carried out in and adjacent to test pits to obtain a quantitative assessment of the consistency of the soils encountered. The DPL soundings were reduced to equivalent SPT N-values (blows per 300 mm penetrated) and presented graphically as N-value versus depth on the test pit profiles.

No groundwater, not even slight seepage, was encountered in any of the test pits.

At the time of profiling, a visual assessment of the conditions encountered in the hole was made in order to allow interpolation of laboratory test results between the sites, and comments were recorded relating to:

- depth of refusal and nature of material on which refusal took place;
- stability of trench sides;
- likely longer term (safe) sideslopes during construction;
- the presence of groundwater/seepage;
- the anticipated utilisation (as bedding or soft backfill) of the soils encountered; and
- any other observations relevant to construction of the pipeline.

It must be accepted that these comments were made without the benefit of laboratory test results or detailed analysis, are indicative only of the observations made on site. The comments must NOT be relied on, and do not form part of the interpretation of the data.

4.5 Borrow Sources (see Annexures B and C)

Sources of material suitable for use as bedding or soft backfill to the pipe were sought at a nominal spacing of 5 km along the pipeline and volumes were proven by digging test pits on a grid of 30 m. Assuming a pipe diameter of 2,000 mm and corresponding trench dimensions, the target volume of material was 100,000 m^3 per borrow pit, which approximates to 200% of the volume of material required as bedding/backfill for 5 km of pipeline. The estimated requirement of 100,000 m^3/5 km ignores the fact that suitable bedding and backfill material may be sourced from the pipe trench.

With reference to borrow sources of potential bedding and selected backfill material, the investigation was aimed at locating material with the following minimum quality characteristics:

a) Maximum particle size 19 mm;
b) Not more than 5% passing the 13.2 mm sieve;
c) Not more than 20% passing the 0.425 mm sieve; and
d) PI less than 12.

While these do not necessarily meet the specification for bedding and selected backfill, they were target values for identifying borrow sources.

The compactability requirements for the selected granular material are ideally as follows:

Table 2: Suitability of granular backfill material

Compactability Factor[4]	Suitability
≤0.1	Material suitable
> 0.1 ≤0.4	Material suitable (except for flexible pipes that may be subject to waterlogged conditions) but require extra care in compaction
> 0.4	Material unsuitable

Where gravel is present below the bedding material, this was sampled and tested to establish its use in gravelling haul and access roads.

The results of the laboratory testing are given in Annexure B and plans of individual borrow pits are given in Annexure C

4.6 Laboratory Testing

Laboratory testing was carried out in order to quantify the characteristics of the materials encountered along the pipeline route.

All laboratory testing was carried out by SANAS-accredited testing laboratories and the test methods are specified on the test results.

- Road Indicator (sieve grading and Atterberg Limit determinations);
- Foundation Indicator (as above, but including hydrometer gradings);
- Compactability and moisture content;
- pH and conductivity;
- CBR tests on potential gravel sources;
- SRB potential;
- Shearbox;
- Triaxial;
- M_s (constrained soil modulus);
- Hydrostatic compression; and
- Soil fertility tests (carried out by ARC).

The results of the laboratory testing are given in the Annexures as follows:

- Annexure A – Centreline Data; and
- Annexure B – Borrow Pit Data.

[4] *per SABS 1200 LB and SABS 0120: Part 3 LB*

4.7 Soil Fertility Testing

Samples of fertile soil were taken from the topsoil (0 to 300 mm) and subsoil (300 to 600 mm), with a minimum of two soil test pits per property, in order to establish baseline parameters of the agricultural properties of the fertile segment. Samples were also taken from borrow pits. The samples, of approximately 2 kg, were placed in clean plastic bags for laboratory testing.

The following soil analyses were determined on each fertile soil sample:

- Plant available nutrients – P, K, Mg, Ca;
- pH (TMH1 A20);
- %C;
- Soil particle size;
- %N;
- Cation Exchange Capacity (CEC); and
- Electric conductivity (TMH1 A21T).

