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Geotechnical Report: Lower Coerney Dam Site: Supplementary Investigations

Support of the Water Reconciliation Strategy for the Algoa Water Supply System

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DEPARTMENT OF WATER AND SANITATION

Directorates: National Water Resource Planning and Options Analysis

Support of the Water Reconciliation Strategy for the Algoa Water Supply System

Geotechnical Report: Lower Coerney Dam Site: Supplementary Investigations

September 2019

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Department of Water and Sanitation
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SUPPORT OF THE WATER RECONCILIATION STRATEGY FOR THE ALGOA WATER SUPPLY SYSTEM

APPROVAL

Title	:	Geotechnical Report: Lower Coerney Dam Site: Supplementary Investigations.
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Document Index

Reports that will be produced as part of this Study are indicated below.

Bold type indicates this Report.

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Executive Summary

Introduction

Aurecon South Africa (Pty) Ltd was appointed by the Department of Water and Sanitation (DWS) to investigate various options for augmenting water supply to Port Elizabeth. As part of the wider study, geotechnical investigations have been conducted at the two most favourable dam sites, namely a site immediately upstream of the existing Scheepersvlakte Dam, called Upper Scheepersvlakte, and a site located in the adjacent catchment, designated the Lower Coerney Dam site.

The Lower Coerney site was subsequently chosen as the preferred option amongst the two sites to be investigated at feasibility level. This decision was supported by the various role players at the Study Management Meeting 12, held on 25 February 2018. The current investigations were recommended to further obtain additional information required for the feasibility design of the Coerney Dam.

This report collates the findings of the supplementary investigations together with the earlier findings into this comprehensive geotechnical report for feasibility design purposes.

These geotechnical investigations (inclusive of the earlier investigations)) included the following elements;

- Geophysical (resistivity) surveys;
- Test pitting including the additional test pitting for the supplementary investigation;
- Rotary core drilling;
- Field testing including SPT's and packer (Lugeon) testing;
- Laboratory testing; and
- Interpretation, analysis and reporting.

Geology of the site

The underlying geology comprises alluvium, colluvium, reworked terrace gravels (mixed origin), thin grey sandstones, siltstones and mudrocks of the Sundays River Formation of the Uitenhage Group; part of a collection of sedimentary strata within the structurally controlled Algoa Basin.

The seismic hazard of the area is considered to be very low and the Peak Ground Acceleration (PGA) values are less than 0.02g, with a 10% probability of being exceeded in a 50-year period.

The dam site is characterised by gentle, almost flat slopes; as is the greater basin. For the most part, the site is covered by very dense bush.

The geological profile is characterised by soil strata with thickness up to 7 m to 8 m on the left flank, but 3 m to 4 m on the right flank and river section. Various horizons are recognised, including topsoil, colluvium as well as colluvium with evidence of pedocrete development, and a horizon of gravel-sands, considered to represent reworked terrace gravels, that blankets the bedrock across the entire dam footprint, as well as within the basin.

Bedrock comprises an alternating succession of sandstones and mudrocks, including silty sandstones. The lateral continuity of these strata is uncertain. The bedrock is characterised by extensive, pervasive weathering, and these rocks are generally considered weak rocks.

The transported soils essentially comprise mixtures of sand, clay and silt; either clayey silt, sandy silt or silty sand. The recent investigation indicates a clay content of 4% to 35%, with the highest content indicated on the mudrocks. A coarser fraction is present within the 'reworked terrace gravels' but is not uniformly distributed. In places a concentrated coarse fraction occurs that might represent former drainage channels, and in other areas the coarse fraction is a minor component.

The permeability of the respective soil strata varies between 1.84 x 10^{-5} cm/s and 7.08 x 10^{-7} cm/s. The suite of dispersivity tests indicates that the soils are at least non-dispersive to intermediate dispersivity.

Dam type, founding conditions and materials

The geological profile, as well as other factors such as the topography, indicates that only an embankment dam is possible at this site. There are no suitable sources of rock in the immediate vicinity, and an earthfill embankment is the only viable option. A cut-off (under the embankment) would generally have to extend to the base of the gravel soils in order to ensure the potential seepage is effectively cut off. The side channel spillway on the left flank would be underlain by soils and bedrock; full concrete lining of the chute will be required and provision for energy dissipation must be included at the downstream end. Bedrock was encountered between 3.4 m and 4.9 m in test pits TP126 and TP125 respectively, at the end of the spillway.

Packer tests within the bedrock yielded variable results, and included some significant losses ascribed to wash-out of weathered, soft rock interbeds.

In assessing various material types within the basin, no clear distinction can be made on the suitability of the various material types for either impervious core material or for semi-pervious shell material. In other words, the properties of the various material groupings do not permit clear definition of their suitability, and therefore clear delineation into different borrow areas for the respective material uses cannot sensibly be made. In view of this, and also considering the almost total compliance of these basin materials with typical homogeneous embankment specifications, it is recommended that the Coerney Dam be constructed as a homogeneous earthfill embankment rather than a zoned embankment.

Involvement of a geotechnical specialist during construction is essential. Activities would include regular inspection of all excavated faces and cut slopes from a stability point of view, oversight of any further geotechnical exploration and quality assurance testing, confirmation of bedrock depth at the spillway end, engineering geological mapping of the cut-off trench and recording of the as-built details, etc.

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Abbreviations

DWS	Department of Water and Sanitation
FSL	Full Supply Level
GPS	Global Positioning System
GWS	Government Water Scheme
mamsl	Metres above mean sea level
NOCL	Non-Overspill Crest Level
ORP	Orange River Project
PGA	Peak Ground Acceleration
SPT	Standard Penetration Test

1 Introduction

Aurecon South Africa (Pty) Ltd was appointed by the Department of Water & Sanitation (DWS) to investigate various options for improving the assurance of supply that is provided by the Scheepersvlakte Dam to the Nooitgedagt WTW, recommend a preferred storage site, and undertake feasibility design. After considering the various options identified, two possible alternate new dam sites were recognised as the most favourable, namely a site immediately upstream of the existing Scheepersvlakte Dam, called Upper Scheepersvlakte, and a site located in the adjacent catchment, designated the Lower Coerney site. The locations of these sites are illustrated below in **Figure 1.1.**

In order to support selection of a preferred site, geotechnical investigations were initiated at both these options. The following geotechnical reports were submitted as part of the evaluation process:

- Department of Water and Sanitation, South Africa 2019, Geotechnical Report: Lower Coerney Dam Site. Report Number P WMA 07/N40/00/2619/2. Prepared by Aurecon South Africa (Pty) Ltd as part of the Support of the Water Reconciliation Strategy for the Algoa Water Supply System.
- Department of Water and Sanitation, South Africa 2019, Geotechnical Report: Upper Scheepersvlakte Report Number P WMA 07/N40/00/2619/1. Prepared by Aurecon South Africa (Pty) Ltd as part of the Support of the Water Reconciliation Strategy for the Algoa Water Supply System.

The Lower Coerney Dam site was subsequently chosen as the preferred option amongst the two sites for further investigation at feasibility level. This decision was supported by the various role players at Study Management Meeting 12, held on 25 February 2018.

Access within the general basin area during earlier investigation was very restricted due to the very dense bush, with only few test pits excavated in the basin. To obtain additional information required for the feasibility design of the Coerney Dam and to manoeuvre the bush, an excavator was proposed for excavation of the additional test pits. This was conducted with the aim of getting deeper profiles for better understanding of the basin ground conditions.

A motivation letter was subsequently sent to DWS for approval to proceed with the additional geotechnical investigation on the 22nd March 2019. This letter was in reference to the need to also confirm materials availability within the basin and to confirm compliance with the required specifications by means of complimentary laboratory testing. The additional geotechnical work was then approved by the DWS and supplementary investigations were conducted during the week of 10-14 June 2019.

This report presents the findings of the supplementary investigations. For ease of reference, however, findings from the previous investigations are incorporated into this report.

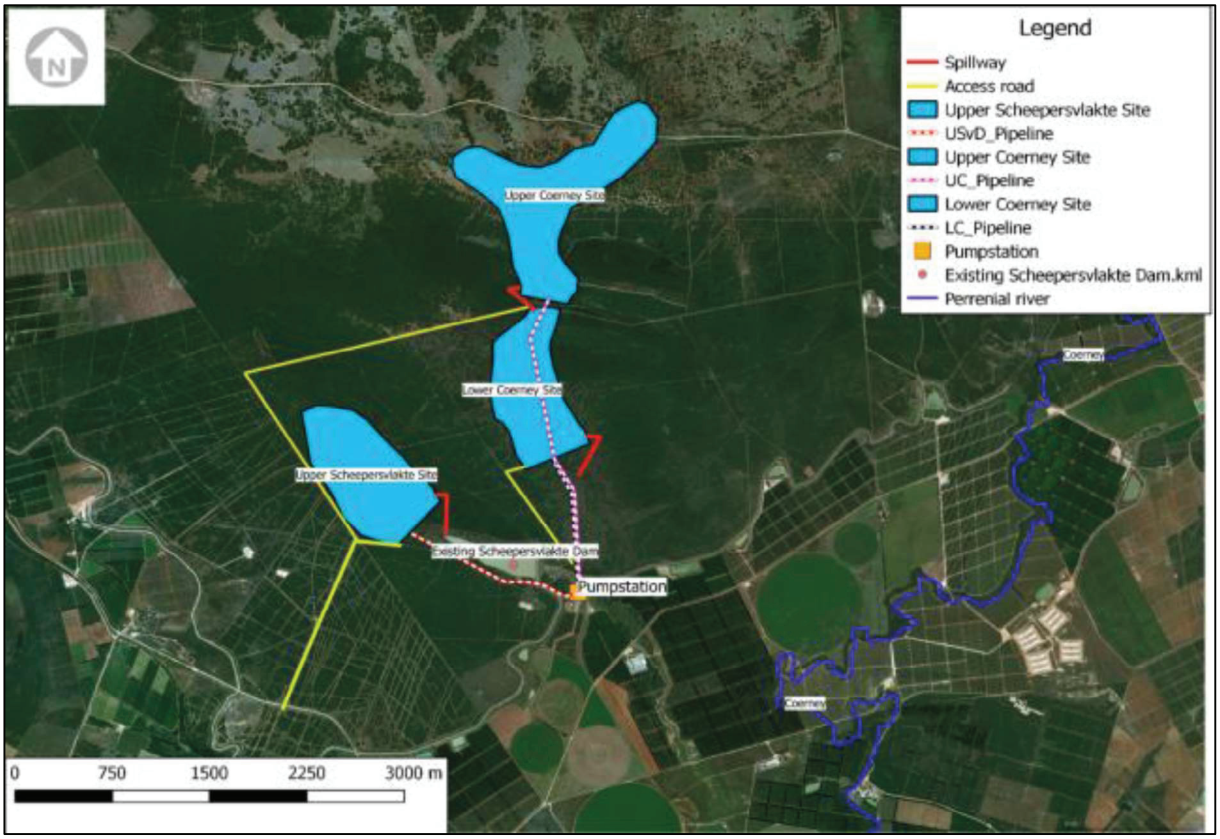

Figure 1.1: General locality plan of the respective alternate dam sites investigated

The preliminary dam details are summarised below in **Table 1-1.**

Table 1-1: Dam design details for Lower Coerney site

Dam feature	Lower Coerney Dam
Type of dam	Zoned Earthfill Embankment
NOC (amsl)	103.8
FSL (amsl)	98.8
Freeboard (m)	5.0
Crest width (m)	5.0
DS slope (1V:H)	2.0
US slope (1V:H)	3.0
Embankment fill volume (m^3)	355,993

Dam feature	Lower Coerney Dam
Core trench volume (m^3)	46,798
Crest length (m)	623
Total gross dam capacity (m^3)	4,600,000
Surface area at FSL (ha)	597,317
Maximum wall height (m)	19.0
Catchment area (km^2)	34
Unrouted SEF Inflow (m^3/s)	890
Spillway configuration description	Concrete-lined, 36 m wide, side channel spillway located on the left abutment. (Note: spillway position dependant on geotechnical conditions) with downstream concrete outlet chamber, 4x4x3m, with 2 valves for the two pipes.
Outlet works description	Dry well tower (19 m high) with inside dimensions of 4x4m. Three offtake levels controlled by valves.
Access road length (km)	1.0

2 Available information

The following available information was used for this investigation:

- Geological map Sheet 3324 Port Elizabeth. Council for Geoscience.
- Geological Survey February 1987. Scheepersvlakte Dam – Side Valley Site; 1st Engineering Geological Feasibility / Design Report – Founding Conditions. Report to Department of Water Affairs.
- Department of Water Affairs (DWA). October 1988. O.R.D.P. Lower Sundays River G.W.S.; Scheepersvlakte Dam. Design Report.
- Department of Water Affairs and Forestry (DWAF). July 1992. O.R.D.P. Lower Sundays River G.W.S.; Scheepersvlakte Dam. Completion Report. (in Afrikaans) Report No N400/10/ED07.
- Outeniqua Lab EC cc. 2016. Geotechnical Report. Geotechnical Site Investigation for the Proposed Scheepersvlakte Irrigation Scheme Dam near Port Elizabeth in the Eastern Cape. Report to Inconsult Engineers, dated 22 July 2016.

3 Previous investigations

Several investigations have been conducted over the years, specifically for the original Scheepersvlakte Dam.

The proximity of the Lower Coerney site to Scheepersvlakte dam site indicates some relevance to general ground conditions as encountered at the Lower Coerney site, but these earlier investigations are not unpacked in this report. One useful reference report was the Completion Report for Scheepersvlakte Dam (DWAF, 1992).

In the reporting on the Scheepersvlakte investigations[1] it was mentioned, however, that earlier investigations were conducted in 1978/79 at what is presumably the current Lower Coerney site, before investigations shifted to the Scheepersvlakte "side-valley" site that proceeded to be constructed. At the time these investigations were also called "Scheepersvlakte" but might be referred to as "Coerney". These original investigations at the Coerney option considered three centre-lines. It is mentioned that 20 boreholes (total length 340.97 m) were drilled; concentrated mostly at an "upper" site. There is also mention of trenching only having been carried out at a "middle" site, while a "lower" site was also investigated.

The Scheepersvlakte "side valley" report (Geological Survey, 1987) mentioned that a separate report would be prepared for these "Coerney" investigations, but it remains doubtful whether this was done. No records of such a report could be located.

A geotechnical investigation of the Coerney site was further carried out in 2016 by Outeniqua Lab EC who were appointed by Inconsult Engineers[2]. The work primarily comprised excavation and profiling of test pits (17 No), accompanied by laboratory testing.

Option analysis, to distinguish between the Upper Scheepersvlakte and Lower Coerney dam sites was conducted in 2018. These investigations were conducted to improve geotechnical information, and update design parameters and costs, to be able to make a final recommendation on the preferred dam site. These investigations included geophysical surveys, test pitting, sampling and laboratory testing, and rotary core drilling.

[1] Scheepersvlakte Dam – Side Valley Site; *1st Engineering Geological Feasibility / Design Report – Founding Conditions.* February 1987. Geological Survey Report.
[2] Outeniqua Lab EC cc. 2016. Geotechnical Report. *Geotechnical Site Investigation for the Proposed Scheepersvlakte Irrigation Scheme Dam near Port Elizabeth in the Eastern Cape*. Report to Inconsult Engineers, dated 22 July 2016.

4 Investigation methodology

Additional test pit investigation was conducted on the Lower Coerney site (preferred option) using a tracked excavator, with the aim of supplementary investigation of the basin area, spillway chute, particularly at the end, and some in-fill test pitting, especially on the upper right flank. The geophysical survey and rotary core drilling methodologies from the previous investigation are kept in this section for ease of reference.

4.1 Geophysical surveys

Resistivity surveys were conducted by specialist geophysicists, Engineering & Exploration Geophysical Surveys cc (EEGS).

The purpose of commencing these geotechnical investigations with the geophysical surveys was primarily to identify sub-surface anomalies that might potentially impact on the envisaged layout, and thus provide potential targets for the boreholes, which would aim to validate these anomalies.

It might be noted that vegetation proved too dense to allow working access, and environmental constraints placed strict limits on the extent of permissible bush clearing. It was therefore necessary to appoint a service provider, B K Bush Clearing, to manually clear cut-lines along these geophysical traverses. It is worth noting that these "cut-lines" had a width intended for pedestrian traffic, not vehicular access, even though in places it was possible to use these cut-lines for access by the TLB. The larger trees were however not cut, and access was still limited.

Three traverses were set out; one longitudinal traverse along the centre-line, one traverse essentially perpendicular to the centre-line, roughly aligned along the intake – outlet conduit, and the third traverse aligned along the spillway. The positions of these traverses are shown in Drawing 112546-GEO-DRG-CC-001-B.

Detailed description of the methodologies, and the equipment used, as well as the results, are presented in the Appendices. The findings are incorporated into the discussion on the geological profiles encountered.

4.2 Test pitting

Test pits were excavated at the dam footprint, spillway, and on the basin as the potential construction material source. A test pit summary is presented below in **Table 4-1**. This table includes test pits excavated during earlier investigations and the recent supplementary investigations, annotated as "LC" and "TP" respectively. In total, forty-one test pits were excavated, with the majority of test pits excavated within the basin during this supplementary investigation, which included some infill investigation on the dam footprint and the spillway. Test pit positions are indicated on the site plan (Dwg 112546-GEO-DRG-CC-001-B).

