Proposed system to facilitate use of pedological information in preliminary stage geotechnical investigations

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DECLARATION

I hereby declare that this Doctoral thesis titled ***Proposed system to facilitate use of pedological information in preliminary stage geotechnical investigations*** is a product of my own, unaided work under the supervision of Dr Danél van Tonder and Prof Marthie Coetzee. The thesis is submitted in fulfilment of the requirements for the degree Doctor of Philosophy in Science at the North-West University. I certify that this work or any part of it has not previously been submitted for a degree or any other qualification at the North-West University or any other institution.

Signature of candidate:

This 23rd day of November 2021.

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ABSTRACT

According to the relevant legislation and standards, urban development in South Africa must be preceded by a preliminary stage geotechnical investigation (PSGI) in order to facilitate decision-making regarding site selection and the feasibility of the proposed development project. Geotechnical assessments are also required as specialist studies for Basic Assessment Reports (BAR) that form part of the Environmental Impact Assessment (EIA) process. The results of PSGIs allow classification and/or ranking of land parcels with regard to the cost and ease of urban development, thereby facilitating the conducting of cost-effective follow-up geotechnical site investigations. These desktop-type studies generally rely on information obtained from published sources, including regional geotechnical maps.

In the light of the scarcity of regional soils data outside major urban centres, the use of readily available pedological information contained in the published land type maps and memoirs is proposed. This resource provides pertinent details on soil forms, soil thicknesses, underlying materials, stoniness of the soil-like overburden and the clay content thereof. However, the nature of the pedological information does not readily allow direct correlation with the regional geotechnical assessment parameters, and the regional soil mapping information is perceived by geopractitioners to be of importance only for agricultural applications. In this light, a soils effects grouping (SEG) system was devised to provide a relatively simple and scientifically based tool to convert pedological information into the relevant geotechnical parlance in accordance with industry-standard parameters suitable for use in preliminary stage geotechnical investigations. Proper application of the refined SEG system relies on the personal experience of the practitioner, thereby ensuring the accuracy of results to the benefit of decision-makers. Application of the refined SEG system on the hand of case studies, as well as in practice, indicates that this approach holds great potential in improving the accuracy and efficacy of desktop-level studies.

However, some limitations do exist, with the depth limit of 1.2 m imposed by the use of the Binomial Soil Classification System on which the land type maps and memoirs are based, hampering accurate interpolation of geotechnical information at depth. Additionally, some inaccuracies with regard to the land type boundaries have been encountered. Conversely, it is envisaged that advances in pedological mapping will in future yield more detailed information, thereby improving the accuracy of preliminary stage geotechnical investigations utilising the refined SEG system.

Keywords: preliminary stage geotechnical investigation, land type, terrain unit, preliminary zonation, PSGI, SEG.

OPSOMMING

Volgens die toepaslike wetgewing en standaarde moet stedelike ontwikkeling in Suid-Afrika deur ‘n aanvanklike geotegniese ondersoek (PSGI) vooruitgegaan word om besluitneming rakende terreinkeuse en geskiktheid te fasiliteer. Geotegniese ondersoeke dien ook as spesialis-studie gedurende die opstel van Basiese Assesseringsverslae wat deel van omgewingsimpakstudies uitmaak. Die resultate van PSGIs is handig om die koste en gemak van ontwikkeling te klassifiseer en te beoordeel, en daardeur koste-effektiewe en gefokusde opvolgondersoeke te fasiliteer. Die aanvanklike ondersoeke maak oor die algemeen op inligting vanaf gepubliseerde bronne, insluitende regionale geotegniese kaarte, staat.

In die lig van ‘n gebrek aan regionale grond inligting buite die hoof stedelike gebiede, word die gebruik van die geredelik beskikbare landtipe kaarte en memoirs voorgestel. Hierdie hulpbron bevat toepaslike besonderhede aangaande grondvorme, laag diktes, onderliggende materiale, klipperigheid van die bolaag, en klei-inhoude van die grondlae. Die karakter van landtipe inligting verhinder egter direkte korrelasie met die regionale geotegniese evalueringsparameters, terwyl geopraktisyns van mening is dat die regionale grondopnames slegs vir landboudoeleindes aangewend kan word. In hierdie lig is ‘n grondeffekgroepering (SEG) stelsel ontwerp om ‘n eenvoudige en wetenskaplik-verantwoordbare hulpmiddel daar te stel waarmee pedologiese inligting in geskikte geotegniese omgangstaal vir gebruik in PSGIs omskep kan word. Behoorlike toepassing van die verfynde SEG stelsel is afhanklik van die persoonlike ervaring van die geopraktisyn, wat sodoende die akkuraatheid van resultate tot die voordeel van besluitnemers verseker. Toepassing van die verfynde SEG stelsel deur middel van gevallestudies, asook in die praktyk, dui daarop dat hierdie benadering groot potensiaal om die akkuraatheid en effektiwiteit van aanvanklike ondersoeke te verbeter, inhou.

Daar is egter enkele beperkings, met die dieptegrens van 1.2 m, wat deur die gebruik van die Binomiese Grondklassifikasiestelsel waarop die landtipe inligting gebaseer is opgelê word, wat die akkurate evaluering van geotegniese inligting op diepte belemmer. Daarbenewens is onakkuraathede met betrekking tot die landtipegrense plek-plek waargeneem. Omgekeerd word voorsien dat vooruitgang in pedologiese kartering in die toekoms meer gedetailleerde inligting sal oplewer, en sodoende die akkuraatheid van PSGIs met behulp van die verfynde SEG stelsel sal verbeter.

Sleutelterme: aanvanklike geotegniese ondersoek, landtipe, terreineenheid, voorlopige sonering, PSGI, SEG.

KAKARETSO

Ho ya ka melawana le ditekanyetso, ntshetsopele ya ditoropo Afrika Borwa e tshwanetswe ho etelwa pele ke tlhatlhobo kapa" preliminary stage geotechnical investigation (PSGI)" ho thusa diqetong mabapi le kgetho ya sebaka le hore na sebaka se loketse kaho.)

Tlhatlhobo ena ya setekhinike e hlokahala hape ele ditlhatlhobo tse etswang ke ditsibi hoba karolo ya ditlaleo tsa mantlha tsa tlhahlo "Basic Assessment Report (BAR)" e hlokahalang ha ho etswa tlhahlobo ya tsutsumetso ho tikoloho "Environmental Impact Assessment (EIA)"

Diphetho tsa PSGI di thusa ho arohanya le ho beha dikarolo tse itseng tsa lefatshe boemong bo itseng mabapi le tjeho le bonolo ba ntshetsopele, mme hona ho etse hore hobe bonolo ho latela metjha e ditjeho tse tlase. Dipatlisiso tsena tsa phaphosing (desktop) di itshetlehile ho tsebo e ngotsweng le dimmapa tsa sebaka

Ka baka la ho fokola ha tlhaiso lesedi ya mebu ya lebatowa, tlhaiso ke hore tsebo ya kgale e fumanwang dingolweng le dimmapeng e sebediswe. Disebediswa tsena di fana ka dintla tse amanang jwalo ka mefuta ya mobu, botenya ba mobu, mohlodi wa mobu, ho ba majwe ha mobu o fumanehang ka hodimo le bongata ba letsopa. Leha ho le jwalo, mofuta wa tlhaiso-leseding ya mobu ha o dumelle ha bonolo ho dumellana ka kotloloho le ditekanyetso tse beilweng mabapi le ho hlahloba tikoloho le tlhaiso ya dintla tsa mobu e bonwang ele bohlokwa fela ho tsa temo. Ka baka lena sisteme ya SEG e entswe ho etsa hore hobe bonolo ho fana ka tsebo ya saense e nepahetseng ho ya ka ditekanyetso tsa indasteri.

Tshebediso e nepahetseng ya SEG e itshetlehile ho tsebo ya motho, tsebo ena e etsa hore diphetho di nepahale ho thusa ba nkang diqeto. Tshebediso ya SEG ena le bokgoni ba ho thusa haholo phanong ya dintlha tse nepahetseng nakong ya "desktop studies".

Leha hole jwao, hona le bofokodi ka baka la hore ho sebediswa botebo ba di mitara tse 1,2, eleng botebo bo sebedisitsweng ho "Binomial Soil Classification System" eo di mmapa di itshetlehileng ho yona. Hona le bofokodi hape ka baka la hore meedi ya mefuta e fapaneng ya mebu ha eya nepahala. Hona le tshepo ya hore ha di mmapa tsa majwe le mebu di ntse di ntlafala, tsebediso ya SEG le yona e tla ntlafala.

Mantswe a bohlokwa : Dipatlisiso tsa pele tsa setekhiniki, mofuta wa mobu, yuniti ya sebaka, pehelo ya pele, PSGI, SEG.

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LIST OF ABBREVIATIONS AND ACRONYMS

AGE	adverse geotechnical effect
AGIS	DAFF geographical information system
ARC	Agricultural Research Council
BAR	Basic Assessment Report
BSCS	Binomial Soil Classification System
CGS	Council for Geoscience
DAFF	National Department of Agriculture, Forestry and Fisheries
DEA&DP	Western Cape Provincial Department of Environmental Affairs & Development Planning
DGSI	detailed geotechnical site investigation
DSM	digital soil mapping
EIA	environmental impact assessment
ENPAT	Environmental Potential Atlas
FAO	Food and Agriculture Organization of the United Nations
GFSH	Greenfields Subsidy Housing
GIS	geographical information system
PSGI	preliminary stage geotechnical investigation
IHC	inherent hazard class
ISCW	Institute for Soil Climate and Water
JAXA	Japanese Aerospace Exploration Agency
NEMA	National Environmental Management Act
NHBRC	National Home Builders Registration Council
NASCS	Natural and Anthropogenic Soil Classification System
PDSA	Plan-Do-Study-Act (Deming Cycle)
RP	“Référentiel Pédologique” (Pedological Referential)
SABS	South African Bureau of Standards
SAICE	South African Institution of Civil Engineering
SAIEG	South African Institute of Engineering and Environmental Geologists
SANS	South African National Standards
SEG	soils effects grouping
STC	soil type category
TSCS	Taxonomical Soil Classification System
USCS	Unified Soil Classification System
WRB	World Reference Base soil classification system

LIST OF NASCS SOIL FORMS WITH ABBREVIATIONS

Natural soil forms

Ab - Abbotspoort
Ad - Addo
Ag - Augrabies
Ak - Askham
Ar - Arcadia
Av - Avalon
Bd - Bloemdal
Be - Bethesda
Bg - Burgersfort
Bk - Bakwena
Bo - Bonheim
Br - Brandvlei
Bv - Bainsvlei
Ca - Carolina
Cc - Concordia
Cg - Coega
Ck - Cookhouse
Cf - Cartref
Ch - Champagne
Ct - Constantia
Cv - Clovelly
Da - Darnall
Dd - Didema
Dm - Dartmoor
Dr - Dresden
Du - Dundee
Dw - Dwaalboom
El - Eland
En - Erin
Er - Ermelo
Es - Estcourt
Et - Etosha
Fw - Fernwood
Ga - Gangala
Gc - Glencoe
Gf - Griffen
Gk - Groenkop
Gl - Glen
Gm - Gamoep
Gp - Graskop
Gr - Garies
Gs - Glenrosa
Hb - Heilbron
He - Henley
Hf - Hofmeyer
Hh - Houwhoek
Hm - Highmoor
Hu - Hutton
Ia - Inanda
Id - Idutywa
Ik - Inhoek
Im - Immerpan
Is - Iswepe
Jb - Jonkersberg
Ka - Katspruit
Kd - Kroonstad
Kf - Kransfontein
Kk - Kinkelbos
Km - Klapmuts
Kn - Knersvlakte
Ko - Kolke
Kp - Kranskop
Kr - Kromme
Ks - Koiingsnaas
Ky - Kimberley
Lc - Lichtenburg
Lg - Long Tom
Lo - Longlands
Lp - Lepellane
Lr - Lauriston
Lt - Lamotte
Ma - Magwa
Mb - Makgoba
Md - Magudu
Mf - Mfabeni
Mg - Manguzi
Mh - Makhasana
Mk - Mkuze
Mw - Milkwood
Mp - Molopo
Ms - Mispah
Mt - Motsane
Mu - Montagu
My - Mayo
Mz - Muzi
Nb - Namib
Ne - Netherley
Nh - Nhlangu
Nk - Nkonkoni
Ns - Nshawu
No - Nomanci
Oa - Oakleaf
Oh - Olienhout
Ou - Oudtshoorn
Pd - Potsdam
Pg - Pinegrove
Pl - Palala
Pm - Palmiet
Pn - Pinedene
Pr - Prieska
Py - Plooysburg
Qf - Quaggafontein
Qt - Queenstown
Rg - Rensburg
Ro - Rooiberg
Rs - Rustenburg
Sa - Sandile
Sb - Spioenberg
Sd - Shortlands
Se - Sepane
Sf - Sendelingsdrif
Sg - Stanger
Sn - Steendal
Sp - Shepstone
Sr - Sweetwater
Ss - Sterkspruit
Sv - Soutvloer
Sw - Swartland
Tb - Tubatse
Tg - Tongwane
To - Tshiombo
Tr - Trawal
Ts - Tsitsikamma
Tu - Tukulu
Um - Umvoti
Ut - Utrecht
Va - Valsrivier
Vb - Vaalbos
Vf - Vilafontes
Wa - Wasbank
We - Westleigh
Wf - Witfontein
Wo - Willowbrook
Wv - Waterval
Zo - Zondereinde

Anthropogenic soil forms

Cu - Cullinan
Gb - Grabouw
In - Industria
Jo - Johannesburg
Mr - Maropeng
St - Stilfontein
Wb - Witbank

CHAPTER 1 INTRODUCTION

1.1 Background: reconnaissance-level geotechnical assessments

The construction of any building within the Republic of South Africa must according to the *National Building Regulations and Building Standards Act* (Act No. 103 of 1977) and amended by the *Standards Act* (Act No. 30 of 1982), the *National Building Regulations and Building Standards Amendment Act* (Act No. 36 of 1984), the *National Building Regulations and Building Standards Amendment Act* (Act No. 62 of 1989), the *National Building Regulations and Building Standards Amendment Act* (Act No. 49 of 1995), and *the Mine Health and Safety Act* (Act No. 29 of 1996) comply with specific standards to ensure a safe and healthy work and living environment (Myburgh, 2018). The requirements for compliance with these standards are detailed in the various parts of SANS 10400 (2012), each corresponding with its relevant part of the National Building Regulations (Myburgh, 2018). Regulation F3, that forms part of Part A: *General Principles and Requirements* of SANS 10400 (2012), specifically refers to a requirement for the conducting of geotechnical investigations, as defined in Part B: *Structural Design* and Part H: *Foundations*, in areas where decision-makers are of the opinion that problem soils, including dolomite land, could occur (Myburgh, 2018). In order to ensure compliance with the above-mentioned standards, the National Home Builders Registration Council (NHBRC) was established through the *Housing Consumer Protection Measures Act* (Act 95 of 1998) as a regulatory authority with regard to residential development (Myburgh, 2018). The resultant Home Builders Manual (NHBRC, 2015) requires compliance with SANS 1936 (2012) for residential development on dolomite land, and with SANS 634 (2012) for the establishment of new townships primarily in so-called “green field” areas (areas where development has not yet disturbed the natural environment). A diagrammatic representation of the relevant regulatory framework as detailed above is detailed in Figure 1.1.

Section 4.1.1 of SANS 634 (2012) defines the following hierarchy regarding the conducting of geotechnical investigations:

“Geotechnical site investigations shall, as necessary, be conducted in the following sequence:

a) preliminary investigation,

b) phase 1 detailed investigation, and

c) phase 2 detailed investigation.”

It must be noted that although the above-mentioned hierarchy is no longer included in the Home Builders Manual (NHBRC, 2015), preliminary stage geotechnical investigations are still regularly requested by developers and project managers to assess the viability of a proposed development prior to the conducting of expensive supporting studies.