Testing was carried out in accordance with the standards given in the Soil Science Society of SA handbook. The test results are given in Annexure A3.4 (for the centreline) and Annexure B2.4 (for borrow pits).

5 GENERAL GEOLOGICAL SETTING

5.1 Regional Geology

The entire site is underlain by sandstones of the Waterberg Group, which are considered to be between 1,700 and 2,000 million years in age (Johnson *et. al*., 2006). Diabase is known from elsewhere on the project to intrude the sandstones, but none was encountered in any of the test pits.

The sandstone is almost entirely covered by Quaternary Age sands, which are younger than 1.8 million years. Occasional outcrops of sandstone occur infrequently, sticking up through the sands as inconspicuous, low-lying “whalebacks”.

The regional geology is shown on Figure 2: Regional Geology (Drawing no. 2A-G3-025).

5.2 Structural Geology

The sandstones of the Waterberg Group are near-horizontally bedded with a very shallow dip towards the north. Prominent NE- and NW-striking lineaments are recognised elsewhere on the project where outcrops exist. Elsewhere on the project, diabase is intruded in irregular bodies (generally sills or inclined sheets) into the Waterberg and, though none was encountered in test pits, they are expected to be present.

5.3 Economic Geology

No deposits of economic value are known to be present along the route.

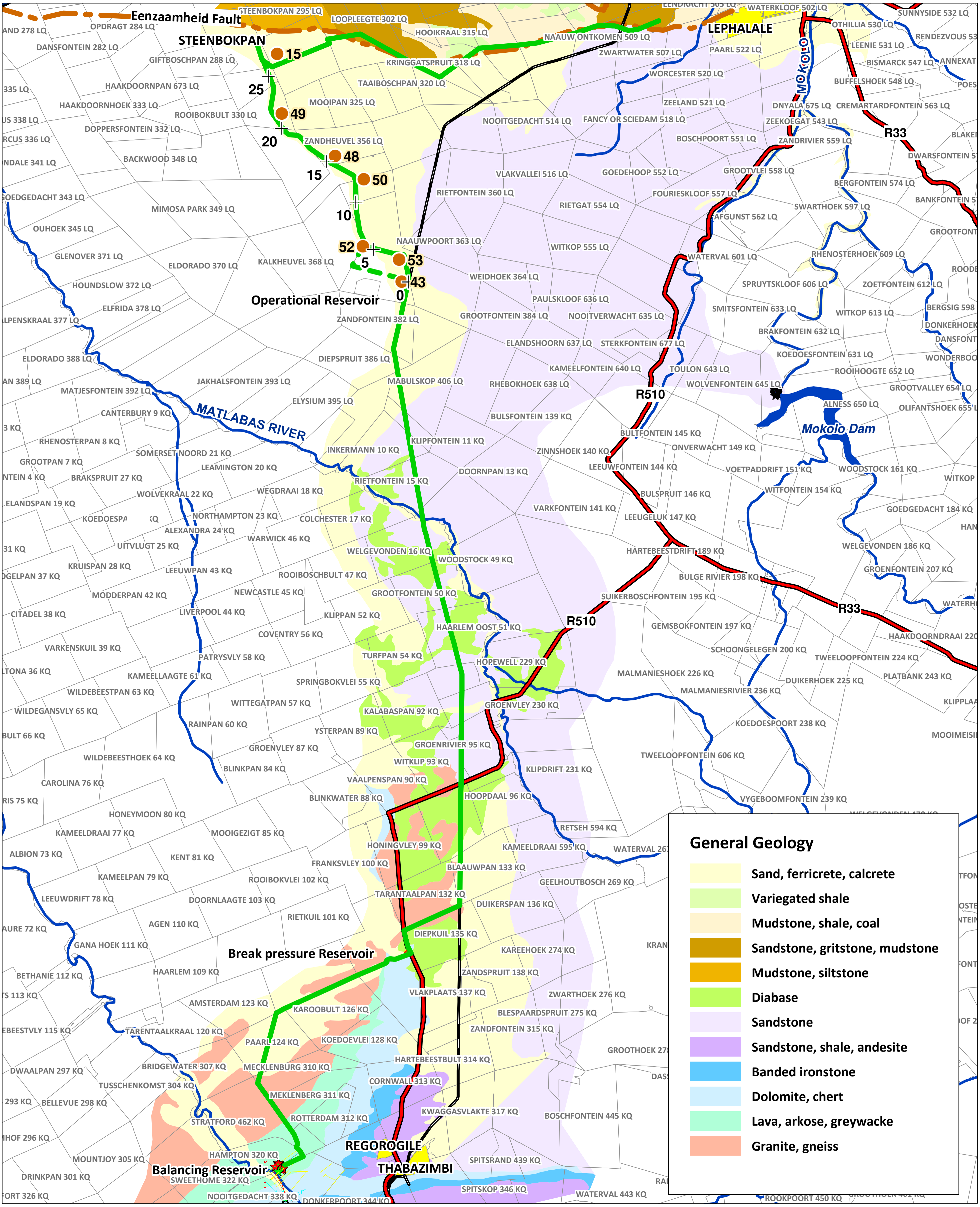
5.4 Climate and Weathering

Average annual rainfall is 400 mm, most of which falls between November and March. Average midday temperatures range between a high of 31.9 C in January to a low of 22.3˚C in June. Average night time temperatures range between about 4˚C in July to about 20˚C in January.

The study area lies to the west of the climatic N = 5 line (Weinert, 1980), which indicates that mechanical disintegration is the dominant mode of weathering, but both chemical and mechanical modes of weathering are likely to have an influence.

5.5 Seismic Hazard

According to Kijko, *et. al*. 2003, the area of interest is associated with Peak Ground Acceleration values between 0,08 and 0,10 g, with a 10% probability of being exceeded in a 50 year period.



A new word for water

Mokolo Crocodile Consultants

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Legend