Table 4-1: Test pit summary

Test Pit No	Coordinates		Termination depth (m)	Remarks
	Y	X		
LC02	-058111	X3702708	2.75	No refusal, no water
LC03	-058187	X3702632	2.4	No refusal, no seepage
LC04	-058140	X3702665	1.35	Near-refusal, no seepage
LC05	-058115	X3702619	2.25	No refusal, no seepage
LC06	-058320	X3702486	1.65	No refusal but slow excavation, no seepage
LC07	-058175	X3702718	2.25	Near-refusal, no seepage
LC08	-058402	X3702424	1.5	No refusal but slow at 1.5 m, no seepage
LC09	-058262	X3702543	2.4	No refusal, no seepage
LC10	-058447	X3702411	1.6	No refusal but slow at 1.6 m, no seepage
LC11	-058381	X3702592	1.95	No refusal but slow at 1.95 m, no seepage
LC12	-058355	X3702759	2.35	Refusal on boulders, no seepage
LC20	-058164	X3702165	1.95	No refusal but slow at 1.95 m, no seepage
LC22	-057865	X3702228	2.4	Refusal on hardpan calcrete, no seepage
LC23	-057735	X3702243	2.25	No refusal, no seepage
TP101	-058062	X3702708	4.2	No refusal, no seepage
TP102	-058165	X3702624	2.8	Refusal on boulders at 2.8m, no seepage
TP103	-058338	X3702744	2.9	No refusal, no seepage
TP104	-058252	X3702577	2.4	No refusal but slow at 2.4, no seepage
TP105	-057929	X3702599	3.6	No refusal but slow at 3.6, no seepage
TP106	-058045	X3702532	3.1	No refusal, no seepage
TP107	-058129	X3702468	2.9	Refusal on sandstone, no seepage
TP108	-058195	X3702391	3.9	Refusal on sandstone, no seepage
TP109	-057867	X3702499	4.1	No refusal but slow at 4.1, no seepage
TP110	-057988	X3702433	3.4	No refusal but slow at 3.4, no seepage
TP111	-058103	X3702367	3.9	No refusal, no seepage
TP112	-058209	X3702277	4.0	No refusal but slow at 4.0, no seepage
TP113	-057805	X3702363	4.5	No refusal, no seepage
TP114	-057907	X3702336	3.7	Refusal on mudstone, no seepage
TP115	-058024	X3702289	4.2	No refusal but slow at 4.2, no seepage
TP116	-057691	X3702130	4.8	No refusal, no seepage
TP117	-057832	X3702102	3.3	Refusal on mudstone, no seepage
TP118	-058004	X3702086	3.3	Refusal on sandstone, no seepage
TP119	-057671	X3701972	2.2	Refusal on hardpan ferricrete, no seepage
TP120	-057836	X3701938	3.7	Refusal on sandstone, no seepage

Test Pit No	Coordinates		Termination depth (m)	Remarks
	Y	X		
TP121	-058020	X3701894	2.9	No refusal but slow at 2.9, no seepage
TP122	-057728	X3701805	2.0	Refusal on hardpan ferricrete, no seepage
TP123	-057767	X3701695	2.7	Near refusal, no seepage
TP124	-057899	X3701616	3.6	Refusal on sandstone, no seepage
TP125	-058386	X3702712	4.9	Refusal on sandstone, no seepage
TP126	-058409	X3702695	3.4	Refusal on sandstone, no seepage
TP127	-058029	X3702727	3.7	Refusal on sandstone, no seepage

The “LC” test pits were excavated using a light JCB 3DX tractor-loader backhoe (TLB), sub-contracted from Renaissance Construction by Tosca Lab (Pty) Ltd, and the “TP” test pits were excavated using a JCB JS290LC Excavator (30-ton) sourced by appointed geotechnical testing laboratory Controlab SA (Pty) Ltd. Note that the excavator was hired from a co-owner of the Scheepersvlakte farm, Mr Boet Muller.

The supplementary investigations were conducted during the week of 10 to 14 June 2019. The initial investigations were conducted from 17 May 2018 to 4 October 2018.

Test pits were profiled by a graduate civil engineer and engineering geologists in accordance with accepted southern African standards (as per Jennings, Brink, and Williams, 1973).

The two-person team carrying out the test pitting ensured compliance with accepted safety requirements as reflected in the South African Code of Practice (SAICE: 2007). Further observance of good safety practice is exhibited by the following;

- Compilation of a Health & Safety File in compliance with the South African OHS Act, including the necessary legal appointments (Section 8(2)(i)).
- Maintaining good management of the machinery (TLB and excavator, respectively, as well as drilling equipment) and the excavation process, including placement of spoil away from the pit edges, maintaining a safe distance from the machine, conducting a full briefing / induction of the operator, excavation of a sloping ramp at one end for easier entry / egress etc.
- Conducting a risk assessment by the competent person prior to entering the test pit. Such safe practices included limited or non-entry into the deeper excavator pits, and primarily profiling from surface spoil.
- Test pits were closed immediately after profiling and sampling. No pits were left open overnight.

Test pit positions were recorded with a Garmin hand-held GPS. Coordinates in the South African grid, WGS84 datum, are reflected in **Table 4.1**.

4.3 Rotary core drilling

A total of six rotary cored boreholes were drilled on the dam footprint / spillway and positions are shown on Drawing 112546-GEO-DRG-CC-001-B. No boreholes were drilled within the general reservoir area. Borehole details are summarised below in **Table 4-2.** All boreholes were drilled vertically.

Table 4-2: Borehole summary

BH No	Coordinates		Elevation	BH length (m)	Remarks
	Y	X			
LC BH01	-58099.59	3702689.25	83.36	15.01	Mid-right flank
LC BH02	-58215.90	3702532.15	89.15	20.45	Intake, lower left flank
LC BH03	-58252.35	3702625.65	84.30	20.43	Outlet, lower left flank
LC BH04	-58170.99	3702620.43	81.82	15.04	Mid -embankment / lowest point
LC BH05	-58427.33	3702391.34	102.01	10.03	Extreme left flank / spillway crest
LC BH06	-58387.47	3702608.97	89.98	10.1	Spillway

Specialist geotechnical drilling contractor, RWBE Geotechnical Drilling, was appointed for the drilling. Where possible, Standard Penetration Testing (SPTs) was carried out. In practice, the presence of gravels and cobbles within the soil profile severely limited the number of tests that were possible. Water acceptance (also referred to as packer or Lugeon) tests were carried out in selected boreholes, after the methodology described by Houlsby (1976).

Boreholes were located to investigate key elements of the dam – with due cognisance of the geophysics survey results. Borehole cores were logged in accordance with accepted standards. Logs are included in the Appendices, as are photographs of the borehole cores.

Boreholes were set out initially using a hand-held GPS, but the completed boreholes were accurately surveyed by DWS Survey Services.

No further drilling was undertaken during the supplementary investigations.

4.4 Laboratory testing

For initial investigations, representative samples were submitted to Tosca Lab in Port Elizabeth for testing. A list of tests conducted is presented below (**Table 4-3**). Samples comprised both disturbed bulk samples as well as undisturbed samples.

Table 4-3: Summary of laboratory tests conducted from initial investigations

Test	Quantities
Foundation Indicators	19
Moisture content	7
Relative density	4
Standard AASTHO (Proctor) compaction	8
Permeability	7
Shear box	10
Suite of dispersivity tests, comprising i) Pinhole test, ii) crumb test, iii) double hydrometer test, and iv) exchangeable sodium percentage (ESP) test.	4

For the supplementary investigations, the majority of the representative samples were submitted to Controlab (Pty) Ltd in East London for testing, with an approximate 10% portion of duplicate samples submitted to Labco (Pty) Ltd laboratories in Port Elizabeth for quality assurance / quality control (QA/QC) purposes. The tests conducted, and respective quantities are summarised in the following tables (Table 4-4 and Table 4-5).

Table 4-4: Bulk sample quantities for laboratory testing at Controlab

Test	Quantities
Foundation Indicators	22
Moisture content	15
Relative density	9
Standard AASTHO (Proctor) compaction	14
Permeability	9
Shear box	9
Suite of dispersivity tests, comprising i) Pinhole test, ii) crumb test, and iii) double hydrometer test.	5

Table 4-5: Duplicate sample quantities submitted for testing at Labco

Test	Quantities
Foundation Indicators	6
Moisture content	3
Relative density	2
Standard AASTHO (Proctor) compaction	3
Falling Head Permeability	2

Detailed test results are included in the Appendices, and the findings are discussed below (Section 6.3).

5 Regional geology

5.1 Stratigraphy and lithology

Geologically, the area of interest falls within the Algoa Basin which is one of the complex grabens and half-graben structures along the present eastern and southern coast associated accumulations of Jurassic and Cretaceous deposits. These basins formed along the margins of the newly-formed African continent at the time of the break-up of Gondwana (Shone, 2006).

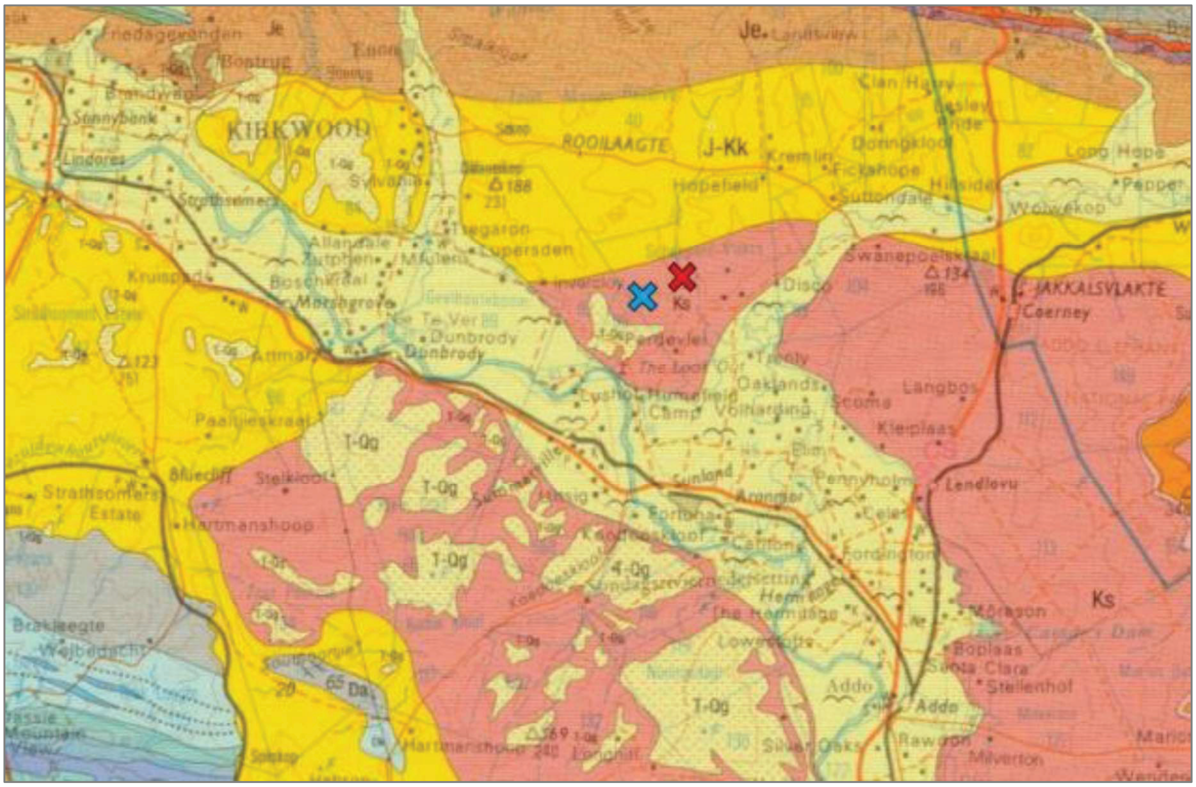

Figure 5.1: Excerpt of geological map (Sheet 3324)

The two site options are marked with crosses (blue = Upper Scheepersvlakte, red = Lower Coerney)

Figure 5.2: Geological explanation, excerpt from geological map

According to the 1:250 000 geological map (Port Elizabeth Sheet 3324, Council for Geoscience), the dam sites are both underlain by the strata of the Sunday River Formation, although in both instances the upper reaches of the respective basins are underlain by strata of the Kirkwood Formation. All are part of Uitenhage Group (**Figure 5.1**, **Figure 5.2**).

The older Kirkwood Formation consists of porous and permeable, coarse- to medium-grained, buff- and olive coloured lithic sandstone. Sandstone beds may be up to several metres thick and of variable lateral extent, interbedded with thick (often more than 30 m thick), red and greyish green siltstones and mudrocks.

The younger Sundays River Formation overlies and appears to grade laterally into the Kirkwood Formation. This Sundays River Formation consists of thin grey sandstones, siltstones and mudrocks. The sandstones are less porous and permeable than the older Kirkwood strata.

The oldest Enon Formation sediments of the Uitenhage Group are located to the north of the area of interest and do not impact directly on the discussion on the prevailing geological and geotechnical conditions of the respective sites. There is however an indirect impact, and this is dealt with at a later point.

5.2 Structural geology and seismic hazard

It is mentioned above that the Algoa basin is a half-graben structure. Such a basin is defined by faulting, in this case on the northern boundary, and the relative subsidence of the 'fault-defined' block (horst) in effect created the basin in which the sediments accumulated. The Algoa basin is known to be more complex than most, with diagonal faults cutting the horst block.

Several other prominent faults are recognised in the general area, including the Coega Fault which extends from west of the Groendal Dam to beyond the mouth of the Coega River. This fault has a vertical displacement in excess of 2000 m. these prominent NW to SE trending faults are as close as 35 - 40 km from the proposed balancing dam sites.

While the sediments within the Algoa Basin are not significantly deformed, and only display a nominal shallow dip towards the present coast, these basins are located within the Cape Fold Belt and the older Table Mountain Group strata are intensely folded. These shallow dips of approximately 10 degrees are seemingly confirmed by detailed mapping of the Scheepersvlakte Dam foundations.

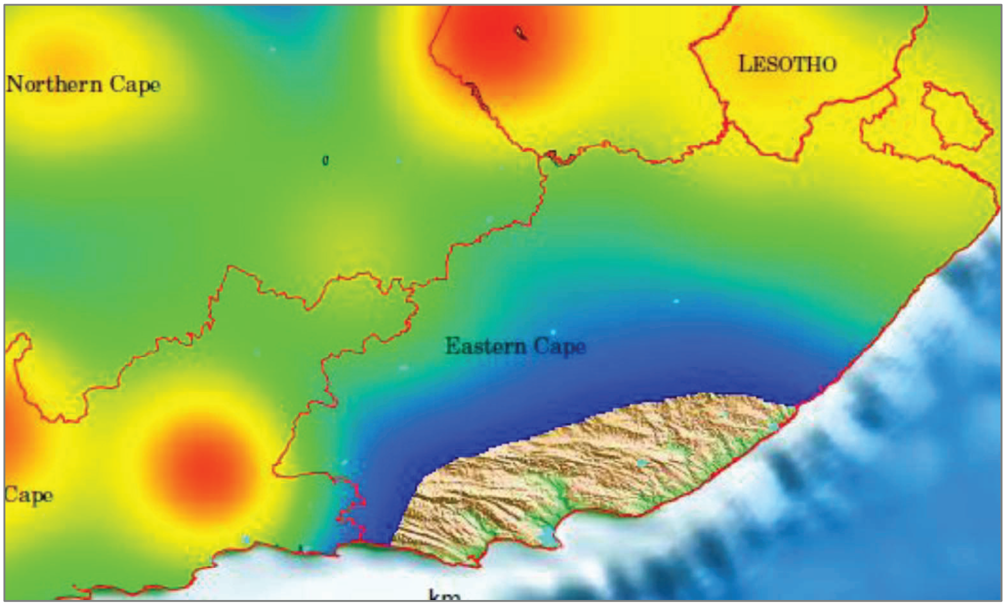

Figure 5.3: Excerpt of the seismic hazard map of South Africa (after Kijko et al, 2003)

Even though the very existence of the Algoa Basin is directly linked to faulting, and other regional-scale faults are also recognised, the seismic hazard of the area is considered to be very low. **Figure 5.3** is an excerpt of the seismic hazard map (after Kijko, et al, 2003) which shows the Peak Ground Acceleration (PGA) values of less than 0.02g, where these are with a 10% probability of being exceeded in a 50-year period.

5.3 Economic geology

There are no known reserves of economically important minerals within the respective dam basins. Within the general area economic activities relating to the geology would revolve around construction materials, including suitable rocks for processing of aggregates, as well as clays for brick-making. There are no such active commercial quarry sites within the Lower Coerney Dam basin.

5.4 Weathering and geomorphology

The area of interest lies to the east of Weinert's N = 5 line and it is estimated that the appropriate value is likely in the order of 3 to 3.5 (Port Elizabeth is at 2.6), as per Weinert, 1980. This indicates that chemical decomposition is the dominant mode of weathering. Typically, this would suggest deep residual soil profiles, but this is not a feature of the profiles encountered.

The higher-lying areas in the general area are also characterised by the formation of pedocretes associated with the African erosion surface; in this instance calcrete and ferricrete. On the respective dam sites, the calcrete formation was recognised, but was not developed to any significant degree. A harder capping of calcrete hardpan or 'duricrust' is noted on the higher-lying areas beyond the dam basin. Hardpan ferricrete was generally recognised north of the basin where it was encountered as very dense sometimes with calcrete concretions in patches.

There is no evidence of erosion and depositions being currently-active geological processes.

The evolution of the sedimentary basin, as well as periods of fluctuating sea levels have however complicated the geological sequence observed. The area extending between the current coast and the Zuurberge mountain range to the north of the dam sites representing a relatively level wave cut platform linked to a period of elevated sea level. Such wave erosion in the period roughly between 20 and 2 million years ago would have resulted in erosion of the older Enon Formation conglomerates at the foothills of the Zuurberge – and redistribution of these gravels in a 'veneer' across the coastal plain, while also concentrating these gravels in alluvial channels.

6 Investigation findings

6.1 Site description

The dam site is characterised by gentle, almost flat slopes; as is the greater basin. For the most part, the site is covered by very dense bush. As mentioned, this required cutting of traverse lines for the geophysical survey to proceed. Limited jeep tracks along farm boundaries also facilitated vehicle access (**Plate 6.1**), specifically downstream of the dam site, and traversing the left flank, and another traversing the basin area. With the exception of these tracks, the bush is generally impenetrable, although open areas were occasionally present. These open spots were targeted during the additional investigations in view of the ease of access for the excavator, and also considering the lesser impact on the natural bush.

For clarity, the description that follows includes the subdivision into respective flanks and river section. It is noted however that there is no clearly defined water course as such, and the concept of ‘river section’ refers more to the relatively flat area between the opposite flanks.

Plate 6-1 General panorama of Lower Coerney site, from the access track a short distance downstream of the centre-line (which is to the left)

6.2 Geological profile

6.2.1 Left flank, including spillway

Subsurface conditions on the left flank, inclusive of the spillway (**Plate 6.2**), have been investigated by geophysical traverses, test pits as well as boreholes, as shown on Drawing 112546-GEO-DRG-CC-001-B. The summarised findings are presented below in **Table 6-1** in the case of the test pits and **Table 6-2** for the boreholes. A longitudinal geological section has been compiled (drawings 112546-GEO-DRG-CC-002A-A and 112546-GEO-DRG-CC-002B-B).

It has been mentioned that the dense bush restricted access, and that this was then achieved chiefly via the narrow cleared intersect lines, and the track which traverses the left flank. The positions of the test pits, as well as the boreholes were partly governed by this access. The test pits were excavated across the left flank; extending from lower flank, to mid- and upper flank areas. A test pit was also excavated midway along the spillway alignment. Supplementary test pits were excavated at the end of the spillway in order to investigate likely founding conditions.