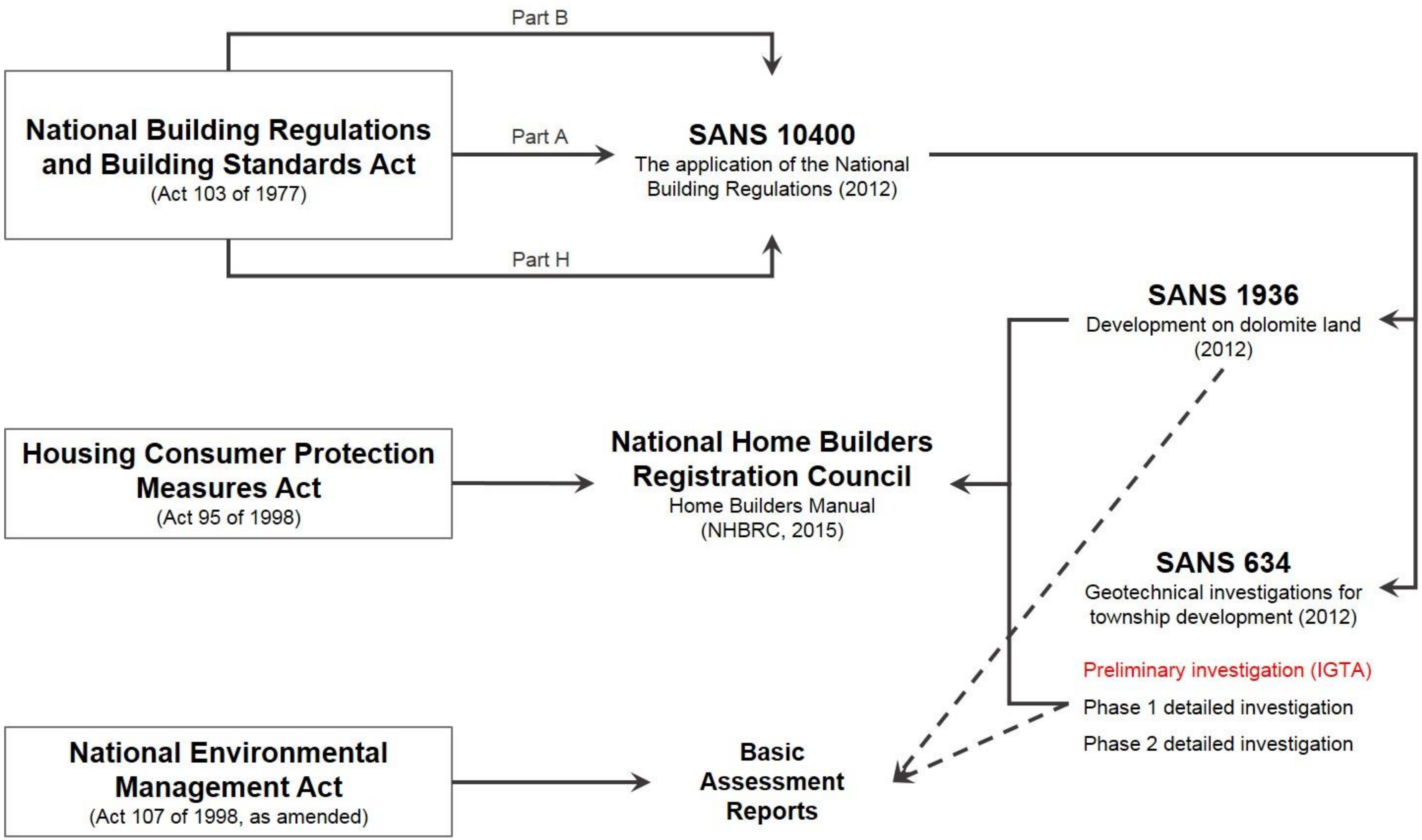


Figure 1.1: Diagrammatic representation of the regulatory framework behind the requirements for the conducting of geotechnical investigations for residential development. Note the positioning of initial geotechnical assessments (PSGI) , developed in this study, within the regulatory framework highlighted in red.

Section 4.2.1 of SANS 634 (2012) further define requirements for the conducting of preliminary investigations during the feasibility phase of proposed residential development, namely: *"The preliminary investigation is commissioned by the client to establish whether or not a parcel of land is suitable for township development."*

Additionally, section 4.2.2 of SANS 634 (2012) states that,

"The investigator shall, with respect to a parcel of land identified by the client, make an initial determination during the preliminary investigation as to whether or not such land is acceptable for the development of a township."

It is important to note that SANS 634 (2012) states that geotechnical investigations should only be undertaken under the direction of a suitably qualified and experienced person registered with the relevant approved professional institutions as specified by either the *Engineering Profession Act* (Act No. 46 of 2000), or the *Natural Scientific Professions Act* (Act No. 106 of 1993).

The results of reconnaissance-level geotechnical investigations for residential development are invariably reported against a list of standardised geological, geotechnical, and geomorphological parameters proposed by Partridge *et al*. (1993), updated and referenced by SANS 634 (2012). This allows grouping of areas covered by soils, pedogenic materials and/or outcrops or sub-outcrops of rocks deemed to have similar effects on development potential and costs.

The series of 1:50 000 scale geotechnical maps produced by the Council for Geoscience provide a comprehensive description of the regional geotechnical character of an area. This resource includes information not obtainable from pedological sources, including land type maps and memoirs, albeit limited to depicting only the most prominent factors in any given area, as well as only covering a very small percentage of the country's surface area. Application of information from these maps is generally limited to geotechnical assessments on a regional scale. Use thereof excludes the assessment of relatively small sites where location with regard to the natural morphology plays an important role in determining localised variations in geotechnical character. It must be noted that the notation utilised for the depiction of the geotechnical characteristics on these maps does not readily correspond to the parameters proposed by Partridge *et al*. (1993), requiring further interpretation to render site classifications in the format required by the NHBRC and other role players.

The phrase '*preliminary stage geotechnical investigation'* (PSGI), as defined by SANS 634 (2012), comprises the "*critical evaluation of information, with the aim of guiding decisions of an issue of public interest*" (Scholes *et al*., 2017). The results of PSGIs are essential elements in the decision-making processes that form part of initial planning with regard to the optimum placement of urban development in relation to soils and geology (Partridge *et al*., 1993, and SAIEG, 1997).

Additionally, the Geotechnical Division of the South African Institution of Civil Engineering (SAICE, 2010) states that typical major civil engineering projects, including infrastructure routes, generally commence with the conducting of a pre-feasibility investigation comprising a desktop study, with results generally verified by means of a site inspection or walkover survey.

A review of the *National Environmental Management Act* (NEMA) (Act No. 107 of 1988) and amended by the *Mineral and Petroleum Resources Development Act* (Act No. 28 of 2002 with effect from 01 May 2004), the *National Environmental Management Amendment Act* (Act No. 56 of 2002), the *National Environmental Management Amendment Act* (Act No. 46 of 2003), the *National Environmental Management Amendment Act* (Act No. 8 of 2004), *National Environment Laws Amendment Act* (Act No. 44 of 2008), the *National Environment Management Amendment Act* (Act No. 62 of 2008), the *National Environment Laws Amendment Act* (Act No. 14 of 2009), the *National Environmental Management Laws Second Amendment Act* (Act No. 30 of 2013), the *National Environmental Management Laws Amendment Act* (Act No. 25 of 2014) and the Environmental Impact Assessment Regulations (2014) revealed that these regulations do not specifically require the conducting of any type of geotechnical investigation as specialist input for environmental impact assessments (EIAs). However, environmental practitioners conducting both basic and comprehensive EIAs invariably require geotechnical reports. These inputs are generally in the form of a basic desktop or reconnaissance-type study, although detailed geotechnical investigations are also requested for development that could adversely affect the natural environment. The Basic Assessment Report (BAR) in terms of the Environmental Impact Assessment Regulations, promulgated in terms of the *National Environmental Management Act* (Act No. 107 of 1988, as amended), requires information on a number of issues regarding groundwater, soil, and geological stability of sites broadly based on the parameters proposed by Partridge *et al*. (1993), namely:

- shallow water table less than 1.5 m deep,
- dolomite, sinkhole or doline areas,
- seasonally wet soils,
- unstable rocky slopes, or steep slopes with loose soil,
- dispersive soil,
- soils with high clay content (clay fraction in excess of 40%),
- any other unstable soil or geological feature, and
- an area sensitive to erosion.

The Western Cape Provincial Department of Environmental Affairs & Development Planning (DEA&DP, 2020) requires description of the following aspects:

- shallow water table (less than 1.5 m deep),
- seasonally wet soils (often close to water bodies),
- unstable rocky slopes or steep slopes with loose soil,
- dispersive soil (soils that deflocculate in water),
- soils with high clay content,
- any other unstable soil or geological feature,
- an area sensitive to erosion,
- an area adjacent to or above an aquifer, and
- an area within 100 m of the source of surface water.

Most of the provincial departments (e.g., the Free State Department of Economic Development, Tourism and Environmental Affairs, 2020) require simple 'yes' or 'no' answers to the above-mentioned aspects, but specifies that an appropriate specialist should be appointed in cases where any of these factors are of concern. The Western Cape also allows 'unsure' as an answer, but states that specialist inputs could be required to substantiate 'yes' or 'unsure' answers (DEA&DP, 2020). The use of the published 1:50 000 scale regional geotechnical maps of the Council for Geoscience (CGS) is also allowed.

1.2 The case for use of pedological information for geotechnical purposes

Interpretation of pedological information for geotechnical purposes has been advocated by several international authors, notably Queiroz Neto (1998) and Paranhos *et al*. (2019). Queiroz Neto (1998) is of the opinion that the current reductionist approach (i.e., division of the field of soil science into distinct specialised disciplines), rather than an integrated overview of soil character, is problematic. He further argues that the value of pedological information should not be limited to agricultural development (i.e., supporting food production), but that soil character is also of importance to engineers and urban planners by influencing the behaviour of water and supporting human-made structures. In this, Queiroz Neto (1998) raises the question whether current soil classification systems are adequate to allow interpretation of pedological information by other scientists. He advocates the use of cartographic units based on the grouping together of soil profiles around a dominant soil character, while also taking its position within the landscape or location along a slope into account. According to Paranhos *et al*. (2019), the establishment of a list of reference soil horizons (i.e., a pedological referential) could allow geopractitioners to utilise pedological information for engineering purposes. Paranhos *et al*. (2019) further stated that combining pedological and geotechnical maps could lead to the definition of mapping units that group together areas with similar geotechnical characteristics mainly through interpretation of the following criteria by means of a desktop-type investigation, namely:

- Pedological aspects:
  - topsoil and sub-surface horizon types, with notes on colour, texture, structure, and porosity,
  - clay activity,
  - drainage classes,
  - vegetation,
  - topography,
  - stoniness, and
  - the presence of lateritic concretions.
- Geotechnical aspects:
  - field observations and representative laboratory test results for the area in question.
- Other aspects:
  - site characterisation by means of aerial photographs, and geological and topographical maps.

Work conducted by Baize *et al*. (2008) resulted in the establishment of a comprehensive soil classification system currently comprising 102 reference types (the so-called “Référentiel Pédologique”, abbreviated RP) based on the morphology of the solum, soil behaviour and properties, and pedogenic processes. Use of this system typically relies on recognition of soil types and its spatial (i.e., geographic) character, with detailed information on the following factors, broadly conforming to that proposed by Paranhos *et al*. (2019), required, namely:

- characterisation of the soil horizons and underlying bedrock,
- assessment of the transitions between horizons, and
- assessment of the environment in which the specific site is located.

Baize *et al*. (2008) specifically state that this system is ideally suited for mapping purposes by scientists from other disciplines.

On a national level, Netterberg (2001) stated that although the geotechnical soil profiling system used by geopractitioners differs from that of pedologists, there is a need for the development of a system that will facilitate the use of South African soils information for engineering purposes. Regional pedological mapping in South Africa is typically conducted by means of the older Binomial Soil Classification System (MacVicar *et al*., 1977) and the Taxonomical Soil Classification System (Soil Classification Working Group, 1991), and more recently the Natural and Anthropogenic Soil Classification Systems (Soil Classification Working Group, 2018). The results of a nationwide pedological mapping programme based on the former classification system is readily available in various formats through published land type maps and memoirs. Several authors (notably Harmse, 1977, Fanourakis, 1990, & Hattingh, 1995) have proposed empirical systems to infer geotechnical properties for the different soil types contained in land type classifications. However, these have not been adopted by the South African engineering geological fraternity, mainly due to its generalised nature, and a reliance on intimate knowledge of the principles behind soils mapping and the different soil classification systems of South Africa that few geotechnical practitioners are familiar with.

1.3 Problem statement

Experience shows that conducting preliminary stage geotechnical investigations (PSGIs) relies on an intimate knowledge of the industry-standard principles and guidelines, as well as the results of more detailed investigations conducted on sites exhibiting roughly similar geomorphological characteristics. Available sources of information include published regional geotechnical maps, technical reports (either within corporate libraries, or available online), and the ENGEODE database of the Council for Geoscience (CGS). It must be noted that the local morphology, climatic regime, hydropedological character, and stratigraphic setting greatly influence site-specific geotechnical characteristics, generally rendering the accurate interpolation of existing information between sites quite problematic, with a resultant significant limitation in confidence in the results of these assessments. However, based on work by national and international authors, it is postulated that regional pedological information, more commonly available in the form of the readily available, but generally overlooked, 1:250 000 scale land type maps and accompanying memoirs, could improve the accuracy and efficacy of these desktop studies.

Given that the conducting of an effective PSGI relies heavily on the personal experience of the geotechnical practitioner, the establishment of a ‘recipe’-type system allowing use of pedological information could allow practitioners outside the engineering geological fraternity to assess the geotechnical character of large areas. This would create a potentially dangerous situation for the geotechnical profession, as well as the engineers, developers and other decision-makers depending on the accuracy of this information.

In the light of the inferred importance of desktop-level geotechnical studies in a variety of applications, including EIAs, this study will explore the following problem statement:

> "Can a scientifically verifiable system be devised that will allow geotechnical practitioners in South Africa to use pedological information to enhance the accuracy and efficacy of reconnaissance-level geotechnical investigations without sacrificing the value of personal experience?"

1.4 Aims and objectives

The primary aims of the study are as follows:

- to develop a system through which generalised geotechnical characteristics based on industry-standard parameters assigned to soil types of the various South African soil classification systems are collated to facilitate the conducting of standardised reconnaissance-level geotechnical assessments on desktop-level for use by various decision-makers, including environmental practitioners involved in EIAs.
- Equally important, this research is intended to soften the inferred resistance within the South African geotechnical fraternity to a source of valuable information, currently deemed of use only in agricultural assessments, by assigning generalised geotechnical properties to pedological soil horizons through application of inferred overlaps between geotechnical and pedological principles.

To achieve these aims, the following objectives are set:

- definition of the requirements within which the proposed system is to be developed, including:
  - assessment of the various geological, geotechnical, and geomorphological parameters proposed by Partridge *et al*. (1993) and others (e.g., the NHBRC),
  - assessment of the principles on which regional soils mapping studies within the South African context are based,
  - assessment of previous attempts to assign geotechnical properties to South African pedological soil horizons,
  - assessment of the requirements for geotechnical investigations as part of the EIA processes.

- development of the refined Soils Effects Grouping (SEG) system based on:
  - expansion of the industry-standard list of adverse geotechnical effects (AGEs), each deemed to have a specific impact on the cost and/or ease of development,
  - allocation of the different AGEs inferred inherent to each of the soil forms comprising both the Binomial Soil Classification System as depicted by the land type inventories, and the Natural and Anthropogenic Soil Classification System for more recent pedological surveys,
  - grouping of the various soil forms into soil type categories (STCs), each deemed to reflect a similar inferred primary geotechnical character,
  - ranking of the STCs based on the inferred aggregated geotechnical behaviour of its' constituents to define the SEGs,
  - development of an effective format to simplify data input and facilitate ease of use, and
  - development of standardised output formats suitable for the rendering of intelligible information for use in preliminary geotechnical interpretation and zonation.
- critically appraising the accuracy and efficacy of the refined SEG system by means of:
  - comparison of the results obtained by means of an PSGI with that obtained during a detailed engineering geological investigation conducted at the same site, and
  - application thereof to aid site selection with regard to development and/or land use that could adversely affect the natural environment.

1.5 Outline of the thesis

The highly variable results of the various geological and pedological processes, and interactions thereof, provide a very broad field of study within which geotechnical practitioners have to function. The technical nature of their work often proves difficult to convey to especially non-technical decision-makers outside their field of expertise. However, the accuracy of this information is of great importance to decision-makers and environmental practitioners. The results of this research thus focus on the establishment of standardised methodology to improve the efficacy of reconnaissance-level geotechnical assessments by the rendering of more accurate results and improved communication thereof.

Chapter one of this thesis provides an overview of regulatory requirements necessitating the conducting of PSGIs to aid assessment of the feasibility of cost-effective residential development, and to prevent or limit damage to the natural environment. The technical principles behind PSGIs are briefly discussed, and pedological information that forms the primary basis for this study are also introduced. This chapter defines the problem statement and details the aims and objectives of the study.

The second chapter explores the available literature detailing the various regional soils mapping systems in use in South Africa, with specific reference to a proposed soil grouping system that allows translation of South African pedological information into an internationally recognisable format. The various influences of localised geological, climatic, and geomorphological factors on soil formation and character are detailed. Thereafter the industry-standard system utilised for the geotechnical characterisation of sites earmarked for residential development is discussed. This chapter also details the various geological, geotechnical, hydropedological, and geomorphological characteristics that could adversely affect residential development, *inter alia* establishing a repository of reference material generally utilised during the conducting of PSGIs. The chapter concludes with an assessment of previous attempts by other authors to facilitate utilisation of pedological information in geotechnical assessments, both locally and internationally.

The methodology used to conduct the research is discussed in Chapter three. The various information sources utilised during the literature study are discussed, and the consecutive steps leading up to the establishment of the SEG system listed. The development of the input and output formats is also documented, as is the reasoning behind the assessment of the efficacy of the SEG system on the hand of relevant case studies.