PIPELINE ROUTES

- Phase 2
- Main Roads
- Borrow Pits
- km distances
- Railway Line
- Rivers
- Farm Boundaries
- Towns

Scale: 1:440,000

5 0 5 10

Kilometers

N

Project: Mokolo and Crocodile (West) Water Augmentation Project

Drawing Title: Regional Geology (Stage 3)

Drawing Number: 2A-G3-025

Rev: FIG 2

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6 INVESTIGATION FINDINGS

6.1 Local Geology

The geology of the area may be summarised as shown on the Table below.

Table 3: Geology

Rock Type	Formation	Group	Remarks
Sand, ferricrete, calcrete, silcrete			Quaternary
Diabase			Post-Waterberg intrusive
Sandstone, conglomerate.	Mogalakwena	Waterberg	
Granite, gneiss			Lebowa Granite Suite

6.2 Centreline Investigation (see Annexure A)

Test pits were excavated at a nominal spacing of 200 m along the pipeline. Areas where access to excavate was not permitted are shown on Drawings 2E-G7-047 to -049, included in Annexure D in Volume 2.3. Drawings 2E-G7-094 to 099 reflect the same data for the Alternative Route following Road D175 in the south. The test pit profiles are given in Annexure A2 and photographs of the test pits in Annexure A5. The test pits dug on the Alternative route are suffixed A (CN/94A to CN135A).

Test pits were dug to refusal or a maximum depth of 4m (this assumes a pipe diameter of 2 m). Pits were excavated using a TLB (New Holland B90B) and profiled by a geospecialist in accordance with the standards given in the Geoterminology Workshop 1990 (Brink and Bruin, 2002). Over most of the length of the pipeline, test pits were, for ease of access, dug within the D175 road reserve. They may thus be up to about 20m off the centreline. They are nevertheless considered to be representative of the conditions along the pipeline.

Access was not permitted onto the boundary between the farms Rooipan 357LQ and Rooipan 355LQ (Chainage 3,100 to 5,850 m). Test pitting was accordingly carried out along Road D175 from the Operational Reservoir (Chainage 0 m) to where the pipeline rejoins the road (Chainage 8,603 on Alternative and Chainage 7,250 m on the preferred or original alignment). This 8,600 m section is, for the purposes of this report, considered to be an Alternative Alignment and will be discussed separately. This alignment is offset up to 2,500 m from the preferred pipeline route.