Table 6-1: Left flank test pits; summarised geological profile (depths in m)

TP no	Topsoil; silty to clayey sand, loose to medium dense, or dense	Colluvium; silty sand with gravels, medium dense to dense, or very dense	Colluvium, partly pedogenic; silty sand with calcrete / ferricrete nodules / near-hardpan, dense to very dense	Mixed origin; clayey silt, very stiff	Residual sandstone, very dense silty sand with sandstone gravel	Sandstone; moderately weathered, hard rock
LC09	0 – 0.4	0.4 – 0.85	0.85 – 1.2	1.2 – 2.4+		
LC11	0 – 0.3	0.3 – 0.5	0.5 – 1.95+			
LC06	0 – 0.2	0.2 – 0.5	0.5 – 1.65+			
LC08	0 – 0.3		0.3 – 1.5+			
LC10	0 – 0.3	0.3 – 0.7	0.7 – 1.6+			
TP104	0 – 0.4	0.4 - 1.3	1.3 – 2.3+			
TP125	0 – 0.5	0.5 – 2.2	2.2 – 4.9			4.9+
TP126	0 - 0.3	0.3 – 1.2	1.2 - 3.4			3.4+
TP103[1]	0.0 – 0.2	0.2 – 2.1			2.1 – 2.9+	

Notes [1]; *TP103 is technically within the river section but is duplicated in the above table to facilitate the discussions.*

Table 6-2: Left flank boreholes, summarised geological profile (depths in m)

BH no	Colluvium; slightly clayey, silty sand	Alluvium / mixed origin; gravels in sand matrix	Mudstone; highly to completely weathered, soft to very soft rock	Mudstone; unweathered, hard rock	Interbedded mudstone / sandstone; highly to moderately weathered, generally medium hard rock	Sandstone; highly (to completely) weathered, hard (soft / to sand) rock	Sandstone; moderately weathered, hard rock
LC BH02	0 – 2.65	2.65 – 7.7	7.7 – 9.75		9.75 – 14.15	15.15 – 19.33	19.33 – 20.45
LC BH03	0 – 1.28	1.28 – 4.05		15.16 – 20.43	4.05 - 12		12 – 15.16
LC BH05	0 - 4	4 – 7.2	7.2 – 10.03				
LC BH06	0 – 5.45	5.45 – 6.7				6.7 – 10.1	

Plate 6-2: General view of left flank conditions, looking here along the spillway alignment in a downstream direction

Boreholes were drilled at specific elements of the proposed dam layout; specifically, the lower flank areas to cover the intake / conduit outlet (boreholes LC BH02 and LC BH03, respectively), as well as the upper flank / crest coinciding with the spillway crest (borehole LC BH05). A further borehole was drilled roughly midway along the spillway chute (LC BH05)

The geophysics profiles confirm the flank is essentially a 'conductor', which would generally be consistent with weathered rock. The left flank, in particular is characterised by a 'conductor'; a slight increase in resistivity is apparent with depth, but this is in a disjointed, irregular manner and the impression of horizontal layering is not readily apparent. The profile indicates a number of the lateral interruptions, which might indicate faulting. This resistivity profile is consistent for the traverse along the centre-line and also the traverse along the spillway alignment.

The various strata identified within the geological profile on the left flank are described in more detail below. For detailed description of the shallow soil strata, reliance is placed on the test pits, while for the deeper soil horizons and the underlying bedrock, the information is derived from the boreholes. The geological profile comprises;

- Topsoil,
- Colluvium,
- Colluvium that has been altered by pedogenic action,
- Alluvium or reworked terrace gravels,
- Bedrock, comprising variable combinations of mudstone, siltstone and sandstone.

The upmost **topsoil** horizon is described as dry, brown, medium dense occasionally loose or even dense, blocky or micro-blocky structure or even shattered occasionally, with occasional burrows or pinholes, otherwise intact silty sand. Roots are typically found. The thickness varies between 0.2 m and 0.5 m.

The general **colluvial material** is described as dry, reddish to orange brown, medium dense to dense, occasionally very dense, intact, slightly clayey, silty sand. In places this horizon might contain minor fine calcrete nodules as well as roots. Minor pinholes are recorded on occasion. In places a minor fraction of fine or medium, angular to sub-rounded gravels is recognised. Only if the presence of the pedogenic nodules is particularly minor is this material considered as 'colluvium'; should the pedocrete development be significant then these soils would be considered to be a 'pedocrete', as referred to below. Thickness varies between 0.2 m and 0.9 m but may be thicker, as encountered in TP125t where a thickness of 1.7 m was recorded.

A colluvial soil stratum with significant **pedocrete** development is identified. These materials comprise dry to slightly moist, dark to reddish brown or orange brown / orange, mottled whitish, intact, slightly clayey silty sand (i.e. as per the above colluvium), with scattered calcrete accretions that vary between powder calcrete to honeycomb calcrete, and calcrete nodules. In limited instances, the stratum contained both calcrete as well as ferricrete nodules. In test pit LC11 the ferruginised sand horizon approaches hardpan ferricrete and comprises very dense silty to sandy (gravel-sized) nodules. The overall consistency varies between dense and very dense. In places distinction can be made between an upper horizon of medium dense to dense consistency, with minor or macro pinholes, and a lower horizon described as dense to very dense. In one instance this stratum was noted to contain sub-rounded, medium gravels of hard rock quartzite. Horizon thickness varies between 0.9 m and 2.7 m.

Test pit LC10 on the extreme upper left flank and TP126 located by the end of the spillway chute terminated in calcrete-cemented and sandstone bedrock respectively, clayey, silty sand with loosely-packed, medium and coarse, sub-rounded quartzite gravels are encountered in these two locations. The boreholes, however, confirm this horizon to extend to all parts of the left flank. Although described as alluvium it is considered more likely to see this deposit as representing reworked terrace gravels. In places these gravels / cobbles appear more concentrated, i.e. comprising a higher proportion of coarse clasts and a relatively minor component of the finer matrix material. These concentrated coarser deposits might represent earlier river / stream channels. This gravel stratum is encountered at depths between 1.28 m and 5.45 m. The stratum thickness varies between 1.25 m and 5.05 m. Broadly this gravel layer is most well developed on the lower flank areas but is intersected at depth across the entire flank. This transported gravel horizon is directly underlain by bedrock.

A single occurrence (test pit LC09) was recorded where a lower soil horizon of **uncertain origin** (i.e. mixed origin) was noted at a depth between 1.2 m and 2.4 m, i.e. a minimum thickness of 1.2 m. This material comprises slightly moist, reddish brown, very stiff, intact clayey silt.

Test pits excavated at the end of the spillway on the lower left flank (TP125 and TP126) indicate the depth to bedrock, i.e. the rockhead, to be between 4.9 m and 3.4m, respectively. The boreholes indicated rockhead to be at depths varying between 4 m and 7.7 m. In essence, bedrock on the left flank can be expected between depths of 3.4 m and 7.7 m

Bedrock comprises a succession of sandstones and mudstones in varying proportions. Horizons of mudstone, or sandstone are recognised, as well as strata where the mudstones / sandstones are interbedded. The boundaries of these lithological changes have not been confirmed with absolute certainty; partly because the boreholes do not intersect all changes, but also due to the often-gradational nature of these variations. It is further expected that significant lateral variation will characterise the strata, and that the horizons are not necessarily laterally continuous. From the limited borehole intersections of traceable contacts, it would appear that the strata dip into the flank at shallow angles of 4° to 5°.

The bedrock is characterised by pervasive weathering, and as a rule the rock mass is weathered throughout.

Two boreholes (only one on the left flank) did however reveal unweathered rock at the base of the borehole. Borehole LC03 intersected unweathered mudstone at a depth of 15.16 m (approximate elevation 69 masl). The uppermost bedrock horizon either comprises mudstone or sandstone; characterised by a 'highly to completely' degree of weathering, to the extent that the rock is soft to very soft and in places is weathered to clay, or sand, depending on whether the rock is mudstone or sandstone. Generally, the profile is characterised by improving weathering with increasing depth; with a progressive change from highly / completely weathered rock at surface to moderately or even slightly weathered rock at the borehole termination depths. At these depths the rock is described as 'hard rock'.

It is worth noting that while the unweathered mudstones classify as hard rock, these rocks are known to be susceptible to slaking, and will therefore rapidly deteriorate upon exposure to the atmosphere. Such propensity to slake will also be experienced within predominantly sandstone horizons, but where interbedded mudstone strata are present.

The generally expected shallow dip of the strata is further borne out by the discontinuities, which reflect the common occurrence of shallow joints dipping at 0° to 10°. This discontinuity set is considered to represent the bedding. Other prominent joints include very steeply dipping / sub-vertical joints (80° to 90°), and less commonly, joints dipping at angles between 40° and 60°. At shallower depths within the bedrock, the rock mass is typically characterised by the interbeds, which have weathered to clay, or sand. Commonly, the drilling within these weak rocks is characterised by notable material losses; which are assumed linked to these weathered interbeds of clay / sand. Even if not lost ('washed'), the weathered interbeds are characteristically weaker than the surrounding material.

6.2.2 River section

The summarised geological profile within the river section, as revealed by test pits and boreholes, is presented in **Table 6-3** and **Table 6-4**, respectively. A measure of overlap is considered in these summary tables, hence the seeming repetition.

Table 6-3: River section, summarised test pit profiles (depths in metres)

TP no	Topsoil; loose to medium dense or dense, silty to medium sand	Colluvium; medium dense or dense, silty sand	Colluvium / partly pedogenic; loose to medium dense / dense	Gravels / cobbles in sand matrix, overall loose to medium dense / very dense; Mixed origin	Alluvium; very dense, silty clayey sand	Residual sandstone, very dense silty sand with sandstone gravel
LC02	0 – 0.3	0.3 – 1	1 – 1.95	1.95 – 2.75+		
LC03	0 – 0.3	0.3 – 1.15	2.05 – 2.4+	1.15 – 2.05		
LC04	0 – 0.3			0.3 – 0.9	0.9 – 1.35+	
LC05	0 – 0.3			0.3 – 2.25+		
LC12	0 – 0.2			0.2 – 2.35+		
TP102	0 – 0.4	0.4 – 1.8		1.8 – 2.8+		
TP103	0 – 0.2	0.2 – 2.1				2.1 – 2.9+

Table 6-4: River section, summarised borehole profiles (depths in metres)

BH no	Colluvium; slightly clayey, silty sand	Alluvium / mixed origin; gravels in sand matrix	Mudstone; highly to completely weathered, soft to very soft rock	Mudstone' slightly to moderately weathered, soft to medium hard rock	Mudstone; unweathered, hard rock	Interbedded mudstone / sandstone; highly to moderately weathered, generally medium hard rock	Sandstone; highly (to completely) weathered, hard (soft / to sand) rock	Sandstone; moderately weathered, hard rock
LC BH02	0 – 2.65	2.65 – 7.7	7.7 – 9.75			9.75 – 14.15	15.15 – 19.33	19.33 – 20.45
LC BH03	0 – 1.28	1.28 – 4.05			15.16 – 20.43	4.05 - 12		12 – 15.16
LC BH04	0 - 2	2 – 3.25		10.95 – 13.3	13.3 – 15.04+		3.25 – 7.5	7.5 – 10.95
LC BH01	0 – 0.8	0.8 – 2.7	4.55 – 10.94	13.1 – 15.01+			2.7 – 4.55 10.94 – 13.1	

The resistivity profile within the central section is characterised by a prominent resistant layer at surface, extending to an estimated depth of 5 m – 10 m. This horizon was considered to represent a measure of cementation within the upper soil horizon. Beneath this surface 'resistor' the profile is characterised by ‘conductors’. Further layering in this regard is not readily apparent, and these conductor values are consistent with weathered rock.

The geological profile within the central portion is characterised by the following strata;

- Topsoil,
- Colluvium,
- Colluvium that is altered by pedogenesis,
- Gravel soils, considered to be of mixed origin (reworked terrace gravels),
- Occasional / rare alluvial stratum,
- Residual soil derived from sandstone, and
- Bedrock

Plate 6-3: River section view, looking towards right flank (test pit LC03 in foreground)

The upper **topsoil** horizon covers the entire central section. The thickness varies between 0.2 m and 0.4 m. The topsoil comprises silty sand and at the time of the test pitting was typically described as dry, with consistency varying between very loose and medium dense. Occasionally the material is dense to very dense. Roots are generally present.

The underlying horizon of **colluvium** was intersected in test pits LC02, LC03 TP102 and TP103. The colluvial material comprises silty sand, or slightly clayey silty sand. The moisture content at the time was described as slightly moist, and the consistency as medium dense, dense and very dense. Pinholes were recognised in the structure. Roots are present. This colluvium is not present across the entire footprint in the river section and is likely patchy. Where present, the thickness varies between 0.7 m and 1.9 m.

Distinction is made between the colluvial material described above, and colluvium which is exhibits evidence of some **pedogenic** alteration. This material is also only evident in test pits LC02 and LC03 and is therefore not developed across the entire footprint. The material is described as slightly moist, reddish brown to light brown, loose to medium dense or dense, silty sand with ferricrete nodules or honeycomb calcrete with calcrete nodules. The thickness of this patchy horizon varies up to 0.9 m.

The stratum of **reworked terrace gravels** is recognised across the entire footprint except in TP103. These materials comprise a coarse fraction of gravels or cobbles of very hard rock quartzite with a matrix of silty to fine sand. The gravels are generally medium to coarse in size, and typically rounded or sub-rounded. The relative abundance of the coarse and fine fractions varies; in places the coarse fraction is tightly packed, i.e. clast-supported but in other strata the matrix dominates, i.e. matrix-supported, and characterised by occasional cobbles / gravels. The overall consistency varies between loose and medium dense or dense or very dense. Occasionally pinholes are recognised within the stratum. Horizon thickness typically varies between 0.6 m and 1.0 m but may be thicker; in the case of test pit LC12 the total thickness of this stratum is greater than 2 m. The boreholes confirm total thickness of this gravel stratum to vary between 1.25 m and 5 m. In the case of test pit LC12, two horizons are recognised; an upper horizon that is predominantly sand with occasional coarser fraction, and a lower horizon where the coarser fraction is dominant.

Sandy **alluvium** was recognised in only one place. Test pit LC04 intersected alluvial silty, clayey sand between depths between 0.9 m and 1.35 m. This sandy stratum was described as very dense.

The very dense silty sand with sandstone gravel material of **residual** origin, derived from the in-situ weathering of the sandstone bedrock, was only encountered in TP103 located at the end of the spillway chute. This material was encountered underlying the colluvium horizon. This stratum was encountered at 2.1 m depth with a minimum thickness of 0.8m to the end of hole at a depth of 2.9 m.

The deeper **bedrock** profile within the river section is mainly confirmed by borehole LC BH04, but other boreholes which confirm the lateral continuity of these horizons include LC BH01. Rockhead is intersected at depths between 2.7 m and 3.25 m (elevations of 80.66 and 78.57 masl, for boreholes LC BH01 and LC BH04, respectively). Test pit TP102 excavated as part of additional confirmatory investigations within the river section indicated bedrock at 2.8 m, which is between the depths of 2.7 m and 3.25 m as identified in the boreholes.

Plate 6-4: Bedrock encountered in TP102, at 2.8m depth

Bedrock comprises interbedded sandstone and mudstone horizons. In borehole LC BH01, drilled on the lower right flank, bedrock predominantly comprises mudstone strata with subordinate interbedded sandstone horizons. In LC BH04 the uppermost horizons, extending from the rockhead at a depth of 3.25 m (roughly 3 m as encountered in TP102) to a depth of 10,95 m, i.e. with a thickness of 7.7 m, the bedrock predominantly comprises sandstone with minor mudstone interbeds, while below 10.95 m depth the rock is predominantly mudstone but with minor sandstone interbeds.

The rock mass is characteristically highly weathered, improving with increasing depth, and unweathered mudstone is intersected at a depth of 13.3 m (LC BH04). Borehole LC BH01, in contrast, shows no improvement in weathering and the rock mass is highly weathered throughout – to a depth of at least 15 m. These weathered rocks generally comprise soft to medium hard rock. The uppermost strata may be very soft rock in places. In addition, certain strata tend to hard rock; typically, the sandstone horizons at depth where highly weathered. Where unweathered mudstone is intersected this also tends to hard rock in places.

It must be noted that the mudstones in particular are susceptible to slaking, i.e. will rapidly disintegrate upon exposure to the elements. This phenomenon will also affect the sandstone beds where interbedded mudstone lenses of laminations occur. Even rock that appears as hard rock will therefore disintegrate on exposure. This characteristic holds implications for foundation excavations and treatment and is discussed in more detail in Section 7.3.

Up to four discontinuity sets are recognised within the rock strata, although some horizons only see one or two sets. Shallow dipping (10°) discontinuities are ubiquitous and represent the bedding planes. Other common joint orientations include moderately steep joints (dipping 50° to 60°) and sub-vertical joints (80° to 90°). Joint surfaces are commonly smooth. Joint infill material is rarely recorded, and generally only staining of the surfaces might be noted. In terms of joint infill, however, it is pertinent to note the occurrence of horizons that are occasionally weathered to clay, particularly within the mudstone horizons. Also relevant are the material losses, particularly within the upper horizons, where these are ascribed to wash-out of very soft rock interbeds.

6.2.3 Right flank

During the initial investigations, the right flank investigations were limited due to dense bush. This meant most investigative points were on the lower right flank with an information gap on the upper flank. The addition of test pits TP101 and TP127 during the supplementary investigations was specifically to better understand the ground conditions of the upper right flank area. The geological profiles are summarised below in **Table 6-5** Error! Reference source not found. and **Table 6-6**. Nearby borehole and test pit profile summaries are included in these tables for greater clarity. The geological longitudinal section is presented in Drawing 112546-GEO-DRG-CC-002A-B.

Results from borehole LC BH01 have been incorporated into the above section on the geological profile in the river section (Section 6.2.2) but is also discussed here in the context of the right flank.

Table 6-5: Right flank, summarised test pit profiles (depths in metres)

TP no	Topsoil; loose to medium dense or dense, silty to medium sand	Colluvium; medium dense or very dense, silty sand	Colluvium / partly pedogenic; loose to medium dense / dense	Gravels / cobbles in sand matrix, overall loose to medium dense / very dense. Mixed origin	Alluvium; very dense, silty clayey sand	Residual sandstone, very dense silty sand with sandstone gravel	Sandstone; highly (to completely) weathered, hard (soft / to sand) rock
LC02	0 – 0.3	0.3 - 1	1 – 1.95	1.95 – 2.75+			
LC04	0 – 0.3			0.3 – 0.9	0.9 - 1.35+		
LC05	0 – 0.3			0.3 – 2.25+			
TP101	0 – 0.4	0.4 – 3.3		3.3 - 3.7		3.7 – 4.2+	
TP127				0 – 3.3			3.3 – 3.7+

Table 6-6: Right flank, summarised borehole profiles (depths in m)

BH no	Colluvium; slightly clayey, silty sand	Alluvium / mixed origin; gravels in sand matrix	Mudstone; highly to completely weathered, soft to very soft rock	Mudstone' slightly to moderately weathered, soft to medium hard rock	Mudstone; unweathered, hard rock	Interbedded mudstone / sandstone; highly to moderately weathered, generally medium hard rock	Sandstone; highly (to completely) weathered, hard (soft / to sand) rock	Sandstone; moderately weathered, hard rock
LC BH04	0 - 2	2 – 3.25		10.95 – 13.3	13.3 – 15.04+		3.25 – 7.5	7.5 – 10.95
LC BH01	0 – 0.8	0.8 – 2.7	4.55 – 10.94	13.1 – 15.01+			2.7 – 4.55 10.94 – 13.1	

The geological profile is characterised by the following horizons;

- Topsoil
- Colluvium
- Colluvium partly altered by pedogenesis
- Reworked terrace gravels,
- Residual sandstone, and
- Bedrock.