Chapter four details the development and refinement of the SEG system, commencing with a discussion of an older iteration of the SEG system and a gap analysis thereof to identify aspects requiring improvement and/or enhancement. This is followed by detailed descriptions of the various elements that comprise the refined SEG system.

The various aspects regarding implementation of the refined SEG system are discussed in Chapter five, including establishment, and detailing of the principles used for the dissemination of pedological information as primary data input, as well as for the rendering and interpretation of results. The chapter concludes with an example of data input, dissemination, and interpretation, and the subsequent rendering of results to illustrate the process behind application of the proposed system as a whole.

Assessment of the accuracy and efficacy of the proposed refined SEG system through the use of a number of case studies, based on pedological information obtained from the available land type inventories, is presented in Chapter six. This chapter is divided into two main sections, each focussing on application of the SEG system for a specific land use.

Chapter seven considers the outcomes of the case studies, as well as experience gained from application of the refined SEG system in practice, in terms of the stated research objectives. Benefits provided by the system are highlighted, and observed limitations are discussed. An avenue for further research that became apparent during the study is also noted.

The thesis is rounded off by a comprehensive list of references utilised during the research.

Fact sheets detailing the inferred geotechnical characteristics of the different SEGs resulting from this study for reference purposes are provided in an annexure to the thesis. These fact sheets include lists of the soil forms from both the old Binomial and new Natural and Anthropogenic soil classification systems comprising each SEG, with an indication of the broad hydropedological character of each, and the corresponding international soil classification proposed by Fey (2010) to allow broader application of the refined SEG system outside the borders of the Republic of South Africa.

Reference to a proposed article introducing and illustrating application of the refined SEG system for publication by a reputable journal is included as a separate annexure.

CHAPTER 2 LITERATURE REVIEW

2.1 Objectives

In order to evaluate the efficacy of the proposed SEG system for preliminary stage geotechnical investigations, a review of the following aspects is essential:

- As the study is primarily based on the interpretation of the results of regional pedological mapping for engineering purposes, it is necessary to review soil mapping methods utilised for both geotechnical and pedological applications in South Africa. The spatial extent, availability and level of detail offered by each method, and regulatory requirements for the conducting of preliminary stage geotechnical investigations will be highlighted. It must be noted that this study does not aim to provide a comprehensive review of the background and history of the various soil mapping techniques and information sources utilised within South Africa, or a detailed discussion on soil formation. However, a generalised discussion of the geological, climatic, and geomorphological factors that influence formation of the different soil groupings is considered relevant to enhance understanding of South African pedology. The review will also focus on the relevant aspects thereof as pertaining to the establishment and efficacy of the proposed SEG system.
- The industry-standard benchmark against which potentially adverse geotechnical properties of natural soil, weathered rock and pedocrete materials (e.g., ferricrete, calcrete, or silcrete) affecting urban development are measured, acts as the foundation on which the results of the study will be built. A thorough review of this resource is thus essential.
- The most important adverse geological and geotechnical characteristics influencing the cost and ease of urban development have to be documented for reference purposes during the conducting of PSGIs.
- As a working knowledge of the different South African soil classification systems and relevant hydropedological principles is necessary to allow use of the SEG system for the conducting of PSGIs, simplified summaries thereof will be provided for reference purposes. These will also be aimed at improving acceptance of these systems within the geotechnical fraternity.
- The results of other national and international studies aimed at utilising pedological information for geotechnical purposes will be assessed, with specific attention given to possible shortcomings contributing to a lack of application thereof within the geotechnical fraternity.

2.2 Soil mapping in South Africa

2.2.1 Introduction

Soil mapping in South Africa has in the past primarily been conducted by means of the regional land type survey programme (discussed in more detail in section 2.2.2) undertaken by the Institute of Soil, Climate and Water (ISCW) of the Agricultural Research Council (ARC) (Paige-Green & Turner, 2007). This project culminated in the establishment of the 1:250 000 scale series of land type maps and memoirs covering most of the surface area of South Africa, available in both hard copy and digital format. More recently, the emergence of precision farming practices has led to the conducting of localised, but more detailed, soil mapping, with information held by commercial and semi-commercial entities not readily available to geopractitioners (Paterson *et al*., 2015).

Cost effective and environmentally sustainable urban development is dependent upon the rapid and accurate identification of geologically or geotechnically stable land (Kleinhans, 2002). To achieve this, regional geotechnical mapping, utilising soil mapping collated with geological and geomorphological information, is conducted. Several systems, ranging from simple to very complex, have been developed for use in South Africa (Kleinhans, 2002). From a review of various regional geotechnical mapping systems, it was found that systems based on the parameters proposed by Partridge *et al*. (1993) are the most practical for the classification of land for urban planning and development (Kleinhans, 2002). The system developed in-house by the Council for Geoscience (CGS), available in hard copy format, was considered most comprehensive and useful, albeit currently still very limited in spatial coverage within South Africa.

2.2.2 Regional soils mapping for agricultural purposes (ARC)

A regional land type survey programme was initiated in 1972 with the aim to establish a nationwide inventory of the natural factors influencing agricultural potential in order to assess the country’s natural agricultural resources. These surveys focused primarily on the definition of climate, terrain form and soil type classes within previously demarcated areas for use in crop production modelling (MacVicar, 1986), culminating in the establishment of land types, representing areas that exhibit a distinct uniformity regarding climate, terrain form and soil types (Paige-Green & Turner, 2007). The land type surveys commenced with the delineation of terrain units, defined as areas exhibiting relatively homogeneous form and slope (Paige-Green & Turner, 2007) on a scale of 1:50 000 by means of existing maps and remote sensing imagery. Five main terrain units were defined (Figure 2.1):

1 ridge crest,

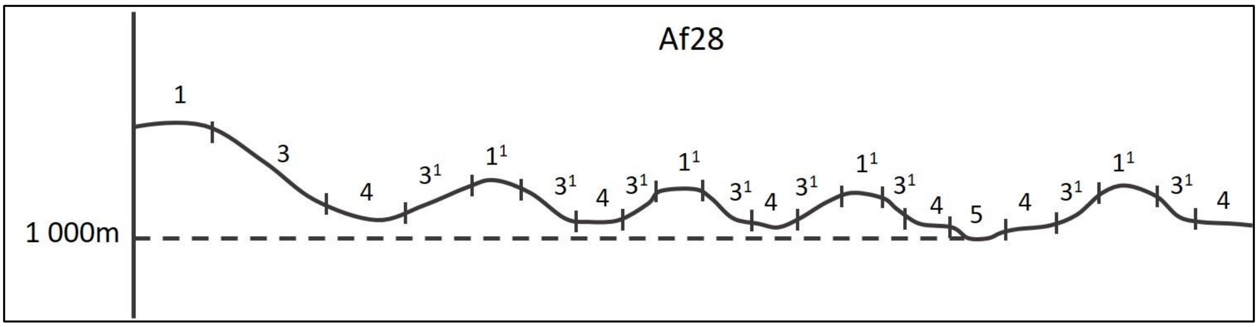
2 scarp edge,

3 mid slope,

4 foot slope, and

5 valley floor.

Finer subdivision where necessary to indicate secondary terrain formation (for example: 3^1 - mid slopes, second phase; MacVicar, 1986), as shown by Figure 2.1. It must be noted that the above-mentioned terrain units roughly correspond to (albeit on a more simplified level) the landform types, as defined by Croukamp (1996), used within the engineering geological fraternity as basic mapping units during the conducting of geotechnical mapping studies on a regional scale.



Note: terrain unit 2 - scarp edge is not depicted in this example.

Figure 2.1: Graphical representation of a typical terrain form, indicating the spatial distribution of terrain units, present within a land type, in this example for the 28th land type under the Af-soil pattern (Table 2.1).

Initial work was followed by field mapping, resulting in the definition of different soil forms within each terrain type. This work culminated in the delineation of pedosystems exhibiting relatively uniform terrain and soil patterns by taking the inter-relationship between soil types and terrain forms, as well as the influence of regional geology and topography, into account. Representative (or modal) soil profiles were then developed for each pedosystem, backed up by detailed laboratory analyses of representative soil samples, as well as follow-up field work (where required) to assist in the differentiation of soil series within the soil forms. These pedosystems were subsequently superimposed on another data set that included climate zones based on vegetation, soils, crop performance, elevation, and topography.

Distinct boundary line types were used to indicate whether each climate zone encompasses either a portion of a pedosystem, a whole pedosystem, or more than one pedosystem, as this has a bearing on agricultural potential assessments. Broader soil groupings (named patterns) were used to number the land types in order to create a collective legend for the planned maps (e.g., Af28 describes the 28th land type included under the Af-soil pattern). Table 2.1 provides a summary of these generalised soil patterns. The land type survey programme eventually stretched over a period of approximately 30 years, including every part of the country, with the results thereof triggering significant advancements in soil classification (Paterson *et al*., 2015).

The resultant land type inventory comprises a series of 1:250 000 scale maps accompanied by corresponding booklets/ memoirs (a typical example is provided in Figure 2.2). Printed and digital copies of the land type maps have been included in the GIS-based Environmental Potential Atlas for each Province (Department of Environmental Affairs and Tourism, 2002), and available for purchase from the Institute for Soil, Climate and Water (ISCW) of the Agricultural Research Council (ARC) via their webpage (ARC-ISCW, 2019). Additionally, the Department of Agriculture, Forestry and Fisheries (DAFF) has recently re-activated an online version of the whole inventory providing free access to the relevant inventories contained within the Comprehensive Atlas Version 2 available through their webpage (DAFF, 2019).

The different types of information of specific interest to this study provided by each of these inventories are illustrated by the relevant sections highlighted in Figure 2.3 (A to H), and includes:

- A: Land type designation, with terrain units and prominence thereof within the land type.
- B: Diagrammatical depiction of regional terrain form, description of average slopes, and regional geological setting.
- C: List of soil forms, soil/ rock complexes, and rock.
- D: Prominence of soil forms, soil/ rock complexes and rock within each terrain unit, provided as both surface area and percentage.
- E: Depth extent of diagnostic soil horizons comprising soil forms, and soil/ rock complexes.
- F: Indication of depth limiting materials underlying diagnostic horizons (where available).
- G: Indication of stoniness and/or shallowness of diagnostic horizons (mechanical limitations).
- H: Clay content as percentage provided for both the topsoil horizons (e.g., A and E) and those occurring at depth (B21).

Table 2.1: Generalised soil patterns used in land type maps and memoirs.

Symbols	Generalised Soil Pattern Descriptions
Aa	Red and yellow apedal, freely drained soils, with humic soils covering > 40% of area.
Ab	Red apedal, freely drained, soils that have undergone leaching.
Ac	Red and yellow apedal, freely drained, soils that have undergone leaching.
Ad	Yellow apedal, freely drained, soils that have undergone leaching.
Ae	Red apedal, freely drained soils > 300 mm thick that have undergone little or no leaching, without regular occurrence of dunes.
Af	Red apedal, freely drained soils > 300 mm thick that have undergone little or no leaching, with regular occurrence of dunes.
Ag	Red apedal, freely drained, soils that have undergone little or no leaching.
Ah	Red and yellow apedal, freely drained, soils that have undergone little or no leaching.
Ai	Yellow apedal, freely drained, soils that have undergone little or no leaching.
Ba	Plinthic catena, uplands duplex and/or margalitic soils rare, with red and/or yellow apedal soils that have undergone leaching dominant.
Bb	Plinthic catena, uplands duplex and/or margalitic soils rare, with mainly yellow apedal soils that have undergone leaching dominant.
Bc	Plinthic catena, uplands duplex and/or margalitic soils rare, with mainly red apedal soils that have undergone little or no leaching dominant.
Bd	Plinthic catena, uplands duplex and/or margalitic soils rare, with mainly yellow apedal soils that have undergone little or no leaching dominant.
Ca	Plinthic catena, uplands duplex and/or margalitic soils common.
Da	Prismacutanic and/or pedocutanic diagnostic horizons dominant, with more than 50% of the duplex soils exhibiting red B-horizons.
Db	Prismacutanic and/or pedocutanic diagnostic horizons dominant, with more than 50% of the duplex soils exhibiting non-red B-horizons.
Dc	Prismacutanic and/or pedocutanic diagnostic horizons dominant, but with > 10% of the soils containing vertic, melanic, and/or red structured, horizons.
Ea	One or more vertic, melanic, or red structured diagnostic horizons.
Fa	Glenrosa and/or Mispah soil forms, where the soils generally do not contain lime.
Fb	Glenrosa and/or Mispah soil forms, where the soils along valley bottoms generally contain lime.
Fc	Glenrosa and/or Mispah soil forms, where the soils in uplands and along valley bottoms generally contain lime.
Ga	Soils with a diagnostic Ferrihumic horizon, dominated by the Lamotte soil form.
Gb	Soils with a diagnostic Ferrihumic horizon, dominated by the Houwhoek soil form.
Ha	Grey regic sands, with mainly deep grey sands covering > 80% of area.
Hb	Grey regic sands, with deep grey sands covering 20-80% of area; soils of patterns *Fa* - *Fc* may be dominant.
Ia	Miscellaneous land classes, with pedologically youthful, deep (> 1 000 mm to underlying rock), unconsolidated deposits covering at least 60% of area.
Ib	Miscellaneous land classes, with exposed rock covering 60-80% of area.
Ic	Miscellaneous land classes, with exposed rock covering > 80% of area.

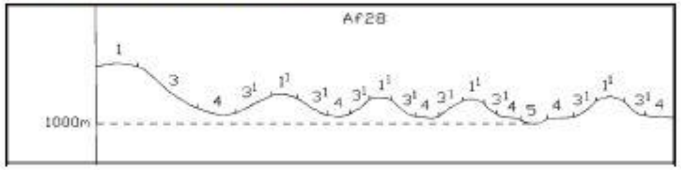
LAND TYPE / *LANDTIP* .... : **Af28**	Occurrence (maps) and areas *Voorkoms (kaarte) en oppervlakte :*		Inventory by *Inventaris deur :*
CLIMATE ZONE *KLIMAATSONE* ...... : 5S	2722 Kuruman (56870 ha)		J F Eloff & S W J Idema
Area / *Oppervlakte* .... : 56870 ha			Modal Profiles *Modale profiele :*
Estimated area unavailable for agriculture			None / Geen
Beraamde oppervlakte onbeskikbaar vir landbou : 690 ha			

Terrain uni ***Terreineenhei*** .... :	1	1(1)	3	3(1)	4	5
% of land type *% van landtipe* .... :	0.5	12	1	28	58	0.5
Area *Oppervlakte (ha)* .... :	284	6824	569	15924	32985	284
Slope / *Helling (%)* .... :	0 - 1	0 - 2	15 - 30	15 - 50	0 - 1	0 - 1
Slope length *Hellingslengte (m)* .... :	50 - 100	20 - 40	200 - 600	40 - 70	200 - 1000	100 - 300
Slope shape *Hellingsvorm* .... :	Z-Y	Z-Y	Z	Z-Y	Z	Z
MB0, MB1 (ha) .... :	0	6824	0	15924	32985	171
MB2 - MB4 (ha) .... :	284	0	569	0	0	114

Soil series or land classes *Grondseries of landklasse*	**Depth** *Diepte* (mm)	MB	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	**Total** *Totaal* ha	%	**Clay content %** *Klei-inhoud %* A	E	B21	**Texture** *Tekstuur* Hor	Class / *Klas*	**Depth limiting material** *Diepte-beperkende materiaal*
Rock / Rots		4	284	100			569	100							853	1.5						
Roodepoort Hu30, Mangano Hu33, Zwartfontein Hu34	600-1200+	0									32985	100			32985	58.0	2-4		4-8	B	fi/meSa	ka,R
Gaudam Hu31, Roodepoort Hu30	>1200	0			6824	100			15924	100					22748	40.0	1-2		2-4	B	fi/meSa	
Killarney Ka20	100-300	0											170	60	171	0.3	20-50		25-50	B	fiSaClLm-SaCl	gc
Kalkbank Ms22	100-250	3											114	40	114	0.2	4-8			A	fiSa	ka