The terms used are on the profiles are defined in Annexure A5. Dynamic Penetrometer Light (DPL or DCP) soundings were undertaken adjacent to and within the test pits in order to provide a quantitative assessment of the consistency of the in-situ materials. These soundings are shown graphically as equivalent SPT N-values (blows per 300 mm penetrated) on the relevant soil profiles.

A summary of the ground conditions at each test pit position along the pipeline route is given on spreadsheets in Annexure A1. Graphical representations of the excavation depth for each test pit are included as Figure 3.

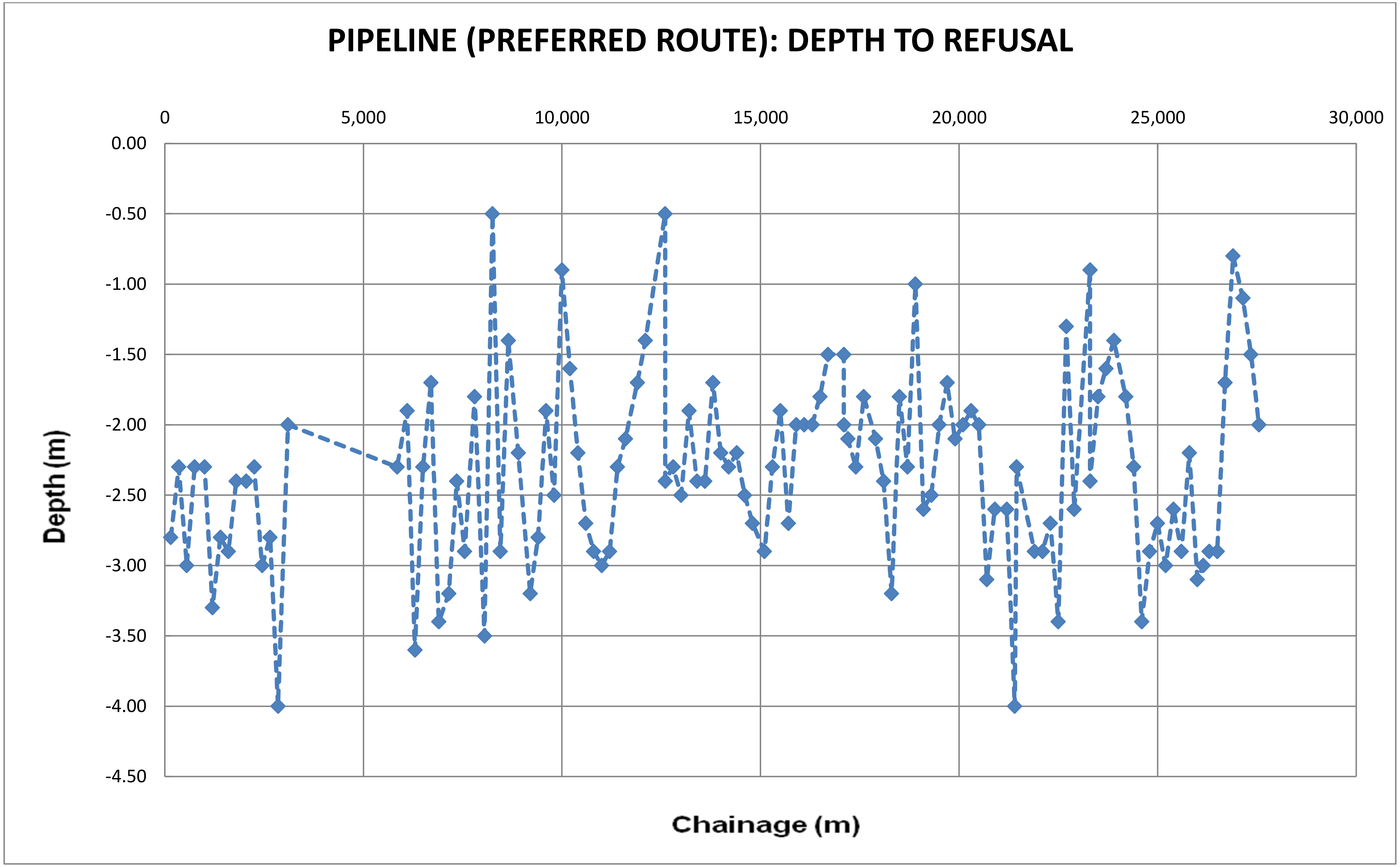

Figure 3: Summary of Refusal Depths – Operational Reservoir to Steenbokpan: Preferred Route (Chainage 0 – 27,600 m)

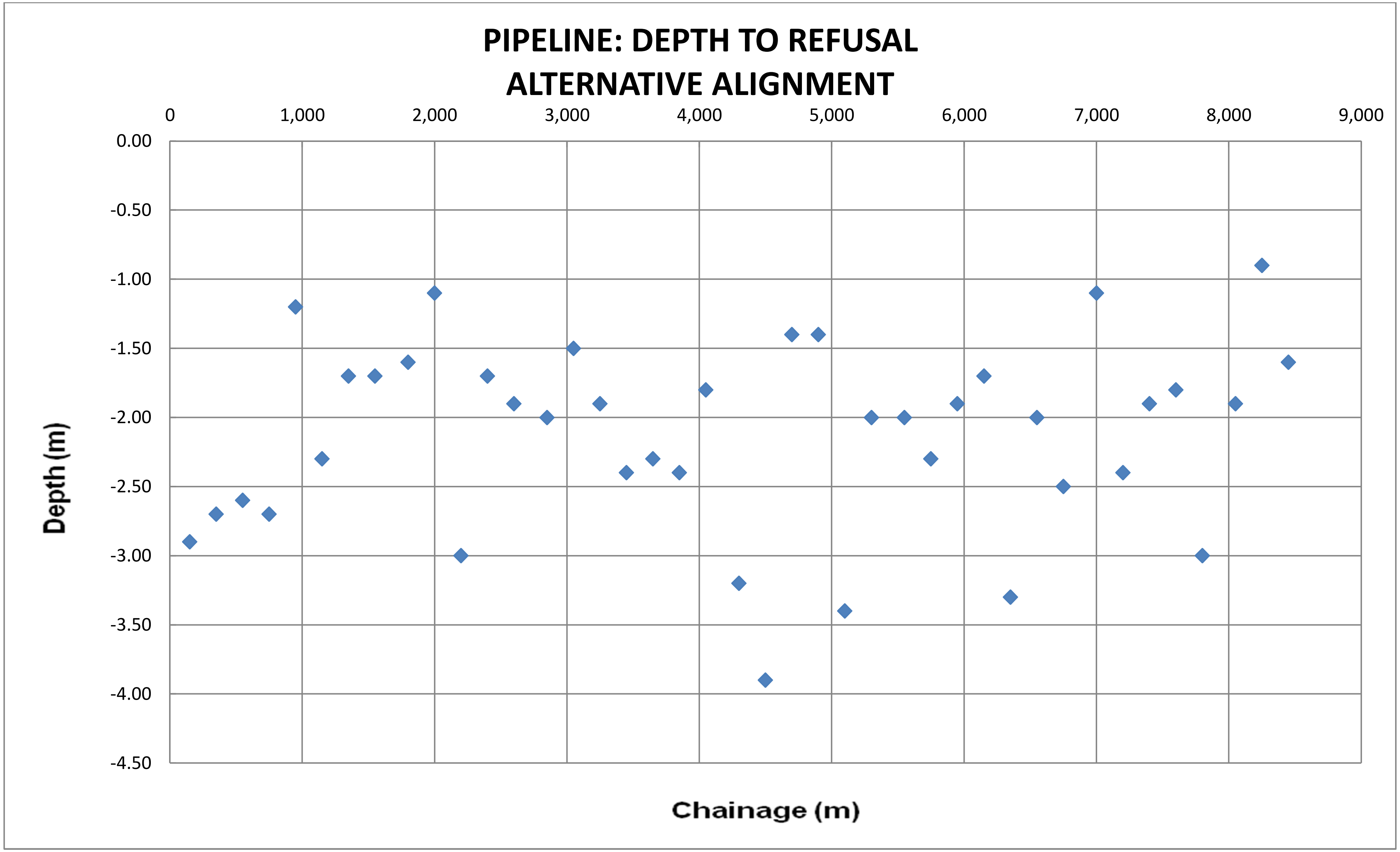

Figure 4: Summary of Refusal Depths – Operational Reservoir to Steenbokpan: Alternative Alignment (Chainage 0 – 8,603 m)