The upper **topsoil** horizon is generally expected to cover the entire flank with the exception of the upper right flank where it was not encountered in TP127. On the lower flank area this horizon is 0.3 m thick, gets to 0.4 m and absent towards the upper flank. The topsoil comprises dry, loose to medium dense and occasional very dense silty sand with minor rounded gravel. Roots are generally present.

The underlying horizon of **colluvial material** comprises silty sand. The moisture content at the time was described as slightly moist, and the consistency as medium dense to very dense. Pinholes were recognised in the structure. This horizon was only encountered in LC02 and TP101 test pits. Roots are present. Thickness varies between 0.7 m to 2.9 m.

An underlying **horizon of colluvium displaying some pedogenic** alteration occurs at depths between 1.0 m and 1.95 m. The material comprises slightly moist, reddish brown to light brown, loose to medium dense, silty sand with ferricrete nodules.

The stratum of **reworked terrace gravels** was intersected in all excavated test pits on the right flank, with depth varying between 1.95 m to 3.7 m at the base of test pit TP101. These gravel and cobbles are encountered as tightly packed in a silty sand matrix with the overall consistency ranging between dense to very dense. The borehole (LC BH01) indicates a thickness of 1.9 m.

Residual soil from sandstone was only encountered in TP101. This stratum was encountered on the upper flank as very dense, slightly ferruginised silty sand. This material was encountered beneath the colluvium horizon. This stratum was encountered at 3.7 m depth with minimum thickness of 0.5 m to the end of the hole.

Bedrock is intersected by borehole LC BH01 at a depth of 2.7 m (elevations 80.66 masl) and on test pit TP127 at a depth of 3.3 m. Bedrock comprises interbedded sandstone and mudstone horizons; predominantly mudstone strata with subordinate interbedded sandstone horizons.

The rock mass is characteristically completely to highly weathered, and shows no improvement in weathering**–** to a depth of at least 15 m. These weathered rocks generally comprise soft to medium hard rock. The uppermost strata may be very soft rock in places. In addition, certain strata tend to hard rock; typically, the sandstone horizons at depth where highly weathered.

It re-iterated that the mudstones in particular are susceptible to slaking, i.e. will rapidly disintegrate upon exposure to the elements. This phenomenon will also affect the sandstone beds where interbedded mudstone lenses of laminations occur. Even rock that appears as hard rock will therefore disintegrate on exposure. This characteristic holds implications for foundation excavations and treatment and is discussed in more detail in Section 7.3.

Generally, two or three discontinuity sets are recognised within the respective rock strata. Shallow dipping (0° - 10°) discontinuities are ubiquitous and represent the bedding planes. Other common joint orientations include moderately steep joints (dipping at 70°) and sub-vertical joints (80° to 90°). Joint surfaces are commonly smooth. Joint infill material is rarely recorded, and generally only staining of the surfaces might be noted. Horizons are recognised where the rock is weathered to clayey sand, or very soft rock in the case of the uppermost sandstone horizon.

6.2.4 Reservoir basin

Test pits were excavated within the reservoir area, primarily to confirm potential for sourcing suitable materials for embankment construction. During the initial investigations access was severely restricted and only three test pits were excavated (numbered LC20, LC22 and LC23), along a track that traverses the basin. The need for further investigations to expand on the knowledge base was however recognised, and to this end a 30-ton tracked excavator was procured for further investigation. The benefits of using an excavator included the ability to excavate deeper profiles as well as greater ease of access. A further important consideration is that this plant replicates the plant to be used during actual construction.

For these additional investigations, twenty further test pits were excavated within the basin, bringing the total to 23. These are numbered TP105 to TP124 as shown in Drawing 112546-GEO-DRG-CC-001-B.

Geological profiles within these test pits are summarised below (**Table 6-7**). The test pits excavated on the dam footprint are also relevant to the description of the soils to be encountered within the general reservoir, but reference is made to the descriptions in the sections above (Sections 6.2.1 to Section 6.2.3).

Table 6-7: Reservoir area, summarised geological test pit profiles (depths in m)

TP no	Topsoil; medium dense to dense, silty sand	Colluvium; dense to very dense, silty sand	Colluvium / partly pedogenic; dense / very dense silty sand, ferruginised, plus ferricrete and calcrete nodules to hardpan	Gravels / cobbles in sand matrix, Overall very dense to medium dense. Reworked terrace gravels	Mudstone; highly to completely weathered, soft to very soft rock	Sandstone; highly (to completely) weathered, hard (soft / to sand) rock
LC20	0 – 0.3		0.3 – 1.95	1.95+		
LC22	0 – 0.25	0.25 – 0.55		0.55 – 2.4+		
LC23	0 – 0.25			0.25 – 2.25+		
TP105	0 – 0.5	0.5 – 3.6				
TP106				0 – 1.6	1.6 – 3.1+	
TP107	0 – 0.3	0.3 – 1.6		1.6 – 2.3		2.3 – 2.9+
TP108	0 - 0.2	0.2 – 0.6	0.6 – 2.2	2.2 – 2.9		2.9 – 3.9+
TP109		0 - 0.7	0.7 – 4.1			
TP110		0 – 0.9		0.9 – 2.1	2.1 – 3.4+	
TP111		0 – 0.6	0.6 – 2.2	2.2 – 3.9+		
TP112	0 – 0.2		0.2 – 4.0+			
TP113	0 – 0.4		0.4 – 4.5+			
TP114	0 – 0.4	0.4 – 1.1		1.1 – 3.2	3.2 – 3.7+	
TP115	0 – 0.4		0.4 – 2.4	2.4 - 4.2+		
TP116	0 – 0.4		0.4 – 4.8+			
TP117	0 - 0.4	0.4 – 1.3		1.3 – 2.6	2.6 – 3.3+	
TP118	0 -0.2	0.2 – 1.2		1.2 – 3.1		3.1 -3.3+
TP119	0 – 0.2		0.2 – 2.2+			
TP120	0 - 0.4	0.4 – 0.8	0.8 – 2.6	2.6 – 3.4		3.4 – 3.7+
TP121	0 – 0.4	0.4 – 2.8		2.8 – 2.9+		
TP122	0 – 0.3	0.3 – 1.3	1.3 – 2.0+			
TP123	0 – 0.3		0.3 – 2.0	2.0 – 2.7+		
TP124	0 – 0.4			0.4 – 3.5		3.5 - 3.6+

The typical soil profile within the reservoir area comprises;

- Topsoil,

- Colluvium,
- Colluvium that is partly pedogenic,
- Reworked terrace gravels / gravelly soils of mixed origin, and
- Bedrock

The upper **topsoil** stratum varies in thickness between 0.2 m and 0.5 m. These soils are described as dry, brown, medium dense sometimes tending to dense, intact to blocky, silty sand. Roots, i.e. organic material, are typically present. Occasionally these soils are pinholed.

Colluvium is encountered on the flanks and in the river section within the reservoir footprint. It is encountered as dry to slightly moist, dense to very dense, silty sand with occasional gravel, sometimes slightly ferruginised and calcritised. Distinction is made between this colluvial material, and mixed colluvium and pedogenic material described below. Where encountered, this material varies in thickness between 0.3 m and at least 3.1 m within the basin.

Material of **mixed colluvial and pedogenic origin** is largely recognised on the left and right flanks within the basin, occasionally encountered within the river section. The northern section of the reservoir largely comprises of ferricrete nodules and hardpan where pedocretes are encountered, and the southern section largely encountering calcrete concretion and nodules. The material comprises slightly moist, dense to very dense, ferruginised or calcritised silty sand. In the northern section (i.e. test pit TP119 and TP122) the material was encountered as very dense to very soft rock, highly cemented into almost hardpan with pockets of grey gravel. Where present, refusal on the hardpan ferricrete was recorded at 2.2 m and 2.0 m respectively. This mixed colluvial / pedogenic material typically varies in thickness between 0.7 m and at least 3.4 m within the basin.

The horizon considered to represent **reworked terrace gravels** is developed across the basin except where the mixed colluvial and pedogenic material is well developed. Thickness varies between 0.7 m and at least 3.1 m. Essentially, this material comprises slightly clayey, silty sand (matrix) with a coarser fraction comprising sub-rounded to sub-angular gravels and cobbles (sandstone and mudstone gravel) and occasional boulders. The gravels and cobbles of this horizon are generally encountered as tightly packed and occasionally calcritised. The overall consistency is dense to very dense, and medium dense in horizons where the sandy matrix predominates.

Bedrock is intersected in some of the test pit pits excavated along the “river section” within the reservoir footprint i.e. TP106, TP107, TP110, TP114, TP117, TP120 and TP124. These strata comprise highly to completed weathered, very soft mudstone and sandstone. These strata are typically interbedded. Bedrock is encountered at variable depths between 1.6 m and 3.5 m.

6.3 Material properties

The annotation "LC" indicates test pits and hence laboratory test results from the initial investigations, with the "TP" indicating test pits and results from the recent supplementary investigations.

In terms of collating the results from both phases of investigation, the usual approach would simply be to consider all results together in a single sample pool. Interrogation of the laboratory data revealed some concerns regarding some test results and pooling the results would have led to skewing of the data. In the light of these apparent anomalies it was therefore decided to separate the results of the respective investigation phases. It is further worth noting that the supplementary investigations prescribed to a principle of testing of duplicate samples (approximately 10%) at an independent laboratory, specifically for quality assurance (QA) purposes. For sake of completeness, all results are included below but greater reliance should be placed on the results emanating from the supplementary investigations.

6.3.1 Foundation Indicator results

Foundation Indicator results, i.e. combined grading analyses including sieve and hydrometer analyses, as well as Atterberg constants, are summarised below in **Table 6-8** (for the initial investigation phase) and **Table 6-9** (for the supplementary investigations)

Table 6-8: Summarised Foundation Indicator results (initial investigations)

Test pit no	Depth (m)	Material type	Soil composition				GM	Atterberg limits			LS (%)	Activity	Unified Class.	AASHTO class.
			Clay (%)	Silt (%)	Sand (%)	Gravel (%)		LL (%)	PI (%)	WPI (%)				
Colluvium														
LC03	0.3 – 1.15	Colluvium	1	35	62	2	0.61	15	4	4	2.0	4.0	SC-SM	A – 4
LC03	0.3 – 2.05	Colluvium	0	41	58	1	0.56	15	3	3	1.5	-	SM	A – 4
Alluvium														
LC04	0.3 – 1.15	Alluvium	1	32	57	10	0.77	17	7	6	3.5	7.0	SC-SM	A – 2 – 4
LC05	1.3 - 2.75	Alluvium	0	8	39	53	2.11	49	20	6	10.0	-	GM	A – 2 – 7
LC07	0.9 – 2.0	Alluvium	0	51	49	0	0.38	25	11	11	5.5	-	CL	A – 6
Colluvium, partly pedogenic														
LC02	1.0 – 1.95	Colluvium + part pedogenic	0	63	36	1	0.3	21	7	7	3.5	-	CL	A – 4
LC06	0.5 – 1.65	Colluvium + part pedogenic	0	53	45	2	0.31	32	18	17	9.0	-	CL	A – 6

Test pit no	Depth (m)	Material type	Soil composition				GM	Atterberg limits			LS (%)	Activity	Unified Class.	AASHTO class.
			Clay (%)	Silt (%)	Sand (%)	Gravel (%)		LL (%)	PI (%)	WPI (%)				
LC08	0.5 – 1.5	Colluvium + part pedogenic	0	58	39	3	0.76	26	12	12	6.0	-	CL	A – 6
LC09	0.4 – 0.85	Colluvium + part pedogenic	0	57	43	0	0.21	37	19	19	9.5	-	CL	A – 6
LC09	0.85 – 1.2	Colluvium + part pedogenic	0	18	34	48	1.78	30	18	8	9.0	-	SC	A – 2 – 6
LC10	1.0 – 1.6	Colluvium + part pedogenic	0	62	36	2	0.31	29	15	14	7.5	-	CL	A – 6
LC11	0.5 – 1.5	Pedogenic	1	22	37	40	1.68	31	10	4	5.0	10.0	SC	A – 2 – 4
LC20	0.9 – 1.95	Pedogenic	0	64	32	4	0.33	39	20	18	10.0	-	CL	A – 6
Mixed origin (reworked terrace gravels)														
LC04	0.3 – 1.35	Terrace gravels	1	32	57	10	0.77	17	7	6	3.5	7.0	SC-SM	A – 2 – 4
LC05	0.3 – 1.3	Mixed Origin	0	30	67	3	0.77	15	5	4	2.5	-	SC-SM	A – 2 – 4
LC05	1.3 – 2.75	Terrace gravels	0	8	39	53	2.11	49	20	6	10.0	-	GM	A – 2 – 7
LC07	0.9 – 2.0	Terrace gravels	0	51	49	0	0.38	25	11	11	5.5	-	CL	A – 6
LC09	1.2 – 2.4	Mixed Origin	4	62	28	6	0.38	39	18	16	9.0	4.5	CL	A – 6
LC23	0.5 – 2.0	Terrace gravels	1	34	61	4	0.59	19	7	4	3.5	7.0	SC-SM	A – 2 – 4

Legend
GM = Grading modulus
LL = Liquid Limit
PI = Plasticity Index
WPI = Weighted Plasticity Index
LS = Linear Shrinkage
Activity = Activity of the soil according to Van der Merwe's 1964 method

Considering the above results from the initial investigations;

No samples of the **topsoil** were tested, as it was considered that the topsoil would be stripped from the footprint due to the organic content (i.e. presence of roots) and would not be a key element in construction.

Alluvial soils largely comprise variable soil types, i.e. silty sand, clayey sand, clayey silt and silty gravel. The sand fractions are approximately between 39% and 57%, silt fraction between 8% and 51%, with clay content almost negligible at 1% and the gravel content varying from zero to 53%. The liquid limit ranges from 17% to 49% which is low to moderate, weighted plasticity index low between 6% and 11% and linear shrinkage low between 3.5% and 10%.

The **colluvial** soils were primarily encountered as silty sand; with the sand fraction of approximately 60% and the silt fraction between 35% and 40%. Clay and gravel fractions are negligible; up to 1% and 2%, respectively. Due to the negligible clay fraction, the Liquid Limits

(LL) as well as the Plasticity Index (PI) values are very low (15%, and 3% to 4%, respectively). The very low PI values further result in identical Weighted PI[3] values on account of the high fraction passing 0.425 mm. These colluvial materials might therefore be considered to exhibit very low plasticity (almost non-plastic).

Where the **colluvial soils also are associated with evidence of pedogenic action**, these soils predominantly comprise sandy silt, where the dominant silt fraction is typically approximately 60% and the lesser sand fraction varies between 35% to 45%. The clay fraction is typically zero, and the gravel fraction is also negligible (only up to 3%). While generally consistent, these materials also exhibit some wide variability which is likely ascribed to variable pedocrete development. Some of these soils are gravelly (40% to 50%), with sand and silt fractions at 35 – 40%, and approximately 20%, respectively. The clay fraction is constant at zero. The Plasticity Indices (PI's) vary between 10% and 20%, i.e. may be considered moderate. Occasional lower values are recorded. Because of the variable gradings, the Weighted PI values show a wider spread; between 4% and 20%. The Liquid Limit values generally vary between 20% and 40% (indicating soils with low to intermediate plasticity), while the Linear Shrinkage values vary between 3.5% and 10%, i.e. low to moderate values.

The gravel soils are considered under the umbrella of '**reworked terrace gravels'** but these materials are not entirely uniform and significant variability is evident. Importantly only the finer fraction was submitted for testing, i.e. the coarse fraction comprising cobbles and boulders, as well as the gravels was not included in the test samples. The finer fraction of these soils generally comprises silty sand, where the sand fraction is between 50% and 70%, and the silt fraction is typically approximately 30% but occasionally as much as 50%. The clay fraction is commonly zero but might be up to 4%. In the context of the selective sampling the gravel fraction is not representative of the bulk sample but was recorded up to 40 – 50%. It has been stated previously that this stratum is, in any event, not uniform. Considering the Atterberg constants, the Liquid Limit varies between 15% and 50% illustrating low to intermediate plasticity, the Plasticity Index ranges between 5% and 20%, i.e. low to moderate values, and the Linear Shrinkage varies between 2.5% and 10%, also considered low to moderate.

It is worth noting that the earlier investigations were mainly focused around the dam footprint area and the spillway chute with little attention given to the general basin for reasons indicated in earlier chapters.

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[3] *A short note regarding PI versus Weighted PI; The Weighted Plasticity Index (WPI) is defined as the value of the plasticity index (PI) times the % passing the 425-micron sieve (0.425 mm sieve), i.e. the Weighted PI is representative of the PI for the whole sample.*

The recent supplementary investigation laboratory results indicate a slightly different picture to the earlier results, most notable are the clay contents which vary from 4 to 35%. These are summarised below in **Table 6-9**.