Terrain type ***Terreintipe :*** B3

Terrain form sketch*Terreinvormskets*



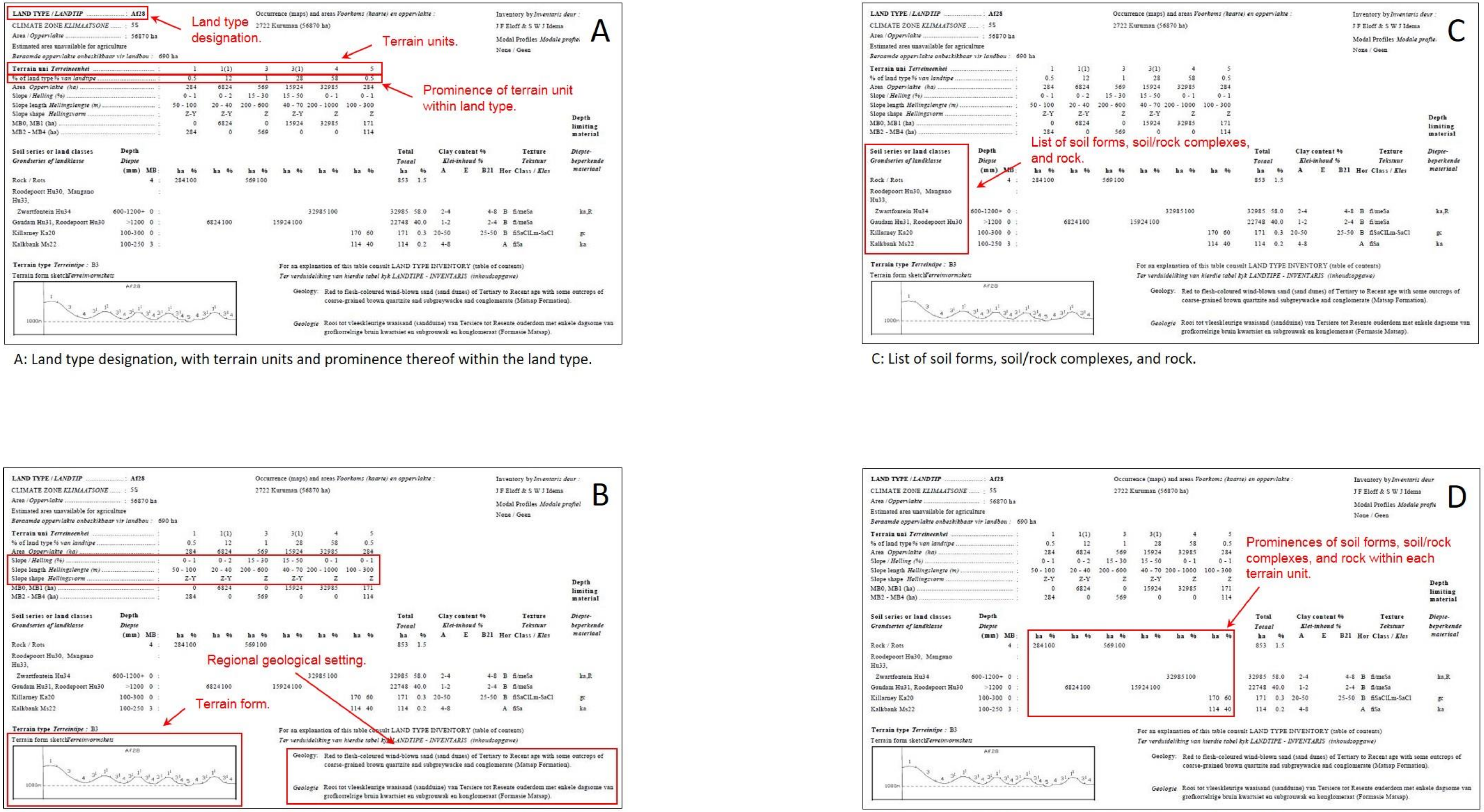
For an explanation of this table consult LAND TYPE INVENTORY (table of contents)

Ter verduideliking van hierdie tabel kyk LANDTIPE - INVENTARIS (inhoudsopgawe)

Geology: Red to flesh-coloured wind-blown sand (sand dunes) of Tertiary to Recent age with some outcrops of coarse-grained brown quartzite and subgreywacke and conglomerate (Matsap Formation).

Geologie Rooi tot vleeskleurige waaisand (sandduine) van Tersiere tot Resente ouderdom met enkele dagsome van grofkorrelrige bruin kwartsiet en subgrouwak en konglomeraat (Formasie Matsap).

Figure 2.2: Land Type Af28 as an example of a typical Land Type Inventory (obtained from the now-obsolete AGIS National Resource Atlas website, accessed in 2014).



Terrain uni *Terreineenheid*	1	1(1)	3	3(1)	4	5
% of land type % *van landtipe*	0.5	12	1	28	58	0.5
Area *Oppervlakte (ha)*	284	6824	569	15924	32985	284
Slope / *Helling (%)*	0 - 1	0 - 2	15 - 30	15 - 50	0 - 1	0 - 1
Slope length *Hellingslengte (m)*	50 - 100	20 - 40	200 - 600	40 - 70	200 - 1000	100 - 300
Slope shape *Hellingsvorm*	Z-Y	Z-Y	Z	Z-Y	Z	Z
MB0, MB1 (ha)	0	6824	0	15924	32985	171
MB2 - MB4 (ha)	284	0	569	0	0	114

Soil series or land classes *Grondseries of landklasse*	Depth *Diepte* (mm)	MB	ha %	ha %	ha %	ha %	ha %	ha %	Total *Totaal* ha	%	Clay content % *Klei-inhoud %* A	E	B21	Hor	Texture *Tekstuur* Class / *Klas*	Depth limiting material *Diepte-beperkende materiaal*
Rock / Rots		4	284 100		569 100				853	1.5						
Roodepoort Hu30, Mangano Hu33,																
Zwartfontein Hu34	600-1200+	0					32985 100		32985	58.0	2-4		4-8	B	fi/meSa	ka,R
Gaudam Hu31, Roodepoort Hu30	>1200	0		6824 100		15924 100			22748	40.0	1-2		2-4	B	fi/meSa	
Killarney Ka20	100-300	0						170 60	171	0.3	20-50		25-50	B	fiSaClLm-SaCl	gc
Kalkbank Ms22	100-250	3						114 40	114	0.2	4-8			A	fiSa	ka

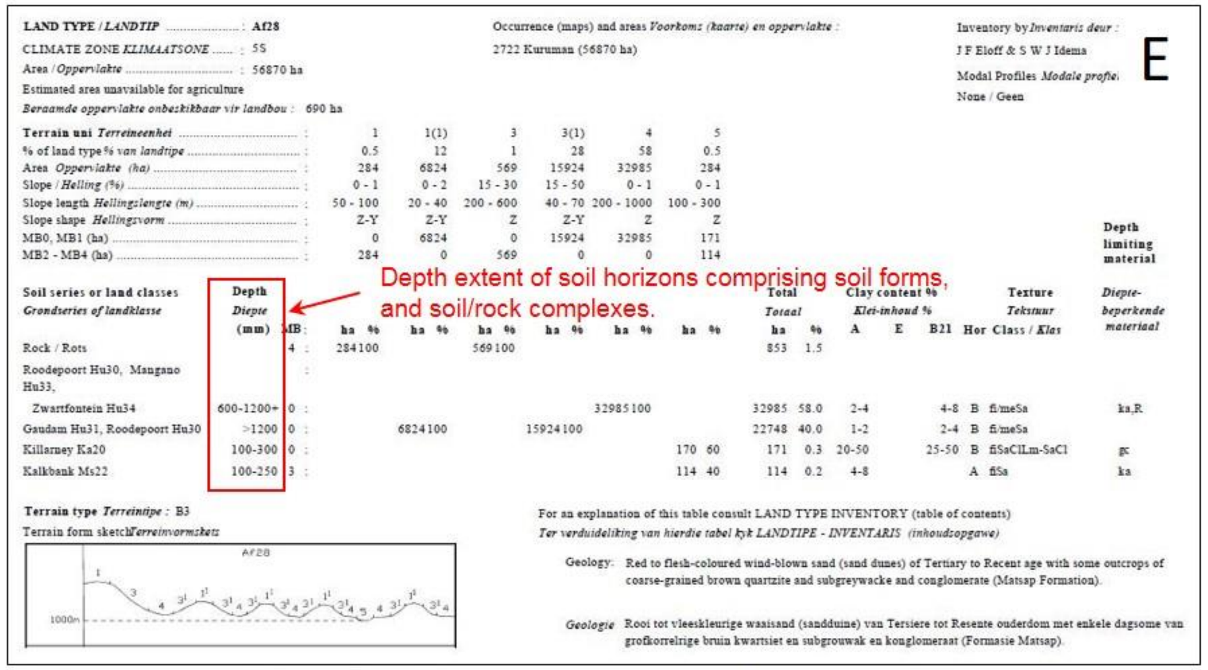
A: Land type designation, with terrain units and prominence thereof within the land type.

C: List of soil forms, soil/rock complexes, and rock.

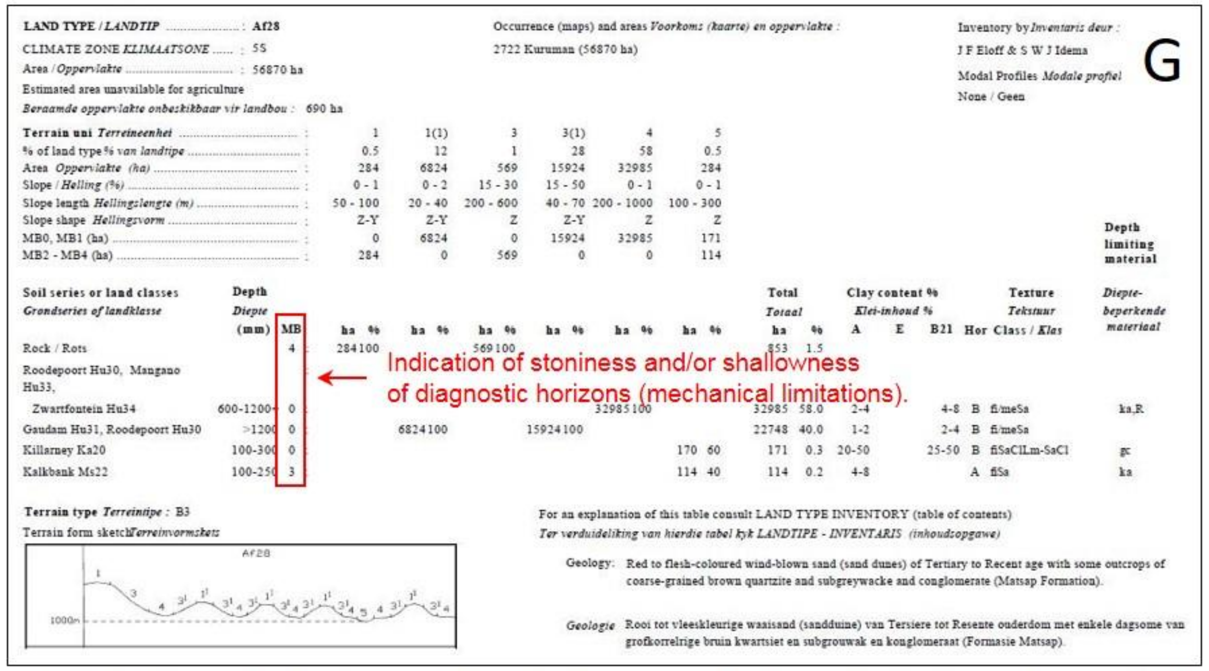
B: Diagrammatical depiction of regional terrain form, description of average slopes, and regional geological setting.

D: Prominence of soil forms, soil/rock complexes and rock within each terrain unit, provided as both surface area and percentage.

Figure 2.3: Breakdown of the various elements comprising the inventory for Land Type Af28.

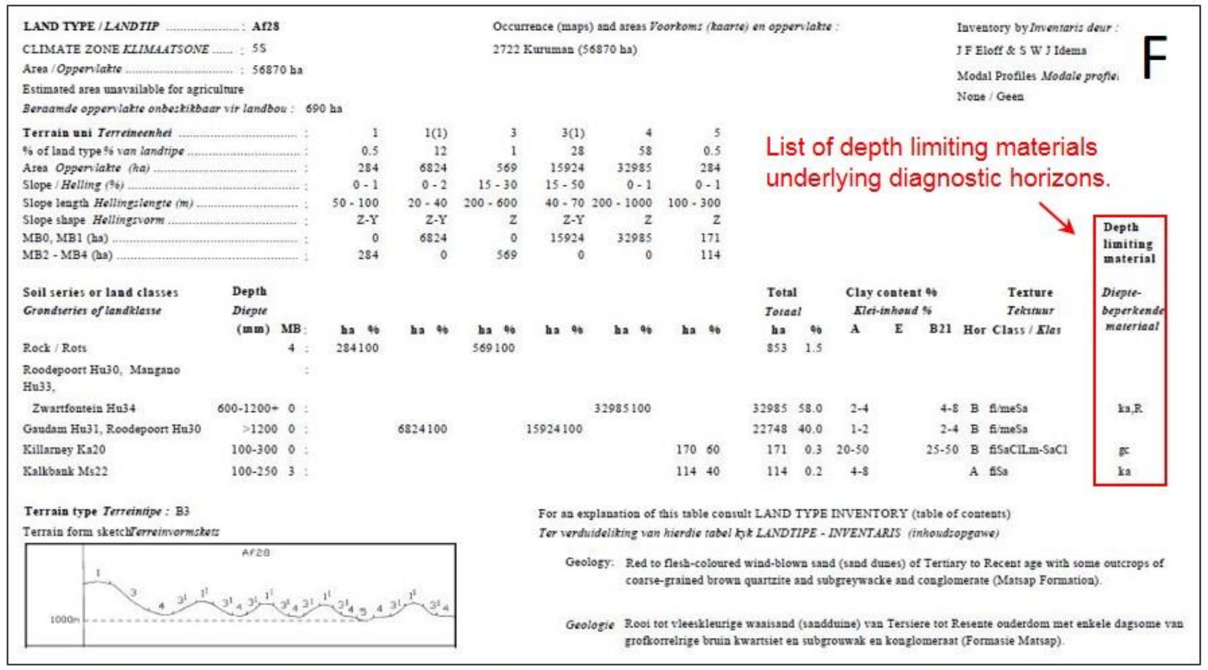


E: Depth extent of diagnostic soil horizons comprising soil forms, and soil/rock complexes.

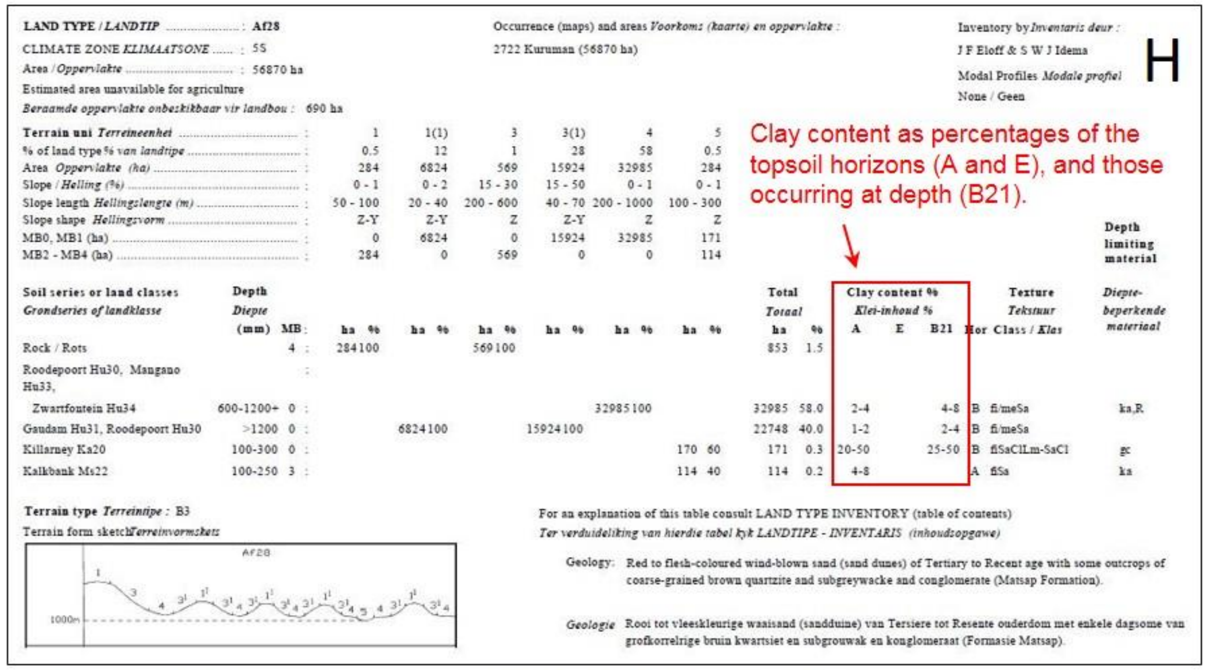


G: Indication of stoniness and/or shallowness of diagnostic horizons (mechanical limitations), namely:

MB0: No mechanical limitations, MB1: many stones, but ploughable,
MB2: large stones & boulders, unploughable, MB3: very shallow soil on rock, and
MB4: lack of soil.



F: Indication of depth limiting materials underlying diagnostic horizons (where available). The glossaries of both the Binomial and Taxonomical Soil Classification System handbooks provide an explanation of the various symbols.



H: Clay content as percentage provided for both the topsoil horizons (e.g., A and E) and those occurring at depth (B21).

Figure 2.3: (continued): Breakdown of the various elements comprising the inventory for Land Type Af28.

2.2.3 Engineering geological mapping for urban development by the Council for Geoscience

Kleinhans (2002) summarised the processes behind a regional mapping programme started in the early 1980s to compile a series of geological and geotechnical maps on a scale of 1:50 000 to support regional planning policies in a readily understandable manner. Since the early 2000s, this programme continued under the auspices of the Council for Geoscience (CGS) (Kleinhans, 2003; and Johnson & Joubert, 2004). The aim of this programme was to provide information to aid future land-use planning, to indicate potential sources of natural materials suitable for use in the construction industry, and to establish a database of borehole and test pit logs for use in site-specific investigations (Johnson & Joubert, 2004).