Slight seepage was encountered in only three test pits (CN/01, CN/12 and CN/94) at between 2 and 3 m depth. None of these pits showed any instability, but collapse (caving) of the sides of the test pits was observed in two test pits (CN/08 and CN/117A).

The DPL soundings are shown as equivalent SPT N-values (blows per 300 mm) and are shown graphically as N-value versus depth on the soil profiles. The majority of the pits terminated on sandstone, ferricrete or calcrete. The TLB used was able to excavate into the weathered zone of the sandstone but refused when unweathered rock was encountered.

Shearbox tests were conducted on sandy materials in order to provide a quantitive assessment of the stability of the test pit sides and allow prediction of their stand-up time. The results of these tests are given in Table 4.

Table 4: Summary of Shearbox test results

TP no.	Depth (m)	Angle of internal friction Ǿ (˚)	Cohesion c (kPa)	Classification (AASHTO/USC)	Comments
CN/23	200 – 2600	30	18	A2-4 / SM	PI = NP
CN/76	200 – 2500	38	0	A2-4 / SM	PI = 3
CN/121	100 – 2400	41	0	A2-4 / SM	PI = NP
CN/127A	200 – 1200	38	0	A2-4 / SM	PI = NP

6.2.1 pH and Conductivity

The pH and conductivity of the soils present was measured in laboratory tests and these indicate that the pH ranges from 4.60 to 8.35, and the conductivity from less than 0.002 to 0.0.033S/m. The results of laboratory tests are shown in Annexure A3.

6.3 Borrow Materials (see Annexure B)

6.3.1 Granular Backfill Material

In order to locate suitable bedding and soft backfill material, an investigation of potential borrow sources was undertaken. It was intended to locate borrow pits (BP) at a nominal spacing of 5 km, each capable of providing at least 100,000 m^3 of material. The results of this investigation are presented in Annexure B, and include test pit profiles and results of laboratory testing, and are summarised hereunder in Table 5. Borrow pit plans are presented in Annexure C in Volume 2.3.

Table 5: Borrow pit summary

BP no.	Location (WGS84 Lo27)		Chainage (m)	Offset to pipeline (m)	Est. volume bedding & soft backfill (m³)	CF (range)
	Y	X				
43#	-041 362	2 658 260	-2,000	on Stage 1	≈100,000	0.32 – 0.39
53+	-040 487	2 641 428	2 300	50 L	50,000	0.30 – 0.34
52	-37 097	2 640 453	6 000	50 L	≈100,000	0.32 – 0.41
50	-35 802	2 634 270	12,800	100 R	≈100,000	0.36 – 0.41
48	-32 678	2 632 164	16,500	200 R	≈100,000	0.31 – 0.46
49	-29 936	2 629 990	20,700	50 R	≈100,000	0.20 – 0.38
15$	-28 890	2 622 230	25,500	500 R (on Stage 4)	≈100,000	0.34 – 0.39

+ BP only parially investigated
# Closest BP to south (on Stage 1)
$ Closest BP to west (on Stage 4)
L = Left/south or west of pipeline R= Right/east of pipeline

In addition to oversize material that is present in some of the borrow materials, roots occur frequently, often for the full depth of the test pits. The roots are shown on the photographs bound into Annexure B. It must be noted that the test pits were positioned to avoid large trees.

The results of the compactability tests undertaken on samples recovered at certain borrow pits are given in Annexure B2.1. The criteria used for this classification are given in Table 2.