Table 6-9: Summarised Foundation Indicator results (supplementary investigation)

Test pit no	Depth (m)	Material type	Soil composition				GM	Atterberg limits			LS (%)	Activity	Unified Class.	AASHTO class.
			Clay (%)	Silt (%)	Sand (%)	Gravel (%)		LL (%)	PI (%)	WPI (%)				
Colluvium														
TP105	1.0 - 3.6	Colluvium	25	59	15	1	0.19	29	14	14	7.0	0.6	CL	A – 6
TP121	0.4 - 2.8	Colluvium	21	41	31	7	0.61	29	14	12	6.5	0.7	CL	A – 6
TP102	0.4 - 1.8	Colluvium	16	39	45	0	0.51	17	6	6	3.0	0.4	CL	A – 4
TP110	0.0 – 0.9	Colluvium	13	38	40	9	0.77	0	SP	0	1.5	0	CL	A – 6
TP118	0.2 – 1.2	Colluvium	6	65	29	0	0.35	22	9	8	4.0	1.5	CL	A – 4
TP122	0.3 – 1.3	Colluvium	17	60	23	0	0.24	19	7	7	3.5	0.4	CL	A – 4
Colluvium, partly pedogenic														
TP113	0.4 - 4.5	Colluvium + part pedogenic	16	55	24	5	0.40	32	16	15	8.5	1.0	CL	A – 6
TP120	0.8 - 2.6	Colluvium + part pedogenic	11	50	37	2	0.47	25	8	8	4.0	0.7	CL	A – 4
TP104	0.4 – 1.3	Colluvium + part pedogenic	26	44	21	9	0.54	42	17	14	8.0	0.7	CL	A - 7 - 6
TP104	1.3-2.3	Colluvium + part pedogenic	34	47	17	2	0.27	42	19	18	9.0	0.6	CL	A - 7 - 6
TP108	0.6 – 2.2	Pedogenic	4	44	27	25	1.19	34	13	8	6.5	3.3	SC	A – 6
TP109	0.7 – 4.1	Colluvium + part pedogenic	27	56	14	3	0.25	35	18	17	9.0	0.7	CL	A – 6
TP115	0.4 – 2.4	Colluvium + part pedogenic	14	66	17	3	0.3	33	17	16	8.0	1.2	CL	A – 6
TP116	0.4 – 4.8	Colluvium + part pedogenic	27	47	26	0	0.27	27	13	13	6.0	0.5	CL	A – 6
TP119	0.8 – 2.2	Pedogenic	16	59	24	1	0.28	26	10	10	5.0	0.6	CL	A – 4
Mixed origin (reworked terrace gravels)														
TP111	2.2 - 3.9	Terrace gravels	12	24	36	28	1.30	27	11	7	5.5	0.9	SC	A – 6
TP101	3.3 - 3.7	Terrace gravels	7	65	27	1	0.33	24	7	7	4.0	1.0	CL	A – 4
TP115	2.4 - 4.2	Terrace gravels	7	65	26	2	0.36	25	8	8	4.0	1.1	CL	A – 4
TP123	2.0 – 2.7	Terrace gravels	11	45	35	9	0.79	34	15	11	7.0	1.4	CL	A – 6
Weathered mudstone bedrock														
TP106	1.6 – 3.1	Mudstone	35	35	18	12	0.56	32	10	9	5.0	0.3	CL	A – 4
TP110	2.1 – 3.4	Mudstone	23	53	21	3	0.36	39	13	12	6.0	0.6	ML	A – 6
TP117	2.6 – 3.3	Mudstone	27	43	4	26	0.84	32	15	11	7.0	0.6	CL	A – 6

Legend GM = Grading modulus

LL	=	Liquid Limit
PI	=	Plasticity Index
WPI	=	Weighted Plasticity Index
LS	=	Linear Shrinkage
Activity	=	Activity of the soil according to Van der Merwe's 1964 method

Considering the above data from the supplementary investigation,

The **colluvial** soils were largely encountered as silty sand, clayey silt and sandy silt materials; the sand fraction is encountered between 15% and 45%, silt fraction between 38% and 65%, clay fraction between 6 and 25%, and the gravel content from negligible up to 9%. It is always worth noting that the coarser (gravel) fraction is not necessarily representative. Obviously larger pieces are removed from the samples when collected. The Liquid Limits (LL) range from zero to 29% and the Plasticity Index (PI) values ranging between slight plastic up to 14%. The Weighted Plasticity Index (WPI) values are from negligible up to 14%, with the Linear Shrinkage values very low between 1.5% and 7.0%. These colluvial materials are considered to exhibit low activity.

The **colluvial soils associated with pedocretes**, are predominately encountered as sandy silt and occasional clayey silt and gravelly silt, where the dominant silt fraction is typically between 44% and 63%, sand fraction varies between 14% and 37%, with clay ranging between 11% and 34% but occasionally as low as 4%, and the gravel content varies from negligible to 9% occasionally up to 25% where pedocrete development has been dominant. The Plasticity Indices (PI's) vary between 8% and 19%, i.e. may be considered moderate. The Weighted PI values show a similar spread to the PI values, encountered as moderate between 8 and 17%. The Liquid Limit values generally vary between 25% and 42% (indicating soils with low to intermediate plasticity), while the Linear Shrinkage values vary between 4% and 9%, i.e. low to moderate values.

The gravel soils representing '**reworked terrace gravels of mixed origin**' were not encountered to be entirely uniform. The testing was largely focused on the finer fraction, with gravel and cobbles not included in the samples. This finer fraction generally comprises silty sand and sandy silt, with the dominant silt fraction varying between 24% and 65%, sand fraction between 26% and 36%. The clay fraction varies from 7% up to 12%, and the gravel content between 1% and 28%. It should again be noted that the gravel fraction is not necessarily representative of the bulk sample for reasons stated above. The Liquid Limit varies between 24% and 34% illustrating intermediate plasticity, the Plasticity Index ranges between 7% and 15%, i.e. low to moderate values, and the Linear Shrinkage considered low with values varying between 4.0% and 7%.

The weathered **mudstone** bedrock was encountered along the "river section" within the basin during the latest supplementary investigations. When excavated, this material largely comprises clayey silt, with the dominant silt fraction encountered between 35% and 55%, clay fraction between 20% and 35%, sand content between 4% and 21%, and the gravel fraction between 3% and 26%. Note again the larger pieces were excluded and therefore this coarser fraction is not necessarily representative. The Liquid Limit values generally vary between 30% and 40% indicating soils with intermediate plasticity, with the Plasticity Index intermediate between 10% and 15%, while the Linear Shrinkage values vary between 5% and 7%.

6.3.2 Physical properties

Relative densities for selected samples are summarised below in **Table 6-10**. Moisture contents are summarised in **Table 6-11**.

Table 6-10: Summarised relative density values

Test pit	Material type	Depth (m)	Origin	Relative density
LC03	Silty sand	0.3 – 2.05	Colluvium	2.600
LC09	Sandy silt	0.4 – 0.85	Colluvium, part pedogenic	2.580
LC06	Sandy silt	0.5 – 1.65	Colluvium, part pedogenic	2.560
LC04	Silty sand with gravel	0.3 – 1.35	Terrace gravel	2.570
TP108	Sandy silt	0.6 – 2.2	Colluvium, part pedogenic	2.601
TP109	Clayey silt	0.7 – 4.1	Colluvium, part pedogenic	2.640
TP111	Silty sand	2.2 – 3.9	Terrace gravels	2.633
TP102	Sandy silt	0.4 – 1.8	Colluvium	2.632
TP105	Clayey silt	1.0 – 3.6	Colluvium	2.611
TP106	Clayey silt	1.6 – 3.1	Mudstone	2.669
TP116	Clayey silt	0.4 – 4.8	Colluvium, part pedogenic	2.652
TP117	Clayey silt	2.6 -3.3	Mudstone	2.679
TP119	Silty sand with gravel	0.8 – 2.2	Pedogenic	2.619
TP115	Sandy silt	0.4-2.4	Colluvium, part pedogenic	2.674
TP122	Sandy silt	0.3-1.3	Colluvium	2.682

Table 6-11: Summarised moisture content results

Test pit no	Material type	Depth (m)	Origin	Moisture Content
TP110	Silty sand	0.0 – 0.9	Colluvium	9.4
TP118	Sandy silt	0.2 – 1.2	Colluvium	7.6
TP105	Clayey silt	1.0 – 3.6	Colluvium	11.4
LC06	Sandy silt	0.5 – 1.65	Colluvium, part pedogenic	12.4

Test pit no	Material type	Depth (m)	Origin	Moisture Content
LC08	Sandy silt	0.5 – 1.5	Colluvium, part pedogenic	8.3
TP104	Sandy silt	0.4 – 1.3	Colluvium, part pedogenic	3.9
TP104	Sandy silt	1.3 – 2.3	Colluvium, part pedogenic	9.2
LC20	Sandy silt	0.9 – 1.95	Pedogenic	10.9
LC04	Silty sand with gravel	0.3 – 1.35	Terrace gravel	6.1
LC23	Silty sand	0.5 – 2.0	Terrace gravel	5.1
LC09	Sandy silt	1.2 – 2.4	Mixed Origin	17.3
TP101	Sandy silt	3.3 – 3.7	Terrace gravel	6.6
TP115	Sandy silt	2.4 – 4.2	Terrace gravel	9.0
TP123	Sandy silt	2.0 – 2.7	Terrace gravel	11.9
TP110	Clayey silt	2.1 – 3.4	Mudstone	13.6
TP111	Silty sand	2.2 – 3.9	Terrace gravels	6.1
TP113	Sandy silt	0.4 – 4.5	Colluvium, part pedogenic	8.7
TP120	Sandy silt	0.8 – 2.6	Colluvium, part pedogenic	6.8
TP121	Sandy silt	0.4 – 2.8	Colluvium	7.6
TP102	Sandy silt	0.4 – 1.8	Colluvium	4.6
TP106	Clayey silt	1.6 - 3.1	Mudstone	7.0
TP108	Sandy silt	0.6 – 2.2	Colluvium, part pedogenic	11.3
TP109	Clayey silt	0.7 – 4.1	Colluvium, part pedogenic	17
TP115	Sandy silt	0.4 – 2.4	Colluvium, part pedogenic	17.6
TP116	Clayey silt	0.4 -4.8	Colluvium, part pedogenic	8.9
TP117	Clayey silt	2.6 – 3.3	Mudstone	7.8
TP119	Silty sand with gravel	0.8 – 2.2	Pedogenic	8.2
TP122	Sandy silt	0.3 – 1.3	Colluvium	7.2

6.3.3 Compaction

Summarised Standard Proctor compaction results are presented in **Table 6-12**.

Table 6-12: Summarised Standard Proctor compaction results

Test pit no	Material	Depth (m)	Origin	Proctor density (kg/m^3)	o m c (%)
LC03	Silty sand	0.3 – 2.05	Colluvium	1857	11.1
TP102	Sandy silt	0.4 – 1.8	Colluvium	1990	10.6

Test pit no	Material	Depth (m)	Origin	Proctor density (kg/m^3)	o m c (%)
TP105	Clayey silt	1.0 – 3.6	Colluvium	1776	15.7
TP121	Sandy silt	0.4 – 2.8	Colluvium	1874	14.4
LC06	Sandy silt	0.5 – 1.65	Colluvium, part pedogenic	1676	18.9
LC08	Sandy silt	0.5 – 1.5	Colluvium, part pedogenic	1759	17.8
LC11	Silty sandy gravel	0.5 – 1.5	Pedogenic	1522	21.7
LC20	Sandy silt	0.9 – 1.95	Pedogenic	1739	22.6
TP108	Sandy silt	0.6 – 2.2	Colluvium, part pedogenic	1773	9.3
TP109	Clayey silt	0.7 – 4.1	Colluvium, part pedogenic	1786	16.3
TP113	Sandy silt	0.4 – 4.5	Colluvium, part pedogenic	1803	14.9
TP115	Sandy silt	0.4 – 2.4	Colluvium, part pedogenic	1870	13.2
TP116	Clayey silt	0.4 – 4.8	Colluvium, part pedogenic	1914	11.1
TP120	Sandy silt	0.8 – 2.6	Colluvium, part pedogenic	1872	14.3
LC09	Sandy silt	1.2 – 2.4	Terrace gravels	1617	23.8
LC23	Silty sand	0.5 – 2.0	Terrace gravels	1826	11.7
LC04	Silty sand with gravel	0.3 – 1.35	Terrace gravels	1868	12.7
TP111	Silty sand	2.2 – 3.9	Terrace gravels	1962	10.6
TP106	Clayey silt	1.6 – 3.1	Mudstone	1966	11.4
TP101	Sandy silt	3.3 - 3.7	Terrace gravels	1990	10.6
TP117	Clayey silt	2.6 - 3.3	Mudstone	1954	12.5
TP119	Silty sand with gravel	0.8 – 2.2	Pedogenic	1812	14.1
TP122	Sandy silt	0.3 – 1.3	Colluvium	1918	10.6

The **colluvium** horizon is characterised by a maximum dry density values (Standard Proctor compaction) in the range of 1776 to 1990 kg/m^3 with an optimum moisture content (omc) values between 10% and 16%.

Typically, the sandy silt and clayey silt of **colluvial / part pedogenic** origin exhibits maximum dry density (Standard Proctor compaction) values in the range of 1676 to 1914 kg/m^3, with optimum moisture contents (omc) between 9.3% and 18.9%. Where the **pedogenic material** is more variable and comprises silty, sandy gravel, the maximum dry density varies between 1522 and 1812 kg/m^3 with an optimum moisture content (omc) of 14% to 23%.

The fine fraction of the **reworked terrace gravels** possesses maximum dry density values in the range of 1617 to 1990 kg/m^3, with optimum moisture contents (omc) between 11% and 24%.

The fines of the excavated **mudstone bedrock** possess maximum dry density values in the range of 1954 to 1966 kg/m^3, with optimum moisture contents (omc) between 11% and 24%.

6.3.4 Shear strengths

Remoulded samples were subjected to slow drained, saturated shear box testing. The results are of significance for the stability of excavation faces and are summarised below in **Table 6-13**.

Table 6-13: Summarised drained slow shear box test results

Test pit no	Material type	Depth (m)	Origin	Maximum effective shear stress kPa	Apparent cohesion given by regression (kPa)	Apparent Friction Angle (°)	Moulded density (kg/m^3)
LC3	Silty sand	03 – 2.05	Colluvium	36.5		18.3	1676
LC3	Silty sand	0.3 – 1.15	Colluvium	38.1		19.2	1693
LC3	Silty sand	0.3 – 2.05	Colluvium	35.4		20.2	1704
LC4	Silty sand with gravels	0.3 – 1.35	Terrace gravels	43.2		26.4	1722
LC6	Sandy silt	0.5 – 1.65	Colluvium, part pedogenic	41.6		21.4	1570
LC8	Sandy silt	0.5 – 1.5	Colluvium, part pedogenic	40.9		24.7	1634
LC9	Sandy silt	1.2 – 2.4	Mixed origin	32.8		23.3	1509
LC11	Silty sandy gravel	0.5 – 1.5	Pedogenic	33.9		20.2	1434
LC20	Sandy silt	0.9 – 1.95	Pedogenic	35.7		24.8	1596
LC23	Silty sand	0.5 – 2.0	Terrace gravel	33.4		19.2	1682
TP102	Sandy silt	0.4 – 1.8	Colluvium		4.9	34	1891
TP106	Clayey silt	1.6 – 3.1	Mudstone		16.1	19.9	1868
TP109	Clayey silt	0.7 – 4.1	Colluvium, part pedogenic		16.9	24.4	1695
TP108	Sandy silt	0.6 - 2.2	Colluvium, part pedogenic		5.9	31.1	1684
TP115	Sandy silt	0.4 – 2.4	Colluvium, part pedogenic		20.1	30.3	1777
TP116	Clayey silt	0.4 – 4.8	Colluvium, part pedogenic		31.5	0.5	1817
TP117	Clayey silt	2.6 – 3.3	Mudstone		26.2	16.8	1856
TP119	Silty sand with gravel	0.8 – 2.2	Pedogenic		9.4	28.1	1721
TP122	Sandy silt	0.3 – 1.3	Colluvium		9.4	28.1	1821

The results indicate that the silty sand and sandy silt material of **colluvial origin** exhibit the values of cohesion of 4.9 kPa to 9.4 kPa, maximum effective shear stress of between 35 kPa to 38.1 kPa, and the angle of shearing resistance between 18 and 34 degrees.

The sandy silt, clayey silt and sandy gravel materials of the **colluvial / partly pedogenic** origin exhibit cohesion values between 5 kPa and 32 kPa, maximum effective shear stress between 33 kPa and 42 kPa, and the angle of shearing resistance between 0.5° and 31°.

The finer fraction of the **reworked terrace gravel or mixed origin gravel** comprises silty sand or sandy gravel material which exhibits maximum effective shear stress of between 32 kPa and 44 kPa, and the angle of shearing resistance between 19° and 27°.

The clayey silt excavated from the **mudstone** bedrock exhibits cohesion values of 16 kPa to 26 kPa, and angle of shearing resistance of 17° to 20°.

6.3.5 Permeability

The results of permeability tests on the remoulded soil samples are summarised below (**Table** 6-14). Results of water acceptance (Lugeon) tests conducted in the boreholes are presented elsewhere (Section 7.3).

Table 6-14: Summarised permeability test results

Test pit No	Material	Depth (m)	Material origin	Permeability (cm/s)
LC04	Clayey, silty sand	0.4 – 1.35	Alluvium	3.16×10^{-6}
LC03	Silty sand	0.3 – 2.05	Colluvium	1.84×10^{-5}
LC03	Silty sand	0.3 – 1.15	Colluvium	2.31×10^{-5}
LC06	Sandy silt	0.5 – 1.65	Colluvium, part pedogenic	4.11×10^{-7}
LC08	Sandy silt	0.5 – 1.5	Colluvium, part pedogenic	3.72×10^{-6}
LC11	Silty, sandy gravel	0.5 – 1.5	Pedogenic	1.88×10^{-6}
LC20	Sandy silt	0.9 – 1.95	Pedogenic	2.62×10^{-7}
TP102	Sandy silt	0.4 – 1.8	Colluvium	3.71×10^{-6}
TP106	Clayey silt	1.6 – 3.1	Mudstone	2.88×10^{-7}
TP108	Sandy silt	0.6 – 2.2	Colluvium, part pedogenic	3.48×10^{-6}
TP109	Clayey silt	0.7 – 4.1	Colluvium, part pedogenic	7.08×10^{-7}
TP115	Sandy silt	0.4 – 2.4	Colluvium, part pedogenic	6.40×10^{-7}
TP116	Clayey silt	0.4 – 4.8	Colluvium, part pedogenic	1.44×10^{-7}
TP117	Clayey silt	2.6 – 3.3	Mudstone	2.59×10^{-7}
TP119	Silty sand with	0.8 – 2.2	Pedogenic	6.07×10^{-7}

Test pit No	Material	Depth (m)	Material origin	Permeability (cm/s)
	gravel			
TP122	Sandy silt	0.3 – 1.3	Colluvium	5.75×10^{-7}

The clayey, silty sand of **alluvium origin** exhibits a permeability of 3.16×10^{-6} cm/s.

The silty sand and sandy silt of **colluvium** yielded permeabilities between 1.84×10^{-5} and 5.75×10^{-7} cm/s.

The **colluvium / part pedogenic** material is variable as encountered on site, and this is reflected in the permeability results. The materials are classified as clayey silt and sandy silt, with permeability measured between 7.08×10^{-7} and 1.88×10^{-6} cm/s.

The **mudstone**, which is of clayey silt material, exhibits a permeability of between 2.59×10^{-7} and 2.88×10^{-7} cm/s.

6.3.6 Dispersivity

Selected samples were subjected to a suite of tests to assess the dispersivity, including the Double Hydrometer, as well as the Pinhole Test and the Crumb Test. No single test is deemed entirely reliable in confirming the dispersivity of a soil, and for this reason a suite of tests is usually conducted.

For the supplementary investigations, the laboratory indicated challenges in outsourcing testing for the exchangeable sodium percentage (ESP) test. As such these are not presented in this report.

Results are summarised below in **Table 6-15**.