Compilation of these maps involved the following (Kleinhans, 2003; and Johnson & Joubert, 2004):

- STAGE 1: Delineation of landform types on 1:10 000 scale orthophotographs based on aerial photographic analysis, after which existing geotechnical information in the form of borehole- and test pit logs and laboratory test results from the Council for Geoscience's ENGEODE database were added to the relevant landforms.
- STAGE 2: Field mapping and sampling, with additional laboratory test, were conducted to verify landform delineation and the accuracy of existing test pit logs and geotechnical information.
- STAGE 3: The existing information, landform delineation, and the results of the additional test pit logging and laboratory tests, as well as geological, geohydrological and topocadastral information, were interpreted and collated, resulting in the compilation of the 1:50 000 scale maps and accompanying reports.
- STAGE 4: The maps and reports were subsequently digitised by means of suitable Geographical Information Systems (GIS) for spatial analysis and storage.

This system relies on the identification of 13 geotechnical factors (Kleinhans, 2003; and Johnson & Joubert, 2004), with the overall effect of each on land-use within any specific area of landform assessed in terms of not only the dominant geotechnical characteristic, but also including all additional factors, culminating in a ranked list of critical and subcritical factors (Table 2.2). Distinct mapping units, each defining an area exhibiting a unique combination of geotechnical factors as highlighted in Table 2.2, are indicated by a code on the 1:50 000 scale maps, thus allowing quick identification of the critical and subcritical geotechnical factors, as well as the associated severity thereof, for a specific study area. This ranking allows preliminary assessment of the financial implication of each geotechnical factor on the cost of development.

Table 2.2: List of geotechnical factors illustrated by the Council for Geoscience's 1:50 000 scale geotechnical series maps (after Kleinhans, 2003; and Johnson & Joubert, 2004).

Severity classes and codes	Description	Financial cost	Environ. implication
CRITICAL FACTORS			
Rank 1 Inundation (flooding)			
Inu2 *area at risk*	Area that experiences flooding by either: (1) flood-water volumes that exceed the channel carrying capacity, in which case the flood waters move out and onto the flood plain that is usually present on both sides of the channel, or (2) sheetwash where flooding is unrelated to a channel and occurs as unconfined flow.	-	High
Rank 2 Sinkhole formation			
Sin2 *area susceptible*	A closed depression of less than 2 m to larger than 10 m in diameter that is formed either by solution of surface carbonate, such as limestone or dolomite, or by the collapse of underground caves. The formation of sinkholes is a natural process. However, the incidence and size of sinkholes is dependent on factors such as the type of carbonate, the rate of solution caused by leaking water pipes and the lowering of water levels in underground caves by excessive pumping.	High	-
Rank 3 Slope instability			
Slo2 *unstable slope*	Area comprising unstable geological materials that could move either gradually (creep), or suddenly as a slump or a slide. The risk of movement is determined by factors such as the nature of the slope (solid rock, colluvial material), gradient of slope, role of water, type and nature of vegetation cover, seismicity and impact of human activities such as undermining of a slope.	Moderate to High	-
Rank 4 Active, expansive or swelling soils			
Act2 *could be present* *Act3* *low expansion expected* *Act4* *moderate expansion expected* *Act5* *high expansion expected*	The amount of expansion in mm (expressed as total soil heave) that can be expected when the moisture in the soil changes. Moisture changes can be due to seasonal changes in rainfall or changes in the level of groundwater due to abstraction, drainage changes or river modification.	High	-
Rank 5 Excavatability of ground			
Exc2 *anticipated (unspecified)* *Exc3* *slight problems: hand-dug* *Exc4* *moderate problems: backactor* *Exc5* *severe problems: blasting / power tools*	The ease with which ground can be dug to a depth of 1.5 m.	High	-
Rank 6 Collapsing or settling of soil			
Col2 *present, but unspecified* *Col3* *low potential (1-5% vol. decrease)* *Col4* *moderate potential (5-10% vol. decrease)* *Col5* *severe potential (10-20% vol. decrease)* *Col6* *very severe potential >20% vol. decrease)*	The extent to which a soil collapses, settles or decreases in volume (expressed as percentage decrease in soil volume) when a load is applied (such as a single-storey house) and an increase in soil moisture occurs. This problem affects mainly open-textured silty- and sandy soils. The amount of settlement depends on the size of load, the amount of moisture in the soil and the structure of the soil.	Moderate	-

Table 2.2: (continued): List of geotechnical factors illustrated by the Council for Geoscience's 1:50 000 scale geotechnical series maps (after Kleinhans, 2003; and Johnson & Joubert, 2004).

Severity classes and codes	Description	Financial cost	Environ. implication
SUBCRITICAL FACTORS			
Rank 7 Subsidence			
Sub2 *induced problems anticipated*	Area has or is likely to experience collapse or subsidence due to either ongoing or abandoned underground mining activities. Where underground mining is deeper than approximately 250 m, induced subsidence at surface is not considered a problem.	**High**	**-**
Rank 8 Erodible soil			
Ero2 *erosional features present*	The extent to which a soil can be eroded by water flow and wind. The erosional feature may be local, such as erosional channels, dongas, gulleys and piping, or it may be of a more regional extent.	Low	High
Rank 9 Dispersive soil			
Dis2 *dispersive (observations in the field)* *Dis3* *slight dispersive reaction in water* *Dis4* *moderate dispersive reaction in water* *Dis5* *strong dispersive reaction in water*	A dispersive soil is prone to disaggregation or deflocculation in contact with water. The dispersivity of the soil is a measure of its susceptibility to erosion. Soil dispersivity is dependent on the mineralogy and chemistry of the soil, water contained in the soil and the eroding water. A simple laboratory test is done to assess a soil's dispersivity. A dispersive soil is likely to develop erosional features similar to those noted for erodible soil.	Low	Low
Rank 10 Acidic soil			
Aci2 *present*	Soils that exhibit pH-values of less than 5 (7 being neutral). Acidic soils can occur naturally (estimated to be greater than 14% of South Africa's land area) or be induced by, for example, acid mine drainage associated with mine rock dumps and slimes dams.	Low	Low
Rank 11 Poorly consolidated soil			
Con2 *present*	Poorly consolidated or highly compressible soils are expected to have low bearing capacities, and therefore liable to differential settlement. Examples of highly compressible materials are area of fills, such as dumping grounds and peat deposits at surface or at depth. The amount of settlement is dependent on the applied load (such as a single-storey house), the moisture content and structure of the soil.	Moderate to High	-
Rank 12 Shallow water table			
Sha2 *present*	A shallow water table is one where the top of the permanently saturated zone occurs close to the ground surface. This definition also includes a perched water table where geological conditions result in a local zone of saturation that is far above the regional water table.	-	High
Rank 13 Permeability of soil			
Per2 *low (> 4x10-6 to 9x10-10 cm/s)* *Per3* *medium (> 4x10-4 to 4x10-6 cm/s)* *Per4* *high (> 4x10-4 cm/s)*	The permeability of a soil is a measure of how easily fluids (usually water) pass through the soil and is related to the degree at which the pores or spaces of the soil are connected to each other. The permeability of the soil is geologically controlled by factors such as the shapes of the mineral grains in the soil, their grain size and the manner in which the grains are held together.	-	High

Some factors (for example: active, expansive, or swelling soils) requiring significant financial input to alleviate or reduce its impact (Table 2.2). Additionally, it also provides an indication of the implied effect of proposed development on each of these factors with regard to the natural environment (Table 2.2), for example: development of an area exhibiting a shallow water table could lead to groundwater contamination (Kleinhans, 2003, and Johnson & Joubert, 2004).

Five financial cost-environmental categories were subsequently established, ranked to indicate an increasing influence of environmental implications, namely:

Category 1 Financially related geotechnical factors,

Category 2 Mainly financially related geotechnical factors with some environmental factors,

Category 3 Combination of financial- and environmentally related geotechnical factors,

Category 4 Mainly environmentally related geotechnical factors and a small number of factors with a low financial cost, and

Category 5 Predominantly environmentally related geotechnical factors.

Each unique geotechnical area depicted on the 1:50 000 scale maps is identified by a colour and composite code, for example in the extract from the 1:50 000 scale 2528CD Rietvlei Dam geotechnical map (CGS, 2001) (Figure 2.4):

$$\mathbf{1^2}$$

where: 1 indicates an area where Act4 and Exc4 conditions (critical), as well as Per2 conditions (subcritical), can be expected (Figure 2.4), and

^{2} indicates the occurrence of a dominant geotechnical factor (in this case, Act) plus one critical and one or more subcritical factors (Figure 2.4).

According to Kleinhans (2002), the 1:50 000 scale geotechnical maps provide a relatively comprehensive overview of the regional geotechnical character of an area based on the most important factors of interest to decision makers and environmental practitioners. However, the published maps at present number only 13 (less than 1% of the total surface area of the country) and predominantly cover portions of some urban centres (i.e., Cape Town, Johannesburg, Polokwane, and Tshwane), and as such urban development in rural areas has to either rely on other sources of regional geotechnical information or require time-consuming site-specific mapping. However, the CGS has embarked on a multi-year program to expand the coverage of the 1:50 000 scale geotechnical maps within the borders of South Africa (Meintjes, 2019).

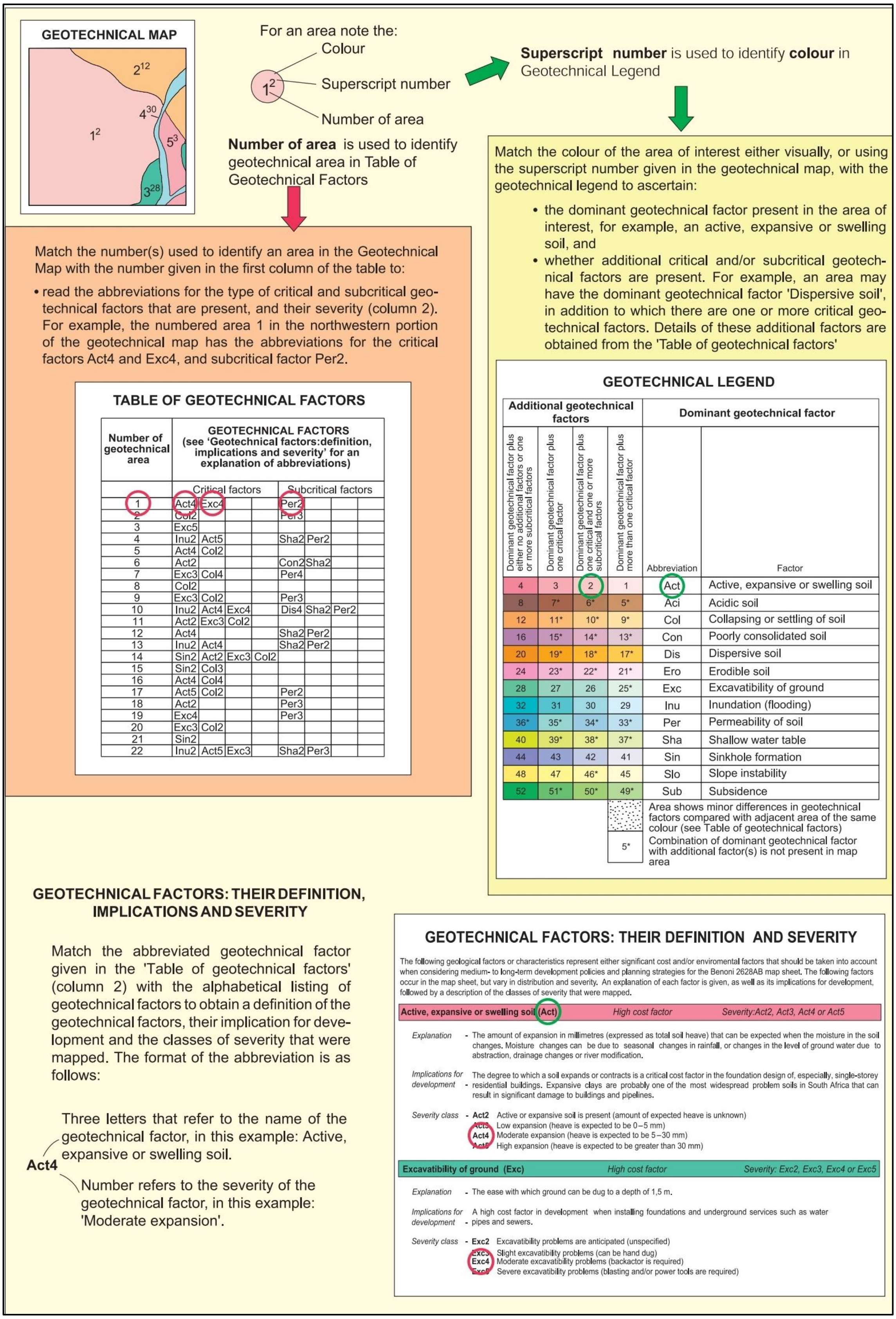


Figure 2.4: Recommended method for the utilisation of information from the Council for Geoscience's 1:50 000 scale 2528CD Rietvlei Dam geotechnical map (Kleinhans, 2003).

2.2.4 Regulatory requirements

In 2002 the National Department of Housing published a set of generic specifications to provide guidance for the conducting of geotechnical investigations for 'project-linked greenfield subsidy project developments' (National Department of Housing GFSH-2, 2002). These standards defined a '*Preliminary (Phase 1) Geotechnical Site Investigation*', intended to assess whether a land parcel earmarked for residential development is suitable for project-linked subsidy development.

The GFSH-2 specifications stated that the preliminary investigations should only be undertaken under the direction of a suitably qualified and experienced person registered with the relevant approved professional institutions as specified by either the Engineering Profession Act (Act No. 46 of 2000), or the Natural Scientific Professions Act (Act No. 106 of 1993).

However, the GFSH-2 standards were subsequently replaced by SANS 634 (2012) that requires assessment of the following generalised geotechnical site characteristics during preliminary site investigations:

- a discussion of the process behind the delineation of preliminary geotechnical zones (also named terrain mapping units) with reference to the classification system proposed by Partridge *et al*. (1993),
- inclusion of a locality map showing site boundaries, coordinates, and property descriptions,
- inclusion of topographical- and geological maps overlaid by the site boundaries,
- a discussion of the generalised geotechnical characteristics of the covering soils, with specific reference to the presence of outcrops, based on the interpretation of maps and remote sensing images, available information from other investigations in the area, and observations made during walk-over surveys or inspections,
- a description of any significant physical surface soil conditions (e.g., floodplains, erosion dongas, undrained depressions, or talus slopes) present within the study area,
- a discussion of perceived surface drainage within the study area, including comments on the presence of prominent water courses,
- an assessment of the possibility of seasonal or prolonged groundwater seepage,
- a discussion of the structural integrity of existing structures within the study area (where present) as indicators of the possible presence of problem soils, and
- a detailed drawing of the study area showing the resultant preliminary geotechnical zones based on the system proposed by Partridge *et al*. (1993).

Table 2.3: List of geotechnical Site Classes (after NHBRC, 2015).

TYPICAL FOUNDING MATERIAL	CHARACTER OF FOUNDING MATERIAL	EXPECTED RANGE OF TOTAL SOIL MOVEMENT (mm)	SITE CLASS
Rock, excluding mud rocks which could exhibit swelling to some depth.	Stable	Negligible	R
Fine-grained soils with moderate to very high plasticity: clays, silty clays, clayey silt, and sandy clays.	Expansive soils	< 7.5 7.5 - 15 15 - 30 > 30	H H1 H2 H3
Silty sands, sands, and sandy and gravelly soils.	Compressible and potentially collapsible soils	< 5 5 - 10 > 10	C C1 C2
Fine-grained soils: clayey silts and clayey sands of low plasticity; sands, and sandy and gravelly soils.	Compressible soils	< 10 10 - 20 > 20	S S1 S2
Contaminated soils; Controlled fill; Dolomitic areas; Landslip; Landfill; Marshy areas; Mine waste fill; Mining subsidence; Reclaimed areas; Uncontrolled fill; and Very soft silts/ silty clays.	Variable	Variable	P

In some cases, limited fieldwork, mainly comprising a walk-over survey and the inspection of exposed soil- and rock layers within existing trenches or excavations, is conducted to corroborate desktop study results. A more comprehensive field survey could significantly increase the cost of such a study.

The results of detailed geotechnical investigations are reported in terms of site classes (Table 2.3) each defining a specific geotechnical constraint with recommended remedial measures specified by the NHBRC (2015) to classify individual plots or specific geotechnical zones within townships for design and construction purposes. However, this falls outside the scope of preliminary stage geotechnical investigations.

The results of detailed geotechnical investigations are also used to calculate generic subsidy variations to allow for adverse site and founding conditions prior to residential development, as provided by the Home Builders Manual (NHBRC, 2015). The suite of parameters used in these calculations are detailed in Table 2.4.

Table 2.4: List of generic subsidy variation parameters for site and founding conditions as included in the Home Builders Manual (NHBRC, 2015).