Of the samples analysed the compactability factor ranges from 0.20 to 0.46, with most being less than 0.40 (i.e. usable for bedding in terms of Table 2). A summary of the laboratory test results for each borrow pit is given in Annexure B1.

The characteristics of each borrow pit are discussed separately.

a) **Borrow pit 43.** The properties of this source are discussed in the Stage 1 report.

b) **Borrow pit 53**. This sand source is located on Portion 4 of the farm Rooipan 357LQ and is immediately adjacent to and on the southern side of the pipeline. It was accessed along the powerline service road which crosses the pipeline at this point. Test pitting began and appeared to identify a potential source of about 240 x 120 m. However, before detailed test pitting (on 30 m grid) could commence, the landowner withdrew permission for further prospecting. Accordingly, only limited laboratory testing was carried out, but it appears that the full source should have the following characteristics:
   - Area approximately 240 x 120 m;
   - 1400 to 2700 mm thick;
   - Classifies as an A2-4 to A2-6;
   - Plasticity Index (PI): 8 to 14;
   - Grading Modulus (GM): 1.05 to 1.23;

- Maximum size: all <4.75 mm;
- Vegetation: bush, grass and trees;
- Estimated volume: 50,000 m^3; and
- Underlain by ferricrete and quartz gravel.

c) **Borrow pit 52**. This sand source is located on the farm Grootlaagte 354LQ and is adjacent to and on the western side of the pipeline. It is accessed along an existing farm road from the D175 gravel road. The source has the following characteristics:
   - Area roughly 300 x 180 m;
   - 1500 to 3000 mm thick;
   - Classifies as an A2-4;
   - Plasticity Index (PI): <5;
   - Grading Modulus (GM): 1.16 to 1.44;
   - Maximum size: 1 sample shows 3 % >9.5 mm;
   - Vegetation: bush and grass;
   - Estimated volume: > 100,000 m^3; and
   - Underlain by ferricrete gravel (and weathered sandstone in places).

d) **Borrow pit 50**. This sand source is located on Portion 1 of the farm Leliefontein 672LQ and is adjacent to and on the eastern side of the pipeline. It is accessed along an existing farm road from the D175 gravel road. The source has the following characteristics:
   - Area roughly 400 x 130 m;
   - 1000 to 2200 mm thick;
   - Classifies as an A2-4;
   - PI: <4;
   - GM: 1.16 to 1.44;
   - Maximum size: 2 samples show up to 24% >9.5 mm;
   - Vegetation: sparse bush and grass;
   - Estimated volume: > 100,000 m^3; and
   - Underlain by ferricrete gravel (and weathered sandstone in places).

e) **Borrow pit 49**. This sand source is located on the Remainder of the farm Schulpadfontein 328LQ and is adjacent to and east of the pipeline. It is accessed along an existing farm road from the D175 gravel road. The source has the following characteristics:
   - Area roughly 440 x 250 m;
   - 1000 to 2100 mm thick;
   - Classifies as an A2-4;
   - PI: <7;
   - GM: 1.04 to 1.25;
   - Maximum size: 1 sample shows 8% >9.5 mm;
   - Vegetation: sparse bush and grass;
   - Estimated volume: > 100,000 m^3; and
   - Underlain by ferricrete gravel (and weathered sandstone in places).

f) **Borrow pit 48**. This sand source is located on Portion 1 of the farm Zandheuwel 356LQ and is about 100m east of the pipeline. It is accessed along an existing farm road from the D175 gravel road. The sand has the following characteristics:

- Area roughly 440 x 250 m;
- 1000 to 2100 mm thick;
- Classifies as an A2-4;
- PI: >9;
- GM: 1.04 to 1.23;
- Maximum size: 2 samples show between 1 and 8% >9.5 mm;
- Vegetation: sparse bush and grass;
- Estimated volume: > 90,000 m^3; and
- Underlain by ferricrete, calcrete gravel (and weathered sandstone in places).

g) **Borrow pit 15**. The properties of this source are discussed in the Stage 4 report.