Table 6-15: Summarised dispersivity test results

Hole no	Material type	Depth (m)	Material origin	Double hydro-meter (%)	Pinhole test	Crumb test	Sodium Adsorption Ratio (SAR)	Extract-able Sodium Percentage (ESP)
LC03	Silty sand	0.3 – 2.05	Colluvium	40.13	ND3	Grade 2	7.22	9.63
LC03	Silty sand	0.3 – 1.15	Colluvium	35.97	ND3	Grade 2	6.71	9.01
LC06	Sandy silt	0.5 – 1.65	Colluvium, part pedogenic	43.26	ND2	Grade 3	6.92	9.26
LC04	Silty sand	0.3 – 1.35	Terrace gravels	48.3	ND2	Grade 2	5.92	8.03

Hole no	Material type	Depth (m)	Material origin	Double hydro-meter (%)	Pinhole test	Crumb test	Sodium Adsorption Ratio (SAR)	Extract-able Sodium Percentage (ESP)
TP105	Clayey silt	1.0 – 3.6	Colluvium	28.6	ND3 or ND4	Grade 1	-	-
TP111	Silty sand	2.2 – 3.9	Terrace gravels	18.5	ND3 or ND4	Grade 2	-	-
TP113	Sandy silt	0.4 – 4.5	Colluvium, part pedogenic	34.2	ND4	Grade 2	-	-
TP120	Sandy silt	0.8 – 2.6	Colluvium, part pedogenic	4.8	ND3 or ND4	Grade 1	-	-
TP121	Sandy silt	0.4 – 2.8	Colluvium	20.2	ND3 or ND4	Grade 2	-	-

For the double hydrometer, the percentage dispersion results for all materials vary between 5% and 50% which is considered non-dispersive to intermediate degree of dispersion (ASTM D4221, 2006).

The Pinhole Test results vary between ND2 to ND4 i.e. between slight dispersive and intermediate dispersivity (after Sherard, 1976).

The Crumb Test results alternated between Grade 1 and Grade 3, i.e. non-reaction and moderate reactions (after Emerson, 1964).

From the initial chemical test results, both the SAR (Sodium Adsorption Ration) as well as the ESP (Exchangeable Sodium Percentage) values indicate an 'intermediate' degree of dispersion, after Harmse (1980).

6.3.7 Rock material strengths

Opportunities for obtaining rock samples suitable for Uniaxial Compressive Strength (UCS) testing were extremely limited. Apart from the sample length requirements, which were at odds with the generally broken nature of the cores, the low strengths of these weak rocks were considered a major hurdle in sample preparation and the chances of the cores surviving the machining process were unlikely. As an alternative, selected core pieces were subjected to Point Load Strength (PLS) Testing. Furthermore, as a way around the limited number of samples, tests from both Lower Coerney as well as Upper Scheepersvlakte boreholes are considered jointly here. These results are presented below (**Table 6-16**).

The difficulties of obtaining accurate rock material strengths for very weak material are acknowledged, but from the above it is evident that the rocks are very weak. Assuming a typical conversion factor of 24 implies that these rocks have the equivalent uniaxial compressive strength values up to 1 MPa, and commonly less than 1 MPa.

Table 6-16: Summarised Point Load strengths

BH No	Depth (m)	Material description	Test type	$I_{s(50)}$ MPa
LC1	5.90	Sandstone, highly weathered, fine-grained	axial	0.01
LC2	10.04	Sandstone, highly weathered, coarse-grained	axial	0.05
LC4	6.38	Sandstone, highly weathered, coarse-grained	axial	0.01
US1	10.85	Sandstone, highly weathered, medium to fine-grained	diametral	0.06
US1	10.85	Sandstone, highly weathered, medium to fine grained	diametral	0.09
US5	2.83	Sandstone, highly weathered	axial	0.03
US4	8.74	Siltstone, highly weathered	diametral	0.03
US4	8.74	Siltstone, highly weathered	axial	0.07
LC2	12.92	Mudstone, unweathered	diametral	0.1
LC3	19.80	Mudstone, unweathered, carbonaceous	diametral	0.03
LC3	15.36	Mudstone, unweathered	diametral	0.03
LC3	19.80	Mudstone, unweathered, carbonaceous	axial	0.11
LC4	14.85	Mudstone, unweathered, carbonaceous	axial	0.09

6.4 Material properties for verification purposes

The results below are from the samples submitted to Labco laboratories as duplicate (10%) samples submitted to an independent laboratory primarily for QA purposes. As such it makes little sense to present this data together with the majority data as this would bias the mean values. The data is included below for record purposes but presented separately.

6.4.1 Foundation Indicator results

Foundation Indicator results are summarised below in **Table 6-17.**

Table 6-17: Summarised Foundation Indicator results (QA)

Test pit no	Depth (m)	Material type	Soil composition				GM	Atterberg limits			LS (%)	Activity	Unified Class.	AASHTO class.
			Clay (%)	Silt (%)	Sand (%)	Gravel (%)		LL (%)	PI (%)	WPI (%)				
Colluvium														
TP105	1.0 - 3.6	Colluvium	28	50	21	1	0.25	27	12	12	5.0	0.4	CL	A - 6
Colluvium, partly pedogenic														
TP108	0.6 - 2.2	Colluvium + part pedogenic	8	28	40	24	1.32	35	13	7	6.0	1.6	SC	A – 6

Test pit no	Depth (m)	Material type	Soil composition				GM	Atterberg limits			LS (%)	Activity	Unified Class.	AASHTO class.
			Clay (%)	Silt (%)	Sand (%)	Gravel (%)		LL (%)	PI (%)	WPI (%)				
TP109	0.7 – 4.1	Colluvium + part pedogenic	27	42	28	3	0.40	29	13	11	5.0	0.5	CL	A – 6
TP113	0.4 – 4.5	Colluvium + part pedogenic	20	48	29	3	0.39	26	11	11	5.0	0.6	CL	A – 6
TP119	0.8 – 2.2	Colluvium + part pedogenic	16	57	27	0	0.29	29	11	11	5.0	0.7	CL	A – 6
Mixed origin (reworked terrace gravels)														
TP115	2.4 – 4.2	Terrace gravels	7	15	31	47	1.85	20	8	3	3.5	1.1	SC	A – 2 – 4

Legend
GM = Grading modulus
LL = Liquid Limit
PI = Plasticity Index
WPI = Weighted Plasticity Index
LS = Linear Shrinkage
Activity = Activity of the soil according to Van der Merwe's 1964 method

The single sample of **colluvial** soil was encountered as sandy silt/ silty clay; with the clay fraction at 28%, silt fraction at 50%, sand fraction around 21% with the gravel content almost negligible at 1%. Due to the clay content, the Liquid Limit (LL) is moderate at 27%, Weighted Plasticity Index moderate at 12% and Linear Shrinkage low at 5.0%. These colluvial materials may be of low potential activity.

The **colluvial / pedogenic soils** comprise sandy silts and silty sand material, with the sand fraction between 27% and 40%, silt fraction ranging between 28% and 57%, clay fraction between 8% and 27% and the gravel content ranging from zero to 24%. The gravel content is quite variable, due to changes in ferricrete nodules content as ascribed to pedocrete development. The Liquid Limit (LL) is considered moderate and varies between 26% and 35%, Weighted Plasticity Index values low to moderate between 7% and 11%, and Linear Shrinkage varying between 5% and 6%. These soils may be considered as being of low potential activity.

Only a single sample of the gravel soils of '**reworked terrace gravels of mixed origin'** was submitted for QA testing. These soils generally comprise a coarse fraction i.e. gravel and cobbles, with silty sand fines as a matrix. The finer fraction comprises sand at 31%, gravel content at 47%, silt fraction at 15% and the clay fraction at 7%. The Liquid Limit (LL) is low at 20%, Weighted Plasticity Index low at 3%, and Linear Shrinkage low at 3.5%. These soils may be considered as of low potential activity.

The above QA results are essentially in agreement with and therefore validate the other majority results tested from Controlab.

6.4.2 Physical properties

Relative densities for selected samples are summarised below in **Table 6-18**. Moisture contents are summarised in **Table 6-19.**

Table 6-18: Summarised relative density values (QA)

Test pit	Material type	Depth (m)	Origin	Relative density
TP105	Silty sand	1.0 - 3.6	Colluvium	2.593
TP115	Silty sand	0.4 – 2.4	Colluvium, part pedogenic	2.552

Table 6-19: Summarised moisture content results (QA)

Test pit no	Material type	Depth (m)	Origin	Moisture Content
TP105	Silty sand	1.0 - 3.6	Colluvium	11.1
TP108	Silty sand	0.6 – 2.2	Colluvium, part pedogenic	13.2
TP115	Silty sand	0.4 – 2.4	Colluvium, part pedogenic	14.2

6.4.3 Compaction

Summarised Standard Proctor compaction results are presented in **Table 6-20.**

Table 6-20: Summarised Proctor compaction results (QA)

Test pit no	Material	Depth (m)	Origin	Proctor density (kg/m^3)	o m c (%)
TP105	Silty sand	1.0 - 3.6	Colluvium	1616	15.0
TP108	Silty sand	0.6 – 2.2	Colluvium, part pedogenic	1542	14.4
TP115	Silty sand	0.4 – 2.4	Colluvium, part pedogenic	1551	17.5

The **colluvium** horizon is characterised by a maximum dry density (Standard Proctor compaction) of 1616 kg/m^3 with an optimum moisture content (omc) of 15%.

The **colluvial / part pedogenic** origin soils exhibit maximum dry density values in the range of 1542 to 1551 kg/m^3, with optimum moisture contents (omc) between 14.4% and 17.5%.

6.4.4 Permeability

The results of permeability tests on the remoulded soil samples are summarised below (**Table** 6-21).

Table 6-21: Summarised permeability test results (QA)

Hole no	Material	Depth (m)	Material origin	Permeability (cm/s)
TP105	Silty sand	1.0 - 3.6	Colluvium	2.58×10^{-7}
TP115	Silty sand	0.4 – 2.4	Colluvium, part pedogenic	2.40×10^{-6}

The silty sand **colluvium** yielded a permeability of 2.58×10^{-7} cm/s and the **colluvium / part pedogenic** material yielded a permeability of 2.40×10^{-6} cm/s.

7 Geotechnical considerations

The nearby Scheepersvlakte Dam, completed in 1990, provides a view of the typical structure layout being considered for the Lower Coerney Dam. In addition, the conditions experienced and recorded in some detail, permit some parallels to be drawn for this Lower Coerney Dam site.

7.1 Site suitability and founding conditions

The site is characterised by gently sloping flanks and a relatively wide river section. Ignoring for a moment the founding conditions, this topography places certain limitations on the favoured structure. The biggest influence on the favoured structure type would however be the founding geology.

The key characteristics of these geological conditions that impact on the selection of the favoured dam type may be summarised as follows;

- Variable soil cover,
- In particular, the presence of mixed gravels in sandy matrix horizon at depth, across the entire footprint, as well as the reservoir area, and
- Weak bedrock comprising sandstones and mudstones, characterised by pervasive weathering.

The availability of suitable construction materials is a further important consideration; this is discussed in more detail below (Section 7.5 Construction materials), but is briefly referred to in this section. These topics are individually addressed below.

7.1.1 Topography

In terms of the topography, the ratio of crest length to the maximum height of the dam is a common consideration in dam type selection. For this Lower Coerney Dam site the ratio is roughly 30, which already points to an embankment dam.

7.1.2 Soil horizons

The cumulative thickness of the various soil strata varies between just less than 3 m to almost 8 m. Soil cover appears shallowest on the right flank, extending into the river section, while on the left flank soil thicknesses are generally between 7 m and 8 m. The soil thickness solely is therefore not reason alone to translate into selection of a specific structure. Of significance in terms of the soil strata, however, is the presence of a gravel horizon at depth. This horizon blankets the entire site, including dam and spillway footprint as well as the basin area, and has implications for the dam type and founding depths. Depths and thicknesses of this horizon beneath the dam footprint are summarised below (**Table 7-1**). The test pits are indicated with no elevation information as these points were not surveyed. A view of in situ conditions as exposed with a test pit is shown below in **Plate 7-1**.

Table 7-1: Gravel horizon beneath dam footprint, summarised depths and thickness (all metres)

BH no	Depth; upper boundary	Elevation (masl)	Depth; lower boundary	Elevation (masl)	Horizon thickness (m)	Comment
LC BH01	0.8	82.56	2.7	80.66	1.9	Lower right flank Coarser fraction comprises 20-40%; finer matrix not recovered
TP101	3.3	-	3.7	-	0.4	Upper right flank Mainly coarse fraction with silty sand matrix
TP127	0	-	3.3	-	3.3	Upper right flank Mainly coarse fraction with silty sand matrix
LC BH02	2.65	86.50	7.7	81.45	5.05	Lower left flank. Matrix typically lost, material recovery 40-90% therefore coarse fraction abundant
LC BH03	1.28	83.02	4.05	80.25	2.77	Lower left flank Matrix mostly lost, recoveries 20 – 100%; conclude variable coarse fraction
LC BH04	2	79.82	3.25	78.57	1.25	River section Matrix lost, recovery 30 – 50%
LC BH05	4	98.01	7.2	94.81	3.2	Upper left flank / spillway crest Coarse fraction a relatively minor component
LC BH06	5.45	84.53	6.7	83.28	1.25	Left flank, mid spillway chute Coarse fraction generally minor component but concentrated at base of horizon.

When initially encountered in some test pits this gravel horizon was considered to represent an alluvial palaeo-channel, i.e. representative of an earlier river course, subsequently buried by younger sediments. On later reflection, with due consideration of the geological history and landscape evolution, and following completion of all the boreholes, this gravel horizon is considered more likely to represent reworked terrace gravels, rather than purely a palaeo-channel. The horizon is however not uniform. In general, the gravels and occasional cobble fraction are relatively minor, typically loosely packed components, and the silty sand matrix is dominant. In some instances, however, this gravel horizon is more ‘concentrated’ with the coarser fraction, predominantly comprising gravels but also occasional cobbles and even rare boulders, is tightly packed, i.e. clast-supported. It is possible that within these lower elevations this concentration of the coarser fraction might be representative of palaeo-alluvial activity, i.e. at least partly represent palaeo-channels.

The significance of this stratum for the dam design is that these materials are potentially highly pervious, and in such cases would represent potential preferred seepage paths. This aspect, including the implications for excavation depths, as well as foundation treatment is discussed in more detail below.

Plate 7-1: The gravelly layer as exposed within a test pit (this view test pit LC22); the boundary indicated by the dotted line

Plate 7-2: Spoil from the same test pit, better illustrating the nature of the gravelly material.

7.1.3 Bedrock

As alluded to above, the soil horizons viewed in isolation do not represent the most decisive factor in determining the dam type. Considering the soil depths jointly with the bedrock conditions is however key in assessing the optimal dam type.

The gravelly horizon described above overlies the bedrock or in some instances the residual sandstone (bedrock) material. As described above, the bedrock comprises a sequence of interbedded sandstones and mudstones, including fine grained silty sandstones. The degree of interbedding is variable throughout the sequence; certain strata would be either entirely sandstone or mudstone, but other horizons are recognised that they are either predominantly sandstone, with relatively minor mudstone interbeds, or vice versa. Aside from the lithological differences, the degree of weathering, together with the nature of the jointing are key influences on the overall bedrock conditions and therefore suitability as founding horizon.

Generally, the bedrock is characterised by pervasive weathering. For the most part the strata are highly weathered, i.e. the effects of the weathering are evident throughout the rock mass.

Typically, where the uppermost rock strata mainly comprise mudstones these are classified as highly to completely weathered, and where the uppermost bedrock horizon comprises sandstone these strata are generally highly weathered, although a thin layer of highly to completely weathered material is also recognised. The significance of the ‘completely weathered’ horizons is that these are approaching a soil in terms of appearance and behaviour. As a result, these upper sandstone strata comprise medium hard to very soft rock where completely weathered; even to sand in some instances. The upper mudstone horizons would generally comprise soft rock to very soft rock. More importantly, in places, the weathering has produced clay layers that vary in thickness from as little as 40 mm to as much as 300 mm[4]. Where an improvement in degree of weathering was noted at depth it is possible to define the thickness of the highly weathered strata; varying between 4.25 m and 11.6 m. With the shallow boreholes on the left flank the base of the highly weathered horizon was not intersected, and even in borehole LC BH01 on the right flank the base was not recorded with the minimum thickness therefore 13.3 m. With only two exceptions where boreholes intersected unweathered rock at the base (boreholes LC BH03 and LC BH04, respectively), any observed improvement in the degree of weathering was only gradational – generally to 'moderate' weathering, or occasionally moderately to slightly weathered. In both the above cases, this unweathered rock comprised mudstone / carbonaceous mudstone, albeit with minor interbedded sandstone strata in LC BH04.

7.1.4 Suitable dam types

The impact of the above discussion on most suitable dam type may be summarised as follows;

- The flat topography favours an embankment dam.
- The soil cover on its own is not a limiting factor, but the underlying bedrock comprises weak rocks. No suitable founding for a mass concrete gravity structure would be defined within shallow depths. It follows that an embankment structure would be optimal in terms of the prevailing founding conditions.
- Although not discussed above (but elaborated on in Section 7.5), the availability of potential construction materials in proximity to the site dictates that an earthfill embankment is favoured, rather than a rockfill structure.

7.2 Excavation depths

The various elements of the envisaged embankment structure have different founding requirements, and these are discussed below. The key elements are listed as follows;

- The embankment, with the impervious core and the outer shell zones considered separately,
- The conduit, including intake and outlet,
- The spillway.

[4] *Note these thicknesses are as recorded on the cores. These weak materials are however susceptible to being washed, i.e. lost, in the drilling process and the horizons thicknesses are not necessarily an accurate representation of actual in situ conditions.*

Typical foundation requirements for an earthfill embankment may be summarised as follows;

- For embankment outer shell zones,
  - A minimum required foundation Deformation Modulus of 0.2 GPa
- For the cut-off trench,
  - A minimum required foundation Deformation Modulus of 2 GPa
  - In addition, the cut-off would be founded on material that would be deemed groutable.

7.2.1 Embankment shell zones

For the embankment shell zones, it is reasonable to assume that foundation excavations will comprise removal of a nominal 300 mm to 500 mm, primarily to ensure the upper, potentially organic-rich, potentially compressible topsoil stratum is removed.

7.2.2 Embankment cut-off

For the cut-off trench, focusing entirely on the geotechnical profile and not considering the hydraulic requirements, the interpreted minimum excavation depths for the respective boreholes are summarised below (**Table 7-2**). The presence of the gravel-sand horizon within the soil profile is worth mentioning in terms of the decisions regarding depth of cut-off trench excavations. It is recognised that this horizon represents a potential pervious layer, albeit likely variably and that some areas might not be as pervious as others. This gravel-sand layer at its deepest is almost 8 m below surface, but in places only extends to depths of 3 m or 4 m. Such depths are not considered excessive, and special treatment is not considered necessary. Considering the potential seepage, and that the depths are not limiting, it is recommended that the cut-off extend, as a minimum, to the base of this gravel-sand layer.