CATEGORY	SUBCATEGORY		PARAMETER USED AS A BASIS FOR THE DETERMINATION OF THE SUBSIDY VARIATION
Seepage/ groundwater	Category 1		Permanent or perched water table less than 1.0 m below ground level.
	Category 2		Permanent or perched water table more than 1.0 m, but less than 1.5 m below ground level.
Erodibility of soil	Category 1 (high risk)		An erodibility index of 1 – 8 and USCS classification of the upper 750 mm of SP (sand poorly graded), SM (silty sand), CL (inorganic clays of low to medium plasticity) or CH (inorganic clays of high plasticity) and ground slope greater than 1:7.5 (± 6˚), or degree of dispersion greater than 40%.
	Category 2 (low risk)		An erodibility index of 9 – 15 and USCS of the upper 750 mm of SP, SM, CL or CH, and ground slope greater than 1:7.5 (± 6˚), or degree of dispersion greater than 40%.
Hard excavation	Category 1		Hard rock excavation (i.e., material that cannot be removed without blasting or wedging and splitting) as% to a depth of 1.5 m.
	Category 2		Boulder excavation (material containing boulders ranging in size between 0.03 and 20 m^3) to a depth of 1.5 m.
Dolomite area designations	D1		No precautionary measures are required.
	D2		Precautionary measures and dolomite risk management are required to maintain a tolerable hazard rating.
	D3		Precaution measures and dolomite risk management in addition to that described for dolomite area designation D2 are required to achieve a tolerable hazard rating.
	D4		Precaution measures and dolomite risk management in addition to that described for D3 rarely enables a tolerable hazard rating to be achieved.
Site class designation	Expansive soils	H1 H2 H3	Designation in terms of Table 2.3.
	Compressible and potentially collapsible soils	C1 C2	
	Compressible soils	S1 S2	
	P(mining subsidence)	Category 1	Old undermining to a depth of between 90 and 240 m below the surface where stope closure has ceased.
		Category 2	Mining within a depth of between 90 and 240 m below the surface, or where total extraction has taken place.
Topography of site	Category 1		Average ground slope flatter than 1:100 (± 0.5˚).
	Category 2		Average ground slope of between 1:20 (± 2˚) and 1:10 (± 4.5˚).
	Category 3		Average ground slope of between 1:10 (± 4.5˚) and 1:7.5 (± 6˚).
	Category 4		Average ground slope of between 1:7.5 (± 6˚) and 1:5 (± 9˚).
	Category 5		Average ground slope of more than 1:5 (± 9˚).
	Not classified		Average ground slope of between 1:100 (± 0.5°) and 1:20 (± 2˚) does not require implementation of remedial measures, and as such is not deemed eligible for variation funding.

USCS: Unified Soil Classification System (Holtz & Kovacks, 1981).

2.2.5 The geotechnical classification system proposed by Partridge *et al*. (1993)

The geotechnical classification system proposed by Partridge *et al*. (1993), as detailed in Table 2.5, comprises a decision-making matrix that assesses the perceived influence (classified as Class 1 - most favourable, Class 2 - intermediate, and Class 3 - least favourable) of 12 geotechnical constraints (numbered from A - least problematic, to K - severely problematic) as part of a reconnaissance-level geotechnical investigation with regard to proposed residential development.

This assessment is conducted for each preliminary geotechnical zone within a study area, which is given a series of alphanumeric labels reflecting the assumed level of effect for each relevant constraint based on the inferred geotechnical characteristics of that specific area (Partridge *et al*., 1993). Explanation of an example of this classification (Figure 2.5, with symbols from Table 2.5) is shown here:

$$\mathbf{1_{A,E,K} \quad 2_{D,I} \quad 3_{F}}$$

where:

1_A: indicates that pockets of potentially collapsible material less than 750 mm thick are expected,

1_E: indicates that low erodibility is expected,

1_K: indicates that there is a less than 10% probability of a seismic event < 100 cm/s^2 within 50 years,

2_D: indicates that moderate soil compressibility is expected,

2_I: indicates that slopes of less than 2° are expected, and

3_F: indicates that in excess of 40% of the volume of material to a depth of 1.5 m is expected to comprise hard rock and/or hardpan pedocrete.

However, it must be noted that this system does not provide decision-makers with guidance regarding the re-use potential of the natural materials to be encountered during development, the trafficability of the site during construction, and the assumed occurrence of self-mulching soil and/or slaking rock.

2.3 South African soil classification systems

2.3.1 Introduction

C.R. van der Merwe undertook the first systematic collation of the available pedological information in South Africa in the early 1930s (Paterson *et al*., 2015). Advances in agricultural

Zone A1*: $1_{C,K}$ $2_{E,I}$ $3_{D,F}$ or S2 H/H1 (R)

Most favourable: low soil-heave expected, and
low seismicity expected.

Intermediate: intermediate erodibility, and
slopes of < 2°.

Least favourable: high soil compressibility expected, and
rock/hardpan pedocrete expected to comprise
> 40% of volume of material to 1.5 m

Zone A2*: $1_{C,K}$ $2_{A,B,E,I}$ $3_{D,F}$ or C2 H/H1 (R)

Most favourable: low soil-heave expected, and
low seismicity expected.

Intermediate: potentially collapsible material > 0.75 m thick,
seepage associated with perched water table
possible at a depth of < 1.5 m,
intermediate erodibility, and
slopes of < 2°.

Least favourable: high soil compressibility expected, and
rock/hardpan pedocrete expected to comprise
> 40% of volume of material to 1.5 m

Figure 2.5: Example of a preliminary geotechnical zonation map with zonal designations as required by SANS 634 (2012) (Calitz, 2020a).

techniques and practices, especially with regard to the cultivation of sugar cane along the KwaZulu-Natal coast in the 1950s, prompted more detailed soils mapping on a national scale. This culminated in the establishment of the first formal hierarchical soil classification system that became the South African Binomial Soil Classification System (BSCS) (MacVicar *et al*., 1977; and Paterson *et al*., 2015). Over time, further research has led to the establishment of the Taxonomical Soil Classification System (TSCS) (Soil Classification Working Group, 1991). The advent of Digital Soil Mapping (DSM) and other technological advances matured into a new soil classification system, the Natural and Anthropogenic System for South Africa (NASCS) (Soil Classification Working Group, 2018).

Table 2.5: Geotechnical classification for urban development (Partridge *et al*. 1993).

CONSTRAINT		1 (most favourable)	2 (intermediate)	3 (least favourable)
A	**Collapsible soil**	Any collapsible horizon or consecutive horizons totalling a depth of less than 750 mm in thickness.	Any collapsible horizon or consecutive horizons with a depth of more than 750 mm in thickness.	A 'least favourable' situation for this constraint does not occur.
B	**Seepage**	Permanent or perched water table more than 1.5 m below ground surface.	Permanent or perched water table less than 1.5 m below ground surface.	Swamps and marshes.
C	**Active soil**	Low soil-heave potential anticipated.	Moderate soil-heave potential anticipated.	High soil-heave potential anticipated.
D	**Highly compressible soil**	Low soil compressibility anticipated.	Moderate soil compressibility anticipated.	High soil compressibility anticipated.
E	**Erodibility of soil**	Low.	Intermediate.	High.
F	**Difficulty of excavation to 1.5 m depth**	Scattered to occasional boulders less than 10% of total volume.	Rock or hardpan pedocretes between 10% and 40% of total volume.	Rock or hardpan pedocretes more than 40% of total volume.
G	**Undermined ground**	Undermining at a depth greater than 200 m below surface (except where total extraction mining has not occurred).	Old undermined areas to a depth of 200 m below surface where stope closure has ceased.	Mining within less than 200 m of surface, or where total extraction mining has taken place.
H	**Stability (dolomite land)**	Possibly stable. Areas of dolomite overlaid by Karoo rocks or intruded by sills. Areas of Black Reef rocks. Anticipated inherent hazard class 1 (see Part 2 of SANS 1636, 2012).	Potentially characterised by instability. Anticipated inherent hazard classes 2 to 5 (see Part 2 of SANS 1636, 2012).	Known sinkholes and dolines (subsidences). Anticipated inherent hazard classes 6 to 8 (see Part 2 of SANS 1636, 2012).
I	**Steep slopes**	Between 2 and 6˚ (all regions).	Slopes between 6° and 18˚ and less than 2° (KwaZulu-Natal and Western Cape); and Slopes of between 6° and 12˚ and less than 2° (all other regions).	More than 18˚ (KwaZulu-Natal and Western Cape); and More than 12˚ (all other regions)
J	**Areas of unstable natural slopes**	Low risk.	Intermediate risk.	High risk (especially in areas subject to seismic activity).
K	**Areas subject to seismic activity**	10% probability of an event less than 100 cm/s^2 within 50 years.	Mining-induced seismic activity more than 100 cm/s^2.	Natural seismic activity more than 100 cm/s^2.
L	**Areas subject to flooding**	A 'most favourable' situation for this constraint does not occur.	Areas adjacent to known drainage channel or floodplain with slope of less than 1%.	Areas within known drainage channel or floodplain.

In the light of the wealth of information regarding the character and thickness of the soil-like overburden and pedocrete occurrences, as well as bedrock conditions, presented by pedological surveys describing roughly the same materials of interest to geopractitioners, it is proposed that both the older BSCS and the new NASCS for South Africa provide powerful tools in determining and understanding the nature and behaviour of the soil-like material of specific interest to geotechnical practitioners, with future advances in the field of pedology also benefiting the geotechnical fraternity.

2.3.1 Binomial Soil Classification System

The Binomial Soil Classification System for the mapping of soils in South Africa was devised based on the science behind soil formation. This was in contrast to the development of separate systems for specific applications (e.g., agriculture or engineering) used in other parts of the world (MacVicar *et al*., 1977). This classification system relies on the grouping of a series of seven master horizons, as summarised in Table 2.6, that differentiates into five diagnostic topsoil- and 15 subsoil horizons (Figure 2.6) based on differences in soil structure, texture, appearance, composition, and origin stemming from soil forming processes. Combinations of these soil horizons define a total of 41 soil forms (Table 2.7), with further differentiation based on clay content, lime content, colour and/or discoloration, degree of leaching and pH describing 504 soil series. The vertical succession of soil layers to a maximum depth of roughly 1.2 m at any given location is thus described as both a Soil Form and Soil Series.

2.3.2 Taxonomical Soil Classification System

Although the Taxonomical Soil Classification System (Soil Classification Working Group, 1991) provides much more detailed soils information, and has been extensively used for at least two decades, soils mapping based on this system, especially on a regional scale, is not readily available to geotechnical practitioners as these are generally privately funded and owned. The additional soil forms that form part of this system have been incorporated into the new Natural and Anthropogenic System for South Africa (Soil Classification Working Group, 2018).

The 73 TSCS soil forms were grouped into broad soil groups by Fey (2010), as discussed in more detail in section 2.3.4.

Table 2.6: Summary of the master horizons according to the Binomial Soil Classification System (MacVicar *et al*., 1977).

HORIZON	CONCEPTS FOR IDENTIFICATION
O	Accumulation of organic material at surface; under saturated or partially saturated conditions, with: O1: undecomposed loose leaves and litter, and O2: partially decomposed organic matter, in some cases mixed with mineral matter.
A	Mineral horizon at surface containing variable amounts of humified organic matter.
E	Mineral horizon occurring beneath an A- or O-horizon exhibiting lower colloidal matter content and pale colours, with a relative accumulation of quartz in the sand- and silt fractions; alternatively exhibits light colour and significant eluviation of colloidal clay.
B	Mineral horizon occurring between A- or E-horizons and C- or R-horizons; exhibiting highly variable range of characteristics, including concentration of silicate clay, sesquioxides, and lime, absence of original rock structure, and development of weak- to strong structure (crumb, granular, blocky, or prismatic).
C	Unconsolidated material defining the transition between soil and unaltered bedrock.
R	Consolidated hard rock.
G	Soil layer exhibiting grey, low chroma matrix colours, in some cases with blue/ green tints, as a result of a strong reduction regime under anaerobic conditions.

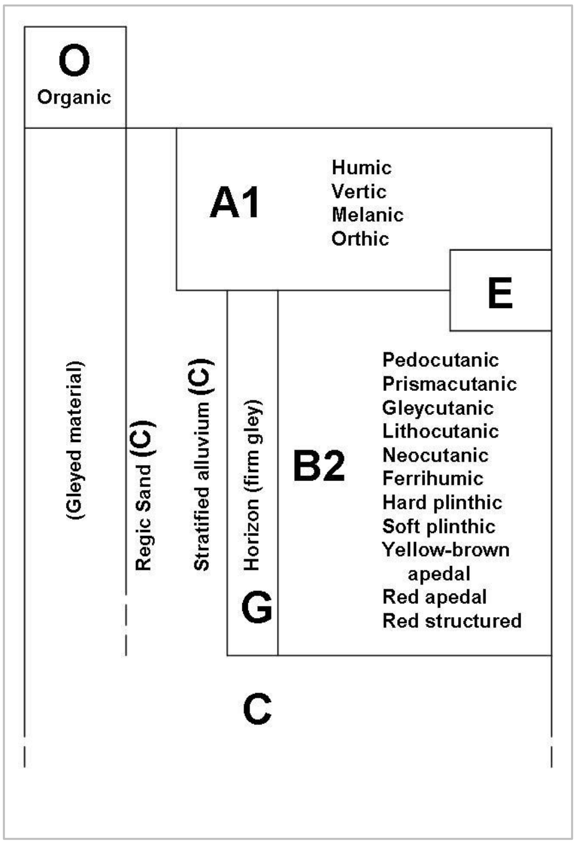


Figure 2.6: Diagrammatic view of the diagnostic horizons of the pedological profile recognised by the Binomial Soil Classification System (after MacVicar *et al*., 1977).

Table 2.7: List of soil forms comprising the Binomial Soil Classification System (MacVicar *et al*., 1977).

SUBSOIL HORIZONS AND MATERIALS	DIAGNOSTIC TOPSOIL HORIZONS				
	Organic	**Humic**	**Vertic**	**Melanic**	**Orthic**
gleyed material	Champagne				
G-horizon			Rensburg	Willowbrook	Katspruit
pedocutanic B/ saprolite					Swartland
pedocutanic B/ unconsolidated material					Valsrivier
pedocutanic B/ unspecified				Bonheim	
prismacutanic B					Sterkspruit
E-horizon/ prismacutanic B					Estcourt
E-horizon/ gleycutanic B					Kroonstad
E-horizon/ yellow-brown apedal B					Constantia
E-horizon/ red apedal B					Shepstone
E-horizon/ neocutanic B					Vilafontes
E-horizon/ ferrihumic B					Houwhoek
E-horizon/ ferrihumic B / unconsolidated material					Lamotte
E-horizon/ lithocutanic B					Cartref
E-horizon/ hard plinthic B					Wasbank
E-horizon/ soft plinthic B					Longlands
soft plinthic B				Tambankulu	Westleigh
yellow-brown apedal B/ soft plinthic B					Avalon
yellow-brown apedal B/ hard plinthic B					Glencoe
yellow-brown apedal B/ gleycutanic B					Pinedene
yellow-brown apedal B/ red apedal B		Kranskop			Griffen
yellow-brown apedal B		Magwa			Clovelly
red apedal B/ soft plinthic B					Bainsvlei
red apedal B		Inanda			Hutton
red structured B					Shortlands
neocutanic B				Inhoek	Oakleaf
regic sand					Fernwood
stratified alluvium				Inhoek	Dundee
lithocutanic B		Nomanci		Mayo	Glenrosa
hard rock/ hardpan ferricrete, calcrete or silcrete/ dorbank				Milkwood	Mispah
unspecified			Arcadia		

2.3.3 Natural Soils and Anthropogenic Materials Classification System

Advances in the field of Soil Science since 1991 have led to the development of a greatly enhanced third edition of the South African soil classification system, namely Soil Classification: A Natural and Anthropogenic System for South Africa (Soil Classification Working Group, 2018). The new system was developed primarily to reflect the importance of soil as a natural entity. A secondary aim was to stimulate interest in the observation and classification of the soil mantle affecting agriculture, hydrology, and the environment, with the results of research regarding the effects of the lateral movement of profile water being of particular importance (Soil Classification Working Group, 2018). A depth limit of 1.5 m was selected to represent the maximum extent for soil form classification. Allowance was made to incorporate the influence of agricultural- and environmental issues on the soil-to-substratum interface and deep substratum continuum in line with new insights in soil taxonomy worldwide (Soil Classification Working Group, 2018). Additionally, application of this limit waives the need to distinguish two subsoil horizons during soil classification. Changes regarding the principles and structure of the new soil classification system include the following of interest to this study (Soil Classification Working Group, 2018):

- The classification system allows for differentiation between natural soils and anthropogenic materials.
- The classification of soils relies on an ‘open system’ that allows inclusion of additional soil horizons beyond those comprising the standard soil forms, thus facilitating description of whole observable soil profiles, rather than being limited to the depth extent allowed for the standard soil forms. This also allows for the description of partially exposed soil profiles.
- Prior restrictions on the position and sequence of diagnostic horizons, strictly classified according to the relevant criteria, have been relaxed, allowing a more accurate description of the properties of a given soil profile.
- A peat horizon, comprising inundated or permanently saturated organic carbon-rich material, has been introduced.
- More prominence is given to indications of soil wetness and/or inundation (gleying) within soil diagnostic horizons.
- The bleached character of certain sub-surface horizons that contain more clay than the overlying layer and undergo periodic saturation while acting as conduits for the lateral movement of soil water, is emphasised (replacing the definition of the former E-horizon where emphasis was placed in colloidal clay eluviation).
- Podzolic characteristics of soils have been granted more prominence in classification (e.g., the occurrence of a plagic plan, and Ortstein hardening).