6.3.2 Gravel for Haul and Access Roads

No specific sources of gravel for use on haul and access roads have been identified. In all the borrow pits discussed above, gravel occurs below the bedding sand. The gravel comprises ferricrete, calcrete and weathered sandstone. The results of the testing on these are given in Annexure B. The sources identified are summarised in Table 6, together with an estimate of the volume of gravel available.

Table 6: Gravel borrow sources

BP no.	Location (WGS84 Lo27)		Ch. (m)	Offset to pipeline (m)	Est. volume (m^3)	Comments
	Y	X				
43#	-041 362	2 658 260	2,000	On Stage 1	10,000	Ferricrete
53+	-040 487	2 641 428	2 300	50 L	4,000	
52	-037 097	2 640 453	6,000	50 L	4,000	Ferricrete, sandstone
50	-035 802	2 634 270	12,800	100 R	10,000	
48	-032 678	2 632 164	16,500	200 R	40,000	
49	-029 936	2 629 990	20,700	50 R	Minor	Refusal on ferricrete
15$	028 890	2 622 230	25,500	500 R	11,000	Ferricrete

+ BP only partially investigated
# Closest BP to south (on Stage 1)
$ Closest BP to west (on Stage 4)
L = Left/south or west of pipeline R= Right/east of pipeline

6.3.3 Commercial Sources of Construction Materials

The nearest known commercial sources of stone and sand aggregate for concrete are in the vicinity of Lephalale. These have been discussed in detail in the Stage 1 geotechnical report. The haul distance from Lephalale to Steenbokpan is about 50 km and to the Operational Reservoir about 65 km.

6.3.4 Chemical Analyses

The chemical analyses show that the pH of the soils tested from borrow pits ranges from 4.35 to 8.75, and the conductivity from 0.001 to 0.210 S/m. The results are given in Annexure B2.1.

6.4 Spoil Sites

Four existing borrow pits (or other excavations), which could potentially be used as spoil sites, were observed along the route. The location of these is shown on Figure 1.

Table 7: Potential spoil sites

Site no.	Co-ordinates (WGS84, Lo27)		Approx. Chainage (m)	Offset (m) (from preferred route)	Estimated volume (m^3)	Comments
	Y	X				
M	-037 949	2 644 719	0,820/	7,000 N+	10,000	Old BP
N	-042 426	2 637 474	12,700	1,200 S+	50,000	Old BP
O	-035 909	2 642 131	18,000	3,000 S	5,000	Old BP
P	-027 383	2 624 039	19,800	1,400 W+	10,000	Old BP

+ N = north S = south W = west

It must be noted that negotiations have not been initiated with the owners of these sites regarding their use as spoil sites, nor has any environmental study been done.

6.5 Excavatability Basis

The excavatability of the materials encountered in the centreline test pits is based on the performance of the TLB used to excavate them (see Table 1). The depth to refusal for each test pit is summarised in Annexure A1 and is shown on the profiles bound into Annexure A2. In most instances refusal occurred on ferricrete or calcrete.

6.6 Observed Groundwater Levels

A total of 163 test pits (121 on Preferred Route and 42 on Alternative Route) were dug along the two pipeline routes and in only 3 was groundwater encountered - slight seepage at between 2 and 3 m depth in test pits CN/01, CN/12 and CN/94. None of these test pits showed signs of instability. A number of non-perennial pans occur along the route and elevated water tables may be found in their vicinity, when they contain water.

No occurrence of hydrophilic vegetation, which might be indicative of shallow groundwater conditions, was observed along the route.

7 SUMMARY AND CONCLUSIONS

The investigation for the pipeline and borrow pits was undertaken by means of test pitting with a TLB. The pits were excavated at nominal 200 m spacing along the pipeline route and at a nominal spacing of 30 m at borrow pit locations.

The geology of the area comprises Waterberg sandstone over the whole route. Quaternary sand blankets the underlying geology.

8 INTERPRETATION

An interpretation of the findings of the geotechnical investigations has been carried out in order to assist in the design process and to aid Tenderers in their pricing of the project. The interpretation is given in Volume 3 of this Report.

9 REFERENCES

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