Table 7-2: Summarised excavation depths for impervious cut-off trench

BH No	Excavation depth (m)	Elevation (masl)	Rockhead depth	Comments
Left flank				
LC BH05	7.2	94.81	7.2	The principle of founding beneath the gravel layer implies an excavation depth of 7.2 m. However, this borehole is located on extreme upper flank area and cut-off depths of 7+ m is perhaps excessive. A shallower cut-off (say 3.5 – 4 m) may be considered, but this would terminate the cut-off within this potentially pervious gravel stratum.
LC BH06	6.7	83.28	6.7	Borehole was drilled on spillway chute alignment but is considered here to be indicative of mid-left flank conditions. Founding beneath gravelly stratum would imply depths of almost 7 m.
LC BH02	7.8	81.35	7.7	Found at 7.8 m i.e. below gravel -sand stratum of reworked terrace gravels.
LC BH03	4.6	79.70	4.05	Found below gravel horizon. Remove uppermost bedrock horizon (thickness 0.55 m) to get beneath very soft rock horizon. Might consider founding immediately beneath gravel soils, but rather remove uppermost horizon of very soft / soft rock / occasionally weathered to sand.
River section				
LC BH04	5.5	76.32	3.25	Possible to found at a minimum depth of 3.5 m but sandstone comprises very soft / soft rock and minor core losses recorded. Preferably found at a depth of 5.5 m.
Right flank				
LC BH01	3.5	83.32	2,7	Found within the upper, highly weathered sandstone stratum, but notably beneath the uppermost highly to completely weathered, very soft rock.
TP101	3.7	-	-	Found below the gravel horizon. Remove all material to 3.7m depth and found on the very dense silty sand of residual sandstone origin
TP127	3.3	-	3.3	Found on the completely to highly weathered, fine grained, soft to medium hard rock. sandstone

Note that the geological conditions are evaluated in all boreholes on the assumption that the respective boreholes are representative of conditions for the embankment – even though the individual borehole might have been drilled for a different purpose or is offset from the centre-line. The two test pits excavated on the upper right flank are added and are in agreement with the borehole drilled on the lower right flank.

7.2.3 Intake and outlet works

In general, the outlet works would comprise an intake structure, outlet pipes within a concrete encasement, and an outlet structure. Boreholes LC BH02 and LC BH03 were drilled at the intake and outlet positions respectively, while the conditions in the central portion of the conduit may be extrapolated from borehole LC BH04. The geological profiles are described above (Sections 6.2.2 and 6.2.1). Implications for the founding of these structures are summarised below (**Table 7-3**).

Table 7-3: Summarised excavation depths for outlet works

BH No	Excavation depth (m)	Elevation (masl)	Thickness of gravel sand stratum (m)	Rockhead depth	Comments
LC BH02 (intake)	2.7	86.45	5.0	7.7	Founding on gravel -sand stratum of reworked terrace gravels. SPT N-value = 43 at depth 2.64 m
LC BH03 (outlet)	1.3	83.00	2.7	4.05	Found on gravel-sand horizon. No SPT test.
LC BH04	2.0	79.82	1.25	3.25	Found at 2 m depth on gravel sand stratum. SPT N-value 66 at depth 1.95 m.

A Standard Penetration Test (SPT) was conducted in borehole LC BH02, at a depth of 2.64 m, i.e. within the horizon of reworked terrace gravels. On the face of it the (single) result of N = 43 suggest dense soils, with an associated allowable bearing capacity of approximately 200 kPa. Another SPT test in borehole LC BH04 yielded an N-value of 66 at a depth of 1.95 m, similarly suggesting allowable bearing capacities in excess of 350 kPa. Some caution must be attached to blindly accepting these values, due to the presence of medium to coarse gravels within the tested horizon and the uncertainty whether the test results are truly representative or might reflect skewed data from interception of these boulders / gravels.

- A key element of founding of the outlet works (intake structure, conduit as well as outlet structure) would be the occurrence of highly variable conditions that might have implications in terms of foundation characteristics, notably the possibility of differential settlement. The reworked gravel-sand stratum is present over the entire footprint and in that sense the founding conditions might be considered relatively uniform, which would mitigate against the possibility of differential settlement. Note that the excavation depths (and founding levels) reflected above in

Table **7-3** do not consider inlet and outlet design levels or conduit design gradient. Such optimisation will be carried out in the design phase and will have implications for final excavation depths within this gravel-sand stratum.

7.2.4 Spillway

Only two boreholes (LC BH05 and LC BH06) provided confirmation of the deeper geological profile along the spillway alignment. Borehole LC BH05 is located at a position corresponding roughly with the spillway ogee, while borehole LC BH06 is located roughly midway along the chute. No borehole is located at the end of the spillway, but test pit LC12 was initially placed at the end and it exposed the upper soil profile. However, to fully understand the founding conditions at the end of the spillway, test pit TP103, TP125 and TP126 were excavated using the tracked excavator for greater depth ability, as indicated in drawing 112546-GEO-DRG-CC-001-B for the supplementary investigations.

It is assumed that the spillway ogee section will comprise a mass concrete, gravity structure. The spillway chute will have to be concrete-lined, as discussed below (Section 7.4).

The mass concrete gravity ogee spillway structure cannot be founded at depths shallower that 7.2 m, i.e. the structure cannot be founded on the soil horizons but must be founded on the underlying bedrock as a minimum. Bedrock was intersected at a depth of 7.2 m, and comprises very soft to soft rock, predominantly mudstone with subordinate sandstone. The borehole was terminated at 10 m, and the extent to which the bedrock condition improves with depth is uncertain. The uppermost bedrock horizon should also be removed prior to concrete placement, in order to remove the weakest material. It should be noted that the mudstone will be susceptible to slaking; Excavation and foundation preparation cycles will have to allow for near-immediate protection of the exposed rock surfaces, typically by casting of a blinding layer immediately following cleaning of the rock surface.

For the remainder of the chute, the same principle will be followed for determination of the founding depths; i.e. that the soil strata must be removed and that the concrete-lining be founded on the underlying bedrock. In places this bedrock will comprise mudstone, and in other areas the rock will be sandstone.

Founding conditions at the end of the spillway chute are of particular importance, as it is at this point where the concrete lining terminates, and the chute transitions to an unlined channel. Appropriate allowance is therefore required for energy dissipation, with the requirement for suitable founding as well as consideration of erodibility and the risk of undercutting of the lined section. Bedrock was encountered between 3.4 m and 4.9 m in test pits TP126 and TP125 respectively, at the end of the spillway. The bedrock was encountered as slightly weathered, hard rock sandstone. The test pit at the further end of the spillway (TP103) indicated residual sandstone to 2.9 m. It is assumed that at this position the bedrock might therefore be present at depths between 3 m and 5 m. The end of the spillway should be founded on the bedrock at depths of 3.5 - 5 m. It is assumed that the usual energy dissipation measures will be incorporated, and that the end of the chute will also include a cut-off to prevent headwards erosion.

7.3 Foundation permeability and foundation treatment

The chief concern regarding foundation permeability is linked to the presence of the gravel–sand horizon, which is known to be present across the entire dam footprint. If left 'untreated' there would be a risk of this stratum functioning as a 'buried channel' or preferential seepage path beneath the embankment. The consequences could then potentially be manifested in the form of uncontrolled seepage and the inability of the reservoir to fill and, in the worst case, internal erosion and failure.

Consideration of likely scenarios relating to seepage within the horizon of reworked terrace gravels has been addressed at a high level by GWA Consulting Hydrogeologists cc (see Appendices). This evaluation was also in the context of the potential for sub-surface seepage occurring in a northerly direction, that might be cut-off by the dam, and create future problems in terms of shallow water tables downstream of the dam. The key points of this evaluation can be summarised as follows;

- Groundwater hydraulic gradients are steep, with low permeability.
- The hydraulic gradients show sub-surface seepage in a southerly direction (downstream).
- With the filling of the reservoir it is expected that these gravels will become saturated over time. Actual flow rates are unconfirmed, but with the knowledge that these reworked terrace gravels are variable, it can be assumed that general seepage rates will be low, but zones of higher seepage flows cannot be excluded.
- With the dam cut-off extending through this gravel layer into the underlying bedrock, it can be assumed that the reservoir will not impact on the geo-hydrological regime downstream of the dam.

The indicated excavation depths for the cut-off (**Table 7-2**) have been defined on the basis of ensuring that this potential seepage path, represented by the gravel–sand stratum, is cut off.

Limited water pressure (packer) tests were carried out within the underlying bedrock to assess the rock permeability. These results are presented on the detailed borehole logs (Appendix B) and are summarised below (**Table 7-4**).

The results of the water acceptances tests in some boreholes indicate some significant losses. These instances are presumed to be associated with weathered zones within the rock mass that are typically associated with material losses. The occurrence of such losses is indicative of very weak material that is ground by the drilling action, and subsequently lost to the circulating drilling fluid. This assumed mechanism is supported by interpretation of the water acceptance test data; specifically, the relationship between the applied pressures and the measured water losses (after Houlsby, 1976). The significance of these losses lies in the possibility that they reflect the potential for erosion damage to the founding rock mass under conditions of seepage and high hydraulic gradients.

If the jointed founding rock mass was characterised by open joints with hard wall rock, for example, the foundation would be considered 'groutable', and foundation treatment comprising foundation grouting (compaction and/or curtain grouting) could be readily specified. In the case of these weathered, weak rocks, which evidently are susceptible to wash out, and are further characterised by interbedded mudstones, which in places are weathered to clays, the 'groutability' of the rock mass is more questionable.

Table 7-4: Summarised Water Acceptance (Packer) Test results

BH No	Test section (depths in m)	Lugeon (UL) value	Comment
LC BH02	7.5 – 10.97	64	Wash out. Weathered zones in mudrock likely origin
	11 – 13.97	12	Wash out. Ascribed to weathered zones which are associated with material losses
	14 – 16.97	0	Tight
	17 – 20.45	35	Turbulent flow. Prominent weathered zone in the sandstone that is associated with prominent staining, and therefore assumed to represent a seepage path.
LC BH03	4.5 – 7.65	0	Tight
	7.5 – 10.58	15	Wash out. No obvious link identified in the core logging.
	10.5 – 12.59	1	Dilation / tight
	12.5 – 13.36	0	Tight
	15.5 – 18.59	0	Tight
	18.5 – 20.43	0	Tight
LC BH04	4 – 7.78	0	Tight
	7.5 – 10.94	13	Wash out. Ascribed to local highly weathered zones, associated with significant material losses.
	11 – 13.94	0	Tight
	13.5 – 15.04	0	Tight

7.4 Erodibility

The question of erodibility of these weak rocks has specific bearing on the spillway chute. Two shallow boreholes were initially drilled to investigate the ground profile in this area on the left flank, namely boreholes LC BH05 and LC BH06. Three test pits have subsequently been excavated at the end of the spillway chute. i.e. TP103, TP125 and TP126. These were added to further investigate ground conditions at the end of the chute.

While steps for a detailed appraisal of the erodibility can be followed, some points of logic are pertinent;

- The soil horizons would offer no resistance to erosion and would clearly be washed away in the case of an earth channel. The silty to clayey sands extend to respective depths of 6.7 m and 7.2 m in the two boreholes and to 3.4 m and 4.9 m in test pit TP126 and TP125 respectively, with residual sandstone encountered between 2.1 m and 2.9 m in test pit TP103 located further into the ‘river’. The basal soil stratum comprises the gravel-sand reworked terrace deposits and even this material is considered to be erodible.
- Within these boreholes the rockhead was intersected at these respective depths of 6.7 m and 7.2 m, between the ogee and approximately midway along the chute, and at depths of 3.4 m and 4.9 m in test pits at the end of the spillway chute.
- The upper bedrock horizon either comprises completely weathered, becoming highly weathered sandstone or interbedded sandstone / mudstone, or highly and occasionally completely weathered mudstone with subordinate sandstone. Irrespective of the lithology, the bedrock comprises weak rock. The mudstones in particular are considered susceptible to slaking.
- A rock mass exposed to the elements would therefore deteriorate over time as the mudstones, or mudstone interbeds, disintegrate (slake). Repetitive cycles of exposed rock disintegrating, and the resulting fine fraction being eroded means that any resistance to erosion is only temporary. The process would even affect a strong rock mass, and in the case of these already weak rocks, the slaking process would simply impact further on rock which is considered to be erodible.

From the above points, it is evident that an unlined spillway chute is not practical or feasible. A concrete lining of the entire length of the spillway chute is necessary in order to prevent erosion; as constructed for the Scheepersvlakte Dam.

Consideration will have to be given to enough energy-damping at the end of the concrete chute, at the point where the water will be released into the river channel.

7.5 Construction materials

It has been stated above (Section 7.1) that the availability of suitable construction materials in proximity to the dam site is a major factor in considering the most suitable structure. Considering that the prevailing conditions favour an embankment dam, the following materials would be required;

- Embankment fill materials, including general fill and impervious core materials,
- Rip-rap for upstream slope protection,
- Concrete aggregates, including coarse aggregate, as well as sand (fine aggregate), for the concrete elements, including the concrete spillway chute, spillway ogee, intake, conduit as well as outlet works.
- Sand for use in filters.
- Other materials that would be required would include materials for roads construction. This aspect is not addressed.

7.5.1 Embankment fill materials

The existing Scheepersvlakte Dam comprises a homogeneous earthfill structure, with various filters, as recorded in the Completion Report (DWA, 1988). The structure includes a cut-off trench, but there is no impervious core. The initial design envisaged a conventional zoned embankment with an impervious core, and shell zones of semi-pervious material. The shortage of semi-pervious material within the basin, however, led to a change in design to a homogeneous embankment.

The following earthfill specifications (**Table 7-5**) were stated in the design report for Scheepersvlakte Dam (DWA, 1988).

Table 7-5: Scheepersvlakte Dam, homogeneous earthfill specifications (DWA, 1988)

Grading analyses			
Sieve size	% passing		
	Maximum	**Minimum**	**Mean**
4.75	100	45.7	89.8
2.00	100	37.0	86.7
0.425	99.2	29.2	80.9
0.150	93.9	220	71.0
0.050	70.0	10.8	46.3
0.005	48.6	00	19.3
0.002	40.7	0.0	16.9
Atterberg limits			
	Maximum	**Minimum**	**Mean**
Liquid limit (%)	43.0	20.0	34.2
Plastic limit (%)	29.1	11.9	18.4
Plasticity Index	25.0	4.0	15.8
Linear shrinkage (%)	10.7	1.3	7.6
Compaction (Std Proctor)			
	Maximum	**Minimum**	**Mean**
Maximum dry density (kg/m^3)	1884	1542	1736

Optimum moisture content (%)	24.2	10.8	16.3
Direct shear			
	Maximum	**Minimum**	**Mean**
Angle of internal friction (°)	45.0	19.4	35.4
Cohesion (kPa)	153.3	9.29	18.8
Triaxial shear			
	Maximum	**Minimum**	**Mean**
Angle of internal friction (°)	44.8	23.6	31.7
Cohesion (kPa)	40.0	0.0	15.5
Coefficient of permeability (cm/sec)			
	Maximum	**Minimum**	**Mean**
	4.1×10^{-5}	1.6×10^{-8}	1.1×10^{-6}
Relative density			
	Maximum	**Minimum**	**Mean**
	2.75	2.50	2.65

The proximity of the Scheepersvlakte Dam to this proposed Lower Coerney site means that certain lessons learnt would be of value to construction of the Lower Coerney dam.

The material properties confirmed in these investigations are tabulated below and compared to typical requirements for the main elements of a zoned earthfill structure, i.e. the impervious core (**Table 7-6**) and the outer shell zones (**Table 7-7**), respectively.

It is worth noting that the material properties results (specifically Foundation Indicator results) used for this evaluation are mainly from the recent supplementary investigations. This has been done for two main reasons; firstly, because the initial results are not entirely compatible with the later supplementary results, and secondly in view of the later investigation focussing mainly on the basin as a possible materials source, and therefore more relevant.

Table 7-6: Summarised material properties and comparison against typical requirements (impervious core), after Badenhorst, 1988

Parameter	Criteria	Material types				
		Colluvium	Colluvium / partly pedogenic	Pedogenic	Mixed origin (reworked terrace gravels)	Mudstone
Grading	>60% passing 0.425 mm sieve	81 – 98% ((6))	85 – 99% ((7))	58 – 98% (2) ((1))	62 – 96% ((4))	72 – 91% ((3))
Clay %	10<%<30	6 to 25% (6) ((5))	11 to 34% ((7))	4 to 16% (2) ((1))	7 – 12 (4) ((2))	23 - 35% (3) ((2))
Liquid Limit %	30<LL<60	0 to 29% (6)	25 to 42% (7) ((5))	26 to 34% (2) ((1))	24 – 34 (4) ((1))	32 – 39% ((3))
Plasticity Index %	12<PI<35	SP to 14% (6) ((2))	8 to 19% (7) ((6))	10 to 13% (2) ((1))	7 – 15 (4) ((1))	10 – 15% (3) ((2))

Parameter	Criteria	Material types				
		Colluvium	Colluvium / partly pedogenic	Pedogenic	Mixed origin (reworked terrace gravels)	Mudstone
Linear Shrinkage %	4<LS<10	1.5 to 7.0% (6) ((4))	4 to 9.0% ((7))	5 to 6.5% ((2))	4 – 7% ((4))	5.0 – 7.0% ((3))
Maximum Dry Density kg/m^3	1450<MDD<1880	1776 – 1990 (5) ((3))	1676 – 1914 (8) ((7))	1522 – 1812 ((3))	1617 – 1990 (5) ((3))	1954 – 1966 (2)
Optimum moisture content omc %	14<omc<25	10.6 – 15.7 (5) ((2))	9.3 – 18.9 (8) ((6))	14.1 – 22.6 ((3))	10.6 – 23.8 (5) ((1))	11.4 – 12.4% (2)
Shear Strength kPa	12<kPa<24	35.4 to 38.1 (4)	40.9 to 41.6 (2)	33.9 to 35.7 (2)	33.4 – 43.2 (3)	
Friction angle	18<Φ°<30	18.3 to 34 (5) ((4))	0.5 to 31.1 (7) ((5))	20.2 to 24.8 ((2))	19.2 – 26.4 ((3))	19.9 to 26.2 ((2))
Permeability *k* cm/s	<1 x 10^{-4}	1.84 x 10^{-5} to 5.75 x 10^{-7} ((2))	7.08 x 10^{-7} to 3.48 x 10^{-6} ((6))	6.07 x 10^{-7} to 1.88 x 10^{-6} ((3))		2.88 x 10^{-7} to 2.59 x 10^{-7} ((2))

Where numbers of total sample quantities are shown in single brackets, while double brackets in turn indicating a number of samples in compliance. Note also the stated maximum PI by Badenhorst (1988) is considered too high.

To facilitate easy comparison where material properties fall outside the broadly-stated objectives, the relevant cells in the above table (**Table 7-6**) have been shaded, with unshaded cells indicating compliant results and the shaded cells indicating results that falls outside compliance boundaries to a variable degree; pale shading indicates a minor discrepancy while darker shading indicates a greater non-compliance.