- Differences in lithic characteristics have been expanded to allow differentiation between saprolithic, geolithic and gleylithic materials.
- The definition of hard rock now allows differentiation between fractured and solid rock.
- The occurrence of relatively thick unconsolidated material exhibiting signs of wetness that does not allow classification as a gley, gleyic or albic horizon, has been accommodated.

The Natural and Anthropogenic Soil Classification System for South Africa is applied as follows (Soil Classification Working Group, 2018):

- Soil materials are initially separated into one of two soil orders, namely:
    - natural soils, and
    - anthropogenic materials.
- The system is primarily based on the definition of soil forms, each comprising a unique vertical succession of diagnostic horizons, defined as follows:
    - Topsoil horizon underlaid by a single gley or indurated subsoil horizon (i.e., hard plinthite, hard carbonate, hard gypsic, dorbank, lithic, and hard rock).
    - Topsoil horizon underlaid by a single diagnostic subsoil horizon extending to a depth of at least 1.5 m.
    - NOTE: the designation of soil forms based on the identification of a single subsoil horizon to a depth of less than 1.5 m, or due to observational limitations, could change if additional information becomes available. Recording of the lower soil depth is, however, then required as a suffix to the soil form name/ code.
    - Topsoil horizon underlaid by two diagnostic subsoil horizons, with the second subsoil horizon extending to a depth in excess of 1.5 m.
    - The presence of additional diagnostic soil horizons beneath the third horizon can be progressively added as suffixes to the soil form name/ code.
- Each soil form is further subdivided into soil families that share the common properties of that soil form, but reflecting variations based on other, less prominent properties.

  NOTE: The system makes provision for the subdivision of soil families into soil series, based on specific soil and/or location-specific properties yet to be defined in the future.

- Classification of an exposed soil profile can be according to any of the following scenarios:

  Scenario 1 Classification of topsoil horizon only.

  Scenario 2 Classification of a topsoil horizon, followed by a gley/ indurated horizon.

Scenario 3 Classification of a topsoil horizon and two diagnostic subsurface horizons.

Scenario 4 Classification of a topsoil and a single thick diagnostic subsurface horizon.

Scenario 5 Classification of a topsoil horizon on a single subsurface horizon to limited depth (limiting depth stated after soil name to indicate provisional status).

Natural soil designations comprise the soil form name (either in full or abbreviated) and family code, followed by any additional diagnostic horizons (again either in full or abbreviated) where present, ending with the limiting depth quoted in brackets (where relevant), for example: Av2210/al/gl (260 cm).

The diagnostic topsoil and subsurface soil layers comprising the 135 natural soil forms are provided in Table 2.8 and Table 2.9 respectively, with the adverse character of the seven anthropogenic soil forms excluding these from further discussion for the purposes of this study.

2.3.4 Discussion of the general character of South African soils according to Fey (2010)

In order to allow translation of the unique South African pedological information into generalised terminology corresponding to the Soil Taxonomy and World Reference Base (WRB) systems in use by pedological practitioners internationally, Fey (2010a and 2010b) introduced a number of soil groups broadly based on internationally recognised pedological qualifier terms. Distinction between these groups is primarily based on the type of topsoil horizon present, or the specific sub-soil horizon or material underlying an orthic topsoil horizon.

Additionally, Fey (2010a) discussed the chemical and physical properties, genesis, and use of the various soil groups. It must, however, be noted that no reference in literature could be found regarding the translation of the newly added NASCS soil forms into WRB terminology; an endeavour that falls outside the scope of this study.

The soil groups defined by Fey (2010a) are discussed in more detail in the following paragraphs, and includes reference to TSCS soil forms, correlating international nomenclature (Fey, 2010b), climatic regime, position in the landscape, stratigraphic origins (where noted), and brief comments on its behaviour of importance to the aims of this study.

The various soil forms according to the TSCS placed within each of the above-mentioned groups (Fey, 2010) and the corresponding NASCS soil forms inferred as part of this study, with the corresponding basic WRB soil classification (FAO, 2014), are provided in Table 2.10.

Table 2.8: List of diagnostic horizons according to the Natural and Anthropogenic Soil Classification System (Soil Classification Working Group, 2018).

Horizon	Critical concepts for identification
TOPSOILS	
peat	Very high organic carbon; dark; wet.
organic	High organic carbon; dark; wet.
vertic	Moderate to strong, coarse blocky structure; dark; slickensides; cracks.
melanic	Moderate to strong, blocky structure; dark; slickensides absent.
humic	Dark; carbon-rich; apedal to weak structure; freely drained.
orthic	None of the above; may be dark, chromic or bleached.
SUBSOILS	
gley	Grey colours (blue-grey in sands); luvic character; apedal to weak structure; little mottling; often wet.
albic	Grey colours; apedal to weak structure; few mottles (< 10%).
gleyic	Grey colours; moderate to strong structure; gley colour variation on ped exteriors.
yellow-brown apedal	Uniform yellow and brown colouring; apedal to weak structure; non-calcareous.
red apedal	Uniform red colouring; apedal to weak structure; non-calcareous.
red structured	Uniform red colouring; moderate to strong structure; red cutans.
soft plinthic	Accumulation of Fe/ Mn mottles (> 10%); grey colours in or below horizon; apedal to weak structure.
hard plinthic	Accumulation of vesicular Fe/ Mn mottles; cemented.
podzol	Enriched with iron and organic matter; commonly dark; occurs in the southern Cape.
plagic pan	Thin, wavy; hardened; dark; occurs in association with podzols in the southern Cape.
prismacutanic	Structured; vertical prisms; abrupt transition; absence of gleying.
pedocutanic	Structured (moderate to strong); blocky; absence of gleying.
neocutanic	Apedal to weak structure; colour variegation; not gleyed; non-calcareous.
neocarbonate	Calcareous (though soil material dominates horizon); apedal to weak structure; colour variegation; absence of gleying.
soft carbonate	Carbonate material dominates horizon (often powdery or nodular); colour variegation; absence of gleying.
hard carbonate	Cemented, calcareous layer; usually hard to very hard; little soil present; occurs in semi-arid to arid areas.
gypsic	Powdery or crystalline gypsum accumulation; may be cemented; occurs in arid areas.
dorbank	Cemented, siliceous layer; usually hard to very hard; little soil present; occurs in arid areas.
alluvial	Unconsolidated; apedal to weak structure; usually has fine striations; may contain wetness; often in low-lying areas.
unconsolidated material with wetness	Unconsolidated; apedal to weak structure; irregular texture variations; gleyed.
regic sand	Recent aeolian deposit; sandy; little or no structure; usually grey to red colours; dunes may occur.
lithic	Dominantly weathering rock material; some soil will be present.
hard rock	Rock material; no soil; may be fractured or solid.

Table 2.9: List of natural soil forms according to the Natural and Anthropogenic Soil Classification System (Soil Classification Working Group, 2018).

Topsoil horizon	Subsoil horizon	Subsoil horizon	Form	Code
PEAT TOPSOIL				
peat	gley	-	Mfabeni	Mf
	albic	-	Nhlangu	Nh
	hard carbonate	-	Muzi	Mz
	hard rock	-	Kromme	Kr
ORGANIC TOPSOIL				
organic	gley	-	Champagne	Ch
	albic	-	Manguzi	Mg
	hard carbonate	-	Makhasana	Mh
	hard rock	-	Didema	Dd
VERTIC TOPSOIL				
vertic	gley	-	Rensburg	Rg
	pedocutanic (thick)		Glen	Gl
	soft carbonate	gley	Zondereinde	Zo
	soft carbonate	hard carbonate	Dwaalboom	Dw
	soft carbonate	lithic	Bakwena	Bk
	hard carbonate	-	Waterval	Wv
	alluvial (thick)		Mkuze	Mk
	lithic	-	Arcadia	Ar
	hard rock	-	Rustenburg	Rs
MELANIC TOPSOIL				
melanic	gley	-	Willowbrook	Wo
	red structured	lithic	Stanger	Sg
	pedocutanic	gleyic	Lauriston	Lr
	pedocutanic	alluvial	Potsdam	Pd
	pedocutanic	lithic	Darnall	Da
	pedocutanic (thick)		Bonheim	Bo
	neocutanic (thick)		Abbotspoort	Ab
	soft carbonate	-	Steendal	Sn
	hard carbonate	-	Immerpan	Im
	alluvial (thick)		Inhoek	Ik
	lithic	-	Mayo	My
	hard rock	-	Milkwood	Mw
HUMIC TOPSOIL				
humic	yellow-brown apedal	gleyic	Dartmoor	Dm
	yellow-brown apedal	red apedal	Kranskop	Kp
	yellow-brown apedal	soft plinthic	Eland	El
	yellow-brown apedal	lithic	Longom	Lg
	yellow-brown apedal (thick)		Magwa	Ma
	red apedal	gleyic	Highmoor	Hm
	red apedal	soft plinthic	Netherley	Ne
	red apedal	lithic	Gangala	Ga
humic (continued)	red apedal (thick)		Inanda	Ia
	neocutanic	soft plinthic	Umvoti	Um
	neocutanic	lithic	Henley	He
	neocutanic (thick)		Sweetwater	Sr
	lithic	-	Nomanci	No
	hard rock	-	Graskop	Gp
ORTHIC TOPSOIL				
orthic	gley	-	Katspruit	Ka
	albic	gley	Kroonstad	Kd
	albic	yellow-brown apedal	Constantia	Ct
	albic	red apedal	Shepstone	Sp
	albic	neocutanic	Vilafontes	Vf
	albic	soft plinthic	Longlands	Lo
	albic	hard plinthic	Wasbank	Wa
	albic	podzol with plagic pan	Tsitsikamma	Ts
	albic	podzol/ unconsolidated material with wetness	Lamotte	Lt
	albic	podzol/ lithic	Houwhoek	Hh
	albic	podzol	Concordia	Cc
	albic	prismacutanic	Estcourt	Es
	albic	pedocutanic	Klapmuts	Km
	albic	neocarbonate	Kinkelbos	Kk
	albic	lithic	Cartref	Cf
	albic	hard rock	Iswepe	Is
	albic (thick)		Fernwood	Fw
	yellow-brown apedal	gleyic	Pinedene	Pn
	yellow-brown apedal	albic	Kransfontein	Kf
	yellow-brown apedal	red apedal	Griffen	Gf
	yellow-brown apedal	neocutanic	Palmiet	Pm
	yellow-brown apedal	soft plinthic	Avalon	Av
	yellow-brown apedal	hard plinthic	Glencoe	Gc
	yellow-brown apedal	soft carbonate	Molopo	Mp
	yellow-brown apedal	hard carbonate	Askham	Ak
	yellow-brown apedal	lithic	Clovelly	Cv
	yellow-brown apedal	hard rock	Carolina	Ca
	yellow-brown apedal (thick)		Ermelo	Er
	red apedal	gleyic	Bloemdal	Bd
	red apedal	neocutanic	Tongwane	Tg
	red apedal	soft plinthic	Bainsvlei	Bv
	red apedal	hard plinthic	Lichtenburg	Lc
	red apedal	soft carbonate	Kimberley	Ky
	red apedal	hard carbonate	Plooysburg	Py
	red apedal	dorbank	Garies	Gr

Table 2.9: (continued): List of natural soil forms according to the Natural and Anthropogenic Soil Classification System (Soil Classification Working Group, 2018).

Topsoil horizon	Subsoil horizon	Subsoil horizon	Form	Code
orthic (continued)	red apedal	lithic	Nkonkoni	Nk
	red apedal	hard rock	Vaalbos	Vb
	red apedal (thick)		Hutton	Hu
	red structured	lithic	Magudu	Md
	red structured	hard rock	Nshawu	Ns
	red structured (thick)		Shortlands	Sd
	soft plinthite	gleyic	Westleigh	We
	hard plinthite	-	Dresden	Dr
	podzol with plagic pan	-	Jonkersberg	Jb
	podzol	unconsolidated material with wetness	Witfontein	Wf
	podzol	lithic	Groenkop	Gk
	podzol	-	Pinegrove	Pg
	prismacutanic	gleyic	Idutywa	Id
	prismacutanic	pedocutanic	Heilbron	Hb
	prismacutanic	alluvial	Utrecht	Ut
	prismacutanic	lithic	Sandile	Sa
	prismacutanic	hard rock	Cookhouse	Ck
	prismacutanic (thick)		Sterkspruit	Ss
	pedocutanic	gleyic	Sepane	Se
	pedocutanic	alluvial	Queenstown	Qt
	pedocutanic	lithic	Swartland	Sw
	pedocutanic	hard rock	Spioenberg	Sb
	pedocutanic (thick)		Valsrivier	Va
	neocutanic	gleyic	Tukulu	Tu
	neocutanic	pedocutanic	Erin	En
	neocutanic	neocarbonate	Makgoba	Mb
	neocutanic	soft carbonate	Etosha	Et
	neocutanic	hard carbonate	Gamoep	Gm
	neocutanic	gypsic	Soutvloer	Sv
	neocutanic	dorbank	Oudtshoorn	Ou
	neocutanic	unconsolidated material with wetness	Tshiombo	To
	neocutanic	alluvial	Quaggafontein	Qf
	neocutanic	lithic	Tubatse	Tb
	neocutanic	hard rock	Bethesda	Be
	neocutanic (thick)		Oakleaf	Oa
	neocarbonate	pedocutanic	Palala	Pl
	neocarbonate	soft carbonate	Addo	Ad
	neocarbonate	hard carbonate	Prieska	Pr
	neocarbonate	gypsic	Sendelingsdrif	Sf
	neocarbonate	dorbank	Trawal	Tr
	neocarbonate	unconsolidated material with wetness	Montagu	Mu

Topsoil horizon	Subsoil horizon	Subsoil horizon	Form	Code
orthic (continued)	neocarbonate	alluvial	Motsane	Mt
	neocarbonate	lithic	Burgersfort	Bg
	neocarbonate	hard rock	Hofmeyer	Hf
	neocarbonate (thick)		Augrabies	Ag
	soft carbonate	unconsolidated material with wetness	Kolke	Ko
	soft carbonate	hard carbonate	Olienhout	Oh
	soft carbonate	gypsic	Koiingsnaas	Ks
	soft carbonate	-	Brandvlei	Br
	hard carbonate	-	Coega	Cg
	gypsic	-	Rooiberg	Ro
	dorbank	-	Knersvlakte	Kn
	alluvial (thick)		Dundee	Du
	unconsolidated material with wetness (thick)		Lepellane	Lp
	regic sand (thick)		Namib	Nb
	lithic	-	Glenrosa	Gs
	hard rock	-	Mispah	Ms

Table 2.10: Grouping of soil forms of the Taxonomical Soil Classification System (Soil Classification Working Group, 1991) proposed by Fey (2010), with corresponding World Reference Base (WRB) classification (Fey, 2010, and FAO, 2014).

SOIL GROUP	**IDENTIFYING CHARACTERISTIC**	**WORLD REFERENCE BASE (WRB) CLASSIFICATION WITH SOUTH AFRICAN SOIL FORMS** **Taxonomical Soil Classification System (TSCS)**
Organic	Organic horizon: wetland peat.	HISTOSOLS: Ch - Champagne
Humic	Humic horizon: humus enriched, free-draining.	ACRISOLS: Lu - Lusiki, No - Nomanci CAMBISOLS: Sr - Sweetwater FERRALSOLS: Ia - Inanda, Kp - Kranskop, Ma - Magwa
Vertic	Vertic horizon: expansive, cracked clay.	VERTISOLS: Ar - Arcadia, Rg - Rensburg
Melanic	Melanic horizon: black clay.	CHERNOZEMS: Bo - Bonheim, Sn - Steendal FLUVISOLS: Ik - Inhoek GLEYSOLS: Wo - Willowbrook LEPTOSOLS: Mw - Milkwood LIXISOLS: My - Mayo PHAEOZEMS: Im - Immerpan
Silicic	Orthic horizon underlaid by dorbank horizon: silica enrichment in arid areas.	DURISOLS: Gr - Garies, Kn - Knersvlakte, Ou - Oudtshoorn, Tr - Trawal
Calcic	Orthic horizon underlaid by soft carbonate or hard carbonate horizon: carbonate / gypsum enriched in arid areas.	CALCISOLS: Ad - Addo, Ak - Askham, Br - Brandvlei, Cg - Coega, Et - Etosha, Gm - Gamoep, Ky - Kimberley, Mp - Molopo, Py - Plooysburg, Pr - Prieska
Duplex	Orthic horizon underlaid by pedocutanic or prismacutanic horizon: marked enrichment in clay with depth.	LUVISOLS: Se - Sepane, Sw - Swartland, Va - Valsrivier SOLONCHAKS: Ss - Sterkspruit STAGNOSOLS: Es - Estcourt, Km - Klapmuts
Podzolic	Orthic horizon underlaid by podzol horizon: enriched by metal humates.	PODZOLS: Cc - Concordia, Gk - Groenkop, Hh - Houwhoek, Jb - Jonkersberg, Lt - Lamotte, Pg - Pinegrove, Ts - Tsitsikamma, Wf - Witfontein
Plinthic	Orthic horizon underlaid by a soft plinthic or hard plinthic horizon: iron enriched, with flecks or hardening.	PLINTHOSOLS: Av - Avalon, Bv - Bainsvlei, Dr - Dresden, Gc - Glencoe, Lo - Longlands, Wa - Wasbank, We - Westleigh
Oxidic	Orthic horizon underlaid by a red apedal, yellow apedal, or red structured horizon: iron enriched with uniform colour.	FERRALSOLS: Bd - Bloemdal, Cv - Clovelly, Gf - Griffen, Hu - Hutton, Pn - Pinedene ACRISOLS / LUVISOLS / NITISOLS: Ss - Shortlands
Gleyic	Orthic horizon underlaid by a gley (G) horizon: reducing, wet conditions.	GLEYSOLS: Ka - Katspruit STAGNOSOLS: Kd - Kroonstad
Inceptic - Cumulic	Orthic horizon underlaid by a neocutanic, neocarbonate, regic sand, or stratified alluvium horizon: new soil on unconsolidated sediments.	ACRISOLS / LIXISOLS / ARENOSOLS / CAMBISOLS: Kk - Kinkelbos, Oa - Oakleaf, Tu - Tukulu, Vf - Vilafontes LUVISOLS / LIXISOLS / ARENOSOLS / CAMBISOLS: Ag - Augrabies, Mu - Montagu ARENOSOLS: Fw - Fernwood, Nb - Namib FLUVISOLS: Du - Dundee
Inceptic - Lithic	Orthic horizon underlaid by a lithocutanic horizon or hard rock: new soil on weathered rock.	LEPTOSOLS: Ms - Mispah LEPTOSOLS / ACRISOLS / LIXISOLS / CAMBISOLS: Cf - Cartref, Gs - Glenrosa
Inceptic - Anthropic	Disturbed material (waste deposits): man-made soil.	TECHNOSOLS: Wb - Witbank

2.3.4.1 Organic soils

This group comprises soils containing an organic horizon comprising decomposing organic material that invariably undergoes saturation for prolonged periods of time (i.e., a gleyed character), with the following aspects in this regard of importance to the aims and purposes of this study:

- TSCS soil form:

  Ch - Champagne.

- WRB class:

  Histosols and Gleysols.

- Climatic regime:

  Cool to cold climate, or in areas exhibiting high rainfall with low evapotranspiration, but absent in similar areas exhibiting hot summers (climatic N-value generally less than 5 [Weinert, 1980]).

- Parent material:

  Predominantly comprises decomposing vegetation.

- Morphological setting:

  Generally present as highly localized pockets in low-lying topography typically indicating of wetland and/ or vlei conditions.

- Inferred geotechnical behaviour:

  Very low density with very poor trafficability and low bearing capacity, could undergo significant shrinkage when dry, and is prone to severe erosion and/ or acidification when dewatered.

2.3.4.2 Humic soils

This group comprises soils containing a humic horizon, generally underlaid by deeply weathered material (saprolite) exhibiting little or no structure, with the following aspects regarding this soil group of importance to note during the conducting of PSGIs:

- TSCS soil forms:

  Ia - Inanda, Kp - Kranskop, Lu - Lusiki, Ma - Magwa, No - Nomanci, and Sr - Sweetwater.

- WRB classes:

  Acrisols (Lu & No), Cambisols (Sr), and Ferralsols (Ia, Kp, & Ma).

- Climatic regime:

  Cool, humid (sub-tropical) climate with high rainfall (Weinert climatic N-value generally less than 5).

- Parent material:

  Mainly hillwash, invariably enriched by an accumulation of organic material.

- Morphological setting:

  Although it could be present throughout the landscape, these soils generally prefer gentle slopes.

- Inferred geotechnical behaviour:

  Generally, well drained, relatively acidic soils with low bulk density that does not readily compact, not prone to significant shrinkage or swelling, with high water retention capacity, although prone to soil-creep along steeper slopes.

2.3.4.3 Vertic soils

This group comprises soils containing a vertic horizon present as a very strongly structured, highly plastic topsoil exhibiting pronounced slickensided texture, in places underlaid by a gleyed material. These soils are generally considered highly detrimental to the cost and ease of development, with the following aspects aiding identification and assessment thereof:

- TSCS soil forms:

  Ar - Arcadia, and Rg - Rensburg.

- WRB class:

  Vertisols.

- Climatic regime:

  Tropical to sub-tropical climate with a significant dry season, thus predominantly in the summer rainfall areas, but very occasionally also found in winter rainfall areas (Weinert climatic N-value generally less than 7.5).

- Parent material:

  Basic or ultrabasic igneous strata (e.g., andesite, basalt, diabase, diorite, dolerite, gabbro, norite, pyroxenite, etc.), or its associated saprolite.

- Morphological setting:

  Generally present along lower-lying topography (although very localized exceptions do occur).

- Inferred geotechnical behaviour:

  Shrinks to a cracked and hard material when dry, swelling to a very wet and sticky material when wet that severely affects trafficability, occasionally exhibiting a self-mulching or crusting character, and in places giving rise to mound-and-basin micro-relief features (known as gilgai topography), with low erosion potential, except where disturbed.

2.3.4.4 Melanic soils

This group comprises soils containing a melanic horizon, present as a dark-coloured, moderately to strongly structured clayey topsoil exhibiting lower plasticity than vertic soils, with a hydromorphic, pedocutanic, calcic, lithic, or cumulic sub-surface character recognised. Although having a lesser impact on development than vertic soils, the correct identification of these soils on the hand of the following aspects are of great importance:

- TSCS soil forms:

  Bo - Bonheim, Im - Immerpan, Ik - Inhoek, My - Mayo, Mw - Milkwood, Sn - Steendal, and Wo - Willowbrook.

- WRB classes:

  Chernozems (Bo & Sn), Fluvisols (Ik), Gleysols (Wo), Leptosols (Mw), Lixisols (My), and Phaeozems (Im).

- Climatic regime:

  Generally sub-arid (Weinert climatic N-value between 5 and 7.5) to sub-humid climate (Weinert climatic N-value between 2 and 5), although it could occur on relatively young landscapes in a more humid climate.

- Parent material:

  Originating from saprolite of basic or intermediate rocks (e.g., andesite, basalt, dacite, diabase, diorite, dolerite, granodiorite, etc., or its derived alluvial or colluvial deposits.

- Morphological setting:

  Variable, but generally occurs near or along valley floors.

- Inferred geotechnical behaviour:

  Prone to a degree of shrink/heave, although, with moderately low infiltration rate, and low erosion potential.

2.3.4.5 Silicic soils

This group comprises soils with a relatively sandy orthic horizon underlaid by a dorbank horizon (i.e., an actively forming, hard to extremely hard silica-cemented layer, considered dissimilar to silcrete, with an abrupt upper boundary) predominantly as a result of the precipitation of silica mobilised during weathering in soils exhibiting relatively high pH in an environment not prone to leaching, but also very occasionally due to biotic activity, with a rhodic, neocutanic, neocarbonate, or orthic topsoil character recognised. The following aspects with regard to the identification of these soils are of importance to note:

- TSCS soil forms:

  Gr - Garies, Kn - Knersvlakte, Ou - Oudtshoorn, and Tr - Trawal.

- WRB class:

  Durisols.

- Climatic regime:

  Present-day arid climate (Weinert climatic N-value in excess of 10).

- Parent material:

  Colluvial and alluvial deposits.

- Morphological setting:

  Nearly level to level or gently sloping plains or erosion terraces.

- Inferred geotechnical behaviour:

  Overlying topsoil generally moderately to well drained, depending on the depth and degree of cementation of the dorbank horizon that is typically hard and brittle and undergoes a degree of shrinkage with associated cracking when dry, in places allowing its removal by means of ripping, that is often used as road construction material, with low to moderate erosion potential especially in areas where with degraded vegetation cover.

2.3.4.6 Calcic soils

This group comprises soils with an orthic horizon underlaid by a soft carbonate or hard carbonate horizon, formed by the continuing accumulation of calcium carbonate (or occasionally, magnesium and gypsum) either due to precipitation as a result of excessive evaporation of soil moisture within the topsoil, re-accumulation of leached calcium at depth, or biotic activity, progressing from neocarbonate through soft carbonate to hard carbonate. The following aspects of importance to identify and assess occurrences of these soils apply:

- TSCS soil forms:

  Ad - Addo, Ak - Askham, Br - Brandvlei, Cg - Coega, Et - Etosha, Gm - Gamoep, Ky - Kimberley, Mp - Molopo, Py - Plooysburg, and Pr - Prieska.

- WRB class:

  Calcisols.

- Climatic regime:

  Predominantly semi-arid (Weinert climatic N-value between 5 and 10) to arid climate (Weinert climatic N-value in excess of 7.5), with many occurrences attributed to paleo-climatic conditions.

- Parent material:

  Variable, with calcium inferred to originate either from lime-rich soil material, rocks, colluvial or alluvial deposits, or from lateral sheet flow or wind-blown dust.

- Morphological setting:

  Variable, but predominantly nearly level to level or gently sloping plains or erosion terraces.

- Inferred geotechnical behaviour:

  Generally, well drained, but occasional temporary ponding of surface water could occur above a practically impermeable hard carbonate horizon, with the topsoil and soft carbonate horizon considered highly prone to erosion, with high pH and an enhanced tendency to retain metal cations emanating from waste disposal sites, and generally well suited for use as road building material.

2.3.4.7 Duplex soils

This group comprises soils with an orthic horizon underlaid by a horizon characterised by a pronounced (thus excluding relatively young neocutanic and lithocutanic horizons) accumulation of clay as a result of eluviation of dispersed clay particles suspended in soil moisture from the overlying horizon (i.e., a luvic character) or from upslope areas, or occasionally through bioturbation (e.g., ants and earthworms), to form a pedocutanic or prismacutanic horizon, occasionally overlaid by a bleached topsoil horizon as a result of the effects of pH fluctuations (ferrolysis). The diverse characteristics exhibited by these soils, some of which could have a significant impact on the cost and ease of development, require careful consideration of the following aspects:

- TSCS soil forms:

  Es - Estcourt, Km - Klapmuts, Se - Sepane, Ss - Sterkspruit, Sw - Swartland, and Va - Valsrivier.

- WRB classes:

  Luvisols (Se, Sw, & Va), Solonchaks (Ss), and Stagnosols (Es & Km).

- Climatic regime:

  Semi-arid (Weinert climatic N-value between 5 and 7.5) to semi-humid climate (Weinert climatic N-value between 2 and 5), but excluding areas with a warm humid climate.

- Parent material:

  Not specifically differentiated, but not associated with weathered basic and ultrabasic rocks (e.g., andesite, basalt, diabase, diorite, dolerite, gabbro, norite, pyroxenite, etc.), with the topsoil and sub-surface horizons generally considered of differing origins.

- Morphological setting:

  Generally, occurs along concave lower-lying topography and river terraces, with the Swartland soil form present along convex upper and mid slopes.

- Inferred geotechnical behaviour:

  Typically, exhibiting a weakly structured topsoil horizon that could become hard when dry or form a crust when wet, giving rise to waterlogging and/ or severe erosion during and after heavy precipitation events, overlying strongly structured (i.e., blocky with small slickensides), relatively impermeable sub-surface material that could exhibit pronounced dispersive behaviour prone to tunnel erosion, with the underlying material either exhibiting lithic, gleyic, or expansive characteristics.

2.3.4.8 Podzolic soils

This group comprises soils with an orthic horizon underlaid by a podzol horizon where the products resulting from the interaction between soluble humic substances and iron and aluminium within sandy soil precipitate within the sub-surface material, but without causing a marked change in soil texture, but in places becoming sufficiently cemented to form a thin wavy placic pan under pronounced varying moisture cycles. Occurrences of these soils are generally limited to specific climatic and morphological conditions, with the following aspects thereof being of importance:

- TSCS soil forms:

  Cc - Concordia, Gk - Groenkop, Hh - Houwhoek, Jb - Jonkersberg, Lt - Lamotte, Pg - Pinegrove, Ts - Tsitsikamma, and Wf - Witfontein.

- WRB class:

  Podzols.

- Climatic regime:

  Predominantly in high rainfall areas in mainly winter rainfall areas (Weinert climatic N-value less than 5), although highly localized occurrences have been encountered in humid summer rainfall areas.

- Parent material:

  Mainly arenaceous sedimentary rocks, and extensive sandy colluvial, alluvial and aeolian deposits.

- Morphological setting:

  Variable, but generally occurs along mid and foot slopes.

- Inferred geotechnical behaviour:

  Generally, freely draining, non-plastic material, with the placic pan occasionally being hard enough to resist excavation by hand.

2.3.4.9 Plinthic soils

This group comprises soils with an orthic horizon underlaid by a soft plinthic or hard plinthic horizon formed mainly by the precipitation of mobilised iron and manganese in groundwater as a result of fluctuating groundwater conditions (i.e., alternating wetting and drying cycles) in the absence of humic material, or occasionally representing relics formed during conditions different than that prevailing at present, or very rarely biotic activity, varying from a weakly ferruginized material exhibiting only mottles and weak cementation through soft plinthite to hard plinthite. The following aspects regarding the identification of these frequently encountered soils apply:

- TSCS soil forms:

  Av - Avalon, Bv - Bainsvlei, Dr - Dresden, Gc - Glencoe, Lo - Longlands, Wa - Wasbank, and We - Westleigh.

- WRB class:

  Plinthosols.

- Climatic regime:

  Mainly sub-humid (Weinert climatic N-value between 2 and 5) to humid climate (Weinert climatic N-value less than 2) with a distinctly dry season, but absent in areas with very low or very high rainfall.

- Parent material:

  Variable, but more prominently associated with sedimentary rocks, and generally absent on basic igneous rocks (e.g., andesite, basalt, diabase, diorite, dolerite, gabbro, norite, pyroxenite, etc.).

- Morphological setting:

  Generally, gentle, concave lower slopes where seasonal lateral groundwater movement can be expected.

- Inferred geotechnical behaviour:

  Apedal horizons above the plinthic horizon generally exhibit good drainage, while occasional seasonal waterlogging of the topsoil could occur above a hard plinthic horizon, with the plinthic material generally considered a resource of road building material.

2.3.4.10 Oxidic soils

This group comprises soil forms with an orthic horizon underlaid by an apedal (comprising porous and friable material without obvious structure) or red structured (comprising firm, dense, sub-angular blocky material) horizon that is uniformly coloured by accumulated red or yellow oxides under aerated conditions that therefore does not exhibit signs of wetness, although the yellow apedal horizon could in places be underlain by material with a weak to strong gleyic character. Identification of these commonly occurring soils rely on assessment of the following aspects:

- TSCS soil forms:

  Bd - Bloemdal, Ct - Constantia, Cv - Clovelly, Gf - Griffen, Hu - Hutton, Pn - Pinedene, and Sd - Shortlands.

- WRB classes:

  Ferralsols (Bd, Ct, Cv, Gf, Hu, & Pn), and Acrisols / Luvisols / Nitisols (Sd).

- Climatic regime:

  Highly variable, with red coloured soils more prevalent in warmer, drier climatic conditions (Weinert climatic N-value in excess of 5), while yellow coloured soils tend to occur in areas with a cooler, moister climate (Weinert climatic N-value less than 5).

- Parent material:

  Highly variable, with the red apedal horizon generally associated with weathered basic igneous rocks (e.g., basalt, diabase, dolerite, gabbro, etc.).

- Morphological setting:

  Predominantly, associated with areas exhibiting gentle slopes, with red apedal soils typically occurring along ridge crests and yellow soils along mid slopes.

- Inferred geotechnical behaviour:

  Apedal horizons generally exhibit good drainage while remaining moist for most of the year, but are prone to shrinking and cracking when allowed to dry out (e.g., next to large trees), while the red structured horizon could undergo a degree of shrinkage/ heave with changes in moisture content, while its potentially self-mulching character could increase the risk of erosion.

2.3.4.11 Gleyic soils

This group comprises soil forms with an orthic horizon underlaid by a gley (old G-) horizon, occasionally separated by an albic (E) horizon, that represents reduction of oxides under anaerobic conditions (typically under saturated conditions that prevail for prolonged periods of time) that results a dominant grey-coloured soil with blue or green discoloration and occasionally mottles that exhibits firmer consistency than that of the overlying horizon in the case of the gley horizon, with the albic horizon generally being loose with low plasticity when wet to hard and brittle when dry. Occurrence of these soils severely affect the cost and ease of development, requiring care consideration of