The values in double brackets within the cells indicate a number of sample results in compliance with the Badenhorst (1988) criteria; against the total number of samples tested (in single brackets).

The following comments summarise broad observations in respect of the suitability of the local materials for use in the impervious core;

- In terms of the material grading, the clay content largely complies with the above criteria with only a few scattered values falling either side of the target range between 10% and 30%. This applies across the spectrum of material types encountered. The percentages passing the 0.425 mm sieves are routinely greater than 60%, and therefore show general compliance. Only a few discrepancies were noted.
- Considering the Atterberg limits i.e. Liquid Limits, Plasticity Index, and Linear Shrinkage, the results again show scatter, reflecting some results falling outside the requirements,

specifically on the low side. The Liquid Limits and the Plasticity Indices (PI's) in particular are sometimes too low, i.e. lower than the stated minima of 30% and 12%, respectively. It must be noted, however, that there remain a large number of values that meet the stated criteria, and that occasional low values should not detract from the general compliance.

- The standard Proctor compaction results show general compliance. The reworked terrace gravel horizon does, however, record some anomalous values, where occasional samples yielded occasional dry density values that were too high, while the optimum moisture contents were too low.
- The shear strength data shows the materials all exhibit greater shear strengths than required, while the friction angles largely comply with the requirements (between 18° and 30°).
- The measured permeabilities all show relatively impervious materials, well within the range required (less than 10^{-4} cm/sec).

Special mention needs to be made of the 'mudstone'. Although bedrock, as opposed to the overlying transported soils, the mudrock in reality comprises soft rock to very soft rock and during excavation using the tracked excavator this material is generally recovered as clayey silt / silty clay with variable sand fraction as well as an occasional coarse fraction. The horizon therefore does not exhibit true rock material properties, and the laboratory testing was in effect conducted on the fine-grained soils. A further point here is that these materials are susceptible to slaking, and once exposed to the elements / excavated it is to be expected that further deterioration will occur – with the mudrock becoming ever-finer; eventually becoming a clay.

It is also pertinent to note lessons from construction of Scheepersvlakte Dam, notably in terms of the required moisture content (DWAF, 1992). As a result of the relatively high moisture requirements (for the homogeneous fill), coupled with the high clay content, construction difficulties were experienced. The high required optimum moisture contents also resulted in compaction problems.

Table 7-7: Summarised material properties and comparison against typical requirements for outer shell zones, i.e. semi-pervious zones (after Badenhorst, 1988)

Parameter	Criteria	Material types				
		Colluvium	Colluvium / partly pedogenic	Pedogenic	Mixed origin (reworked terrace gravels)	Mudstone
Grading	>40% passing 0.425 mm sieve	81 – 98% ((6))	85 – 99% ((7))	58 – 98% ((2))	62 – 96% ((4))	72 – 91% ((3))
Clay %	<10%	6 to 25% (6) ((1))	11 to 34% (7)	4 to 16% (2) ((1))	7 – 12 (4) ((2))	23 - 35% (3)

Parameter	Criteria	Material types				
		Colluvium	Colluvium / partly pedogenic	Pedogenic	Mixed origin (reworked terrace gravels)	Mudstone
Liquid Limit %	LL <30	0 to 29% ((6))	25 to 42% (7) ((3))	26 to 34% (2) ((1))	24 – 34 (4) ((3))	32 – 39% (3)
Plasticity Index %	4< PI<12.5	SP to 14% (6) ((3))	8 to 19% (7) ((4))	10 to 13% ((2))	7 – 15 (4) ((3))	10 – 15% (3) ((2))
Linear Shrinkage %	0<LS<7	1.5 to 7.0% ((6))	4 to 9.0% (7) ((2))	5 to 6.5% ((2))	4 – 7% ((4))	5.0 – 7.0% ((3))
Maximum Dry Density kg/m^3	1750<MDD<2100	1776 – 1990 ((5))	1676 – 1914 (8) ((7))	1522 – 1812 (3) ((1))	1617 – 1990 (5) ((4))	1954 – 1966 ((2))
Optimum moisture content omc %	6<omc<16	10.6 – 15.7 ((5))	9.3 – 18.9 (8) ((6))	14.1 – 22.6 (3) ((1))	10.6 – 23.8 (5) ((4))	11.4 – 12.4% ((2))
Shear Strength kPa	kPa<12	35.4 to 38.1 (4)	40.9 to 41.6 (2)	33.9 to 35.7 (2)	33.4 – 43.2 (3)	
Friction angle	28<Φ°<38	18.3 to 34 (5) ((2))	0.5 to 31.1 (7) ((5))	20.2 to 24.8 (2)	19.2 – 26.4 (3)	19.9 to 26.2 (2)
Permeability *k* cm/s	>1 x 10^{-4}	1.84 x 10^{-5} to 5.75 x 10^{-7} (2)	7.08 x 10^{-7} to 3.48 x 10^{-6} (6)	6.07 x 10^{-7} to 1.88 x 10^{-6} (3)		2.88 x 10^{-7} to 2.59 x 10^{-7} (2)

Where numbers of samples are shown in single brackets and double brackets indicating a number of samples in compliance with the criteria

As per the above table, the shading of the cells has been applied to highlight where the material properties are not fully compliant with the requirements for a typical outer shell zone with unshaded cells indicating compliant results and the shaded cells indicating results that fall outside the criteria, to variable degrees; with pale shading indicating a minor discrepancy while darker shading indicates a greater non-compliance. The values in double brackets indicate the number of compliant results, while the number in single brackets reflects the total number of samples tested for the particular horizon.

A broad summary of the general material suitability for use in the outer semi-pervious / shell zones can be presented as follows;

- The grading is all in complaint in that the fraction passing the 0.425 mm sieve is greater than 40%. The clay contents, however, are generally non-compliant across all materials encountered in the basin; being too high, i.e. generally above the maximum of 10%. At times these clay fractions are as much as 35%.
- The Atterberg limits results yielded scattered values, with a limited number of results falling outside the desired criteria. Some Liquid Limit values are as high as approximately 40%

which is significantly higher than the required 30% maximum. Several Plasticity Index values and some Linear Shrinkages are also encountered to be outside the acceptable range. The results from the clay / silt soils excavated from the mudstone bedrock can be excluded from this discussion.

- In terms of the compaction characteristics, the materials generally fall within the acceptable range for the maximum dry density, i.e. between 1750 and 2100 kg/m^3., however some fall on the low side of the acceptable range, particularly for the pedogenic and terrace gravel materials. Similarly, the optimum moisture contents (omc) show some scatter, and at time the values are too high (up to 24%) against the desired maximum of 16%.
- Shear strengths are generally very high, i.e. significantly greater than required, generally varying between 33kPa and more than 40kPa, against the required maximum of 12kPa. Friction angles are generally low, but there is some scatter and some values fall within the target range between 28° and 38°.
- Very low permeabilities were recorded, where no measured permeabilities satisfied the criteria for semi-pervious material, i.e. a permeability greater than 10^{-4} cm/sec. Recorded values varied between 10^{-5} and 10^{-7} cm/sec which speaks to the clay contents for the various materials which typically varied between 10% and 25%, although some anomalous values were also recorded.

In assessing the various material types available in the basin in terms of suitability for use as either impervious core material or semi-pervious shell material it is evident that the materials show wide scatter in their properties. No clear distinction can therefore be made between the various materials types in terms of their suitability for either impervious core material, or for semi-impervious shell material. In other words, the properties of the various material groupings do not permit clear definition of their suitability – and therefore clear delineation into different borrow areas for the respective material uses cannot sensibly be made.

On the other hand, if the properties of the various material types are evaluated in terms of the specifications for the homogeneous embankment constructed for Scheepersvlakte Dam (see Table 7-5) then the general compliance of the soils within this Lower Coerney basin is evident. Only limited values fall outside these specifications, specifically some Atterberg limits in the form of an occasional Liquid Limit, or some Plasticity Index values which are less than 12% and therefore slightly on the low side.

In view of no clear ability to delineate the basin materials into sources suitable for placing into either the impervious core, or the semi-pervious outer shells, and at the same time considering the almost total compliance of these basin materials with typical homogeneous embankment specifications, it is recommended that the Lower Coerney Dam be constructed as an homogeneous earthfill embankment rather than a zoned embankment.

7.5.2 Filter sands

Sands suitable for use in the various filter zones are not readily available in the general area of the proposed Lower Coerney site. This is also borne out by experiences during construction of the Scheepersvlakte embankment. No sources of natural sand for use in the filters could be identified. Initially, the manufactured crusher sand was used, but there were limitations due to the crusher being required to produce coarse aggregate. Subsequently, a number of options were explored whereby various sources of sands were mixed with crusher run from a number of commercial crushers. Such products were hauled from as far afield as Patterson, or the Uitenhage district, some 40 km away.

7.5.3 Coarse aggregate for concrete

The investigations did not actively target the proving of potential hard rock sources that might be crushed to produce coarse aggregate. Certainly, there are no expectations for such potential sources within the Lower Coerney basin. Even in the general area of the Lower Coerney site and the Lower Sundays River valley in general, the chances of identifying a suitable source of coarse aggregate are remote. The general geology comprises weak sandstones and mudstones or siltstones which are not associated with crushed aggregates. The volumes of concrete required would be quite limited, however, and it is most likely that coarse aggregate requirements would be met from commercial sources.

7.5.4 Possible commercial sources

A number of possible commercial sources for sand and coarse aggregates have been identified – but all are located some distances away from Lower Coerney site.

- The sand quarry (Potgieter Quarries) located in the Paterson area is one option. However, attempts to contact the quarry and identify the quantities and the materials they produce has proven to be impossible at this stage.

The closest identified possible commercial sources are located in the Uitenhage and Coega areas, located more than 60 km away from site. The following potential sources details are summarised below:

- Harbron Quarries is located in the Uitenhage area, approximately 50 km from site. This quarry manufactures all types of sand and stone products. The quarry is located at coordinates, i.e. 33°46'1.71"S, 25°21'38.92"E.

- Denver Afrimat Aggreates quarry is located about 70 km from Lower Coerney site, also in the Uitenhage area (coordinates: 34°54’8.15” S, 25°26’56.96” E). This quarry produces both sand and aggregates. Available sand products are plaster sand, crusher sand, super sand and filling sand. Stone products vary from 4.75 mm to 53 mm in size with G1 to G7 base and subbase material.
- The Glendore Sand and Stone produces sand and coarse aggregates from the Sonop sand quarry and Coega Kop quarry respectively. Sonop quarry is located about 75km from site (i.e. coordinates: 33°46’41.47”S, 25°42’29.27”E) and Coega Kop Quarry at about 65 km from site (i.e. coordinates: 33°46'19.64"S, 25°37'21.44"E). Sonop quarry manufactures a range of sand products from dune concrete sand, filling or bedding sand, building sand, sandpit sand etc. The Coega Kop quarry manufactures 13 mm and 19 mm concrete stones with G5 basecourse and subbase materials and gabion stones.

7.6 Stability of cut slopes

Construction activities will result in temporary cut slopes, for instance for the cut-off trench, but also for the intake, conduit and the outlet work, as well as for the spillway ogee and chute excavations. These excavated faces within the soil horizons might be as deep as 8 m.

The gravel–sand stratum of reworked terrace gravels is a concern in terms of the stability of cut slopes. Where the cut slopes intersect this horizon, there is a likelihood that ravelling, and spalling will occur within these gravel soils. This can result in undercutting of the overlying strata, and an associated risk of slope failure. The stability of these horizons will be further compromised when wet. Excavation within these gravels also carries the risk that removal of the coarser fraction can result in further disturbance of the stratum, and due care is called for in these instances.

All slopes must be cut to safe angles, and/or shored as appropriate; particular attention must be paid to the gravel–sand horizons as described above. It is essential that these safe slope angles for these cut faces be verified by a suitably qualified and experienced geotechnical practitioner.

7.7 Reservoir basin slope stability

The slopes defining the reservoir basin are characteristically very gently sloping. There are consequently no concerns regarding the possibility of catastrophic failure of the reservoir slopes to the extent of being a risk to the structure.

8 Conclusions and Recommendations

This report presents the findings of the ground investigations conducted at the Lower Coerney dam site. **Table 8-1** has been revised to include geotechnical considerations from the supplementary investigations:

Table 8-1: Summarised geotechnical factor for Lower Coerney Dam site

Geological factors	Lower Coerney
General geology	Underlain by strata of the Sundays River Formation, Uitenhage Group, comprising thin grey sandstones, siltstones and mudrocks.
Geological profile; dam footprint	***Left flank;*** (upper), soils to 7.2 m (including horizon of gravelly soils 4 m **–** 7,2 m); very soft rock mudstone, subordinate sandstone from 7.2m. ***Central section*** (conduit **–** intake and outlet) *Intake*; sandy soil to 2.65 m; gravelly soils to 7.7 m; soft to very soft rock (occasionally to clay) mudstone from 7.7 m; medium hard to hard rock interbedded mudstone / sandstone from 9.8 m. *Outlet*; sandy soil to 1.3m; gravel-sand horizon to 4 m; very soft to soft rock sandstone from 4 m; soft to medium hard rock sandstone interbedded mudstone from 4.6m; hard rock sandstone from 12 m. *Central section*; sandy soils to 2 m; gravelly horizon to 3.25 m; soft to very soft rock sandstone from 3.25 m; medium hard rock sandstone from 5.5 m; hard rock sandstone from 7.5 m; mudstones more prominent from 11 m. ***Right flank***; topsoil to 0.8 m; gravelly horizon to 2.7 m; highly weathered, medium hard to soft rock from 2.7 m. Interbedded sandstones, mudstones. The **upper right flank** comprises upper soils to 3.3 m and 4.2 m where bedrock is encountered
Founding considerations	A gravelly horizon (1.2 m to 5 m thick) is recognised which occurs across the footprint; considered to represent reworked terrace gravels. Note however the horizon is variable. Mostly the matrix was not recovered in the boreholes, but this stratum represents a potential preferred seepage path (a buried channel). Cut-off design is to consider this feature.
Excavation depths	For the **cut-off**, on the extreme / uppermost left flank, the principle of excavating to base of alluvial gravels implies a depth up to 7.2 m, maybe some relaxation allowed on extreme upper flank.; in central section assume minimum depth of 5.5 m but note some variability; on mid right flank consider minimum depth of 3.5 m (below gravel layer).
Foundation treatment	Mudrocks are susceptible to slaking; provision must be made for immediate protection after exposure. As above re presence of potential 'buried channel'; must ensure cut-off intersects this stratum. Permeability of rock mass is generally very low / tight, but instances of wash-out of softer strata are recorded. The 'groutability' of these weathered rocks is however uncertain. At face value the outlet conduit could likely be founded on the gravel-sand stratum, but this does not consider required founding levels.

Geological factors	Lower Coerney
Spillway; geological profile	Upper spillway (near ogee / sill); soils to 4 m; gravelly soil horizon to 7.2 m; very soft / soft rock (mainly mudstone, subordinate sandstone) from 7.2 m. Lower spillway (actually midway); soils to 5.45 m; gravelly soils to 6.7 m; very soft rock sandstone (sand in places) from 6.7 m; interbedded sandstone / mudstone from 8 m. End of spillway: bedrock encountered as slightly weathered hard rock sandstone is encountered between 3.4 m and 4.9 m.
Spillway considerations	Soils underlain by weak bedrock that would be susceptible to erosion. Assume full concrete lining is required. The appropriate energy dissipation must be incorporated at the end of the spillway lining, and measures must be incorporated to prevent undercutting of the concrete. The end of spillway should then be founded on the bedrock which should be encountered beyond 2.9 m depth, with all the upper horizons removed prior to placement of concrete
Reservoir slopes	Natural slopes are essentially flat / gently sloping; no slope stability issues foreseen.
Construction materials	No clear distinction can be made between the various materials types within the basin in terms of their suitability for either impervious core material, or for semi-impervious shell material. Clear delineation into different borrow areas for the respective material uses therefore cannot sensibly be made. However, these materials do exhibit almost total compliance with specifications for use in a homogeneous earthfill embankment, and it is therefore recommended that the Lower Coerney dam be constructed as a homogeneous earthfill embankment rather than a zoned embankment. Other materials like coarse aggregate for concrete and filter sands / fine aggregate will have to be imported.

The following should be borne in mind, together with consideration as stated in the above table:

- Involvement of a geotechnical specialist during construction is essential. Activities would include regular inspection of all excavated faces and cut slopes from a stability point of view, oversight of any further geotechnical exploration and quality assurance testing, confirmation of bedrock depth at the spillway end, engineering geological mapping of the cut-off trench and recording of the as-built details, etc.
- One of the first actions on establishing a contractor would be the controlled backfilling of all geotechnical investigation points (boreholes and test pits that are located on the dam footprint).

9 Report limitations

1. Aurecon Ground Engineering has prepared this report for the use of our Client, Department of Water and Sanitation (DWS). The report has not been prepared for use by parties other than the Client, and the Client's respective consulting advisors.
2. This report has been written with the express intent of providing sufficient information for Preliminary Design purposes. The geotechnical investigation has been conducted in accordance with accepted practice, and the opinions and conclusions expressed are made in good faith, based on the information available to the Ground Engineering team of Aurecon at the time of preparing this report.
3. There are always some variations in subsurface conditions across a site due to geological conditions that cannot be defined fully even by exhaustive investigation. Hence, it is possible that the measurements and values obtained during the investigation may not represent the extremes of conditions which exist within the site. The precision with which subsurface conditions are identified depends on the method of drilling, the frequency and recovery of samples, the method of sampling, and the uniformity of the subsurface conditions. Subsurface conditions may therefore vary from the conditions encountered in the test pit / borehole locations.
4. The borehole logs and test pit profiles represent the subsurface conditions at the specific test location only. Boundaries between zones on the logs are often not distinct, but rather are transitional and have been interpreted. The soil descriptions in this report are based on accepted methods of classification and identification employed in geotechnical practice, as stated in this report. Classification and identification of soil involves judgement, and the Aurecon Ground Engineering infers accuracy in the classification and identification methods to the extent that is common in current geotechnical practice, and within the limitations of the ground investigation that was performed.
5. Furthermore, subsurface conditions, including groundwater levels can change over time. The groundwater conditions described in this report refer only to those observed at the place and time of observation noted in the report. These conditions may vary seasonally or as a consequence of construction activities in the area. This should be borne in mind, particularly if the report is used after a protracted delay or a period of protracted climatic conditions.
6. Should conditions exposed at the site during subsequent investigation or construction works vary significantly from those provided in this report, we request that Aurecon (Tshwane) Ground Engineering be informed and have the opportunity to review any of the

findings or conclusions of this report. It is highly recommended that during construction the site conditions be inspected by a representative of Aurecon Ground Engineering to confirm the geotechnical conditions and interpretations as well as recommendations in this report.

Note: the above list of limitations should be considered a live document, subject to amendment over time. This serves to highlight specific limitations and risks to the Client. These listed limitations are not protection against substandard work.

10 References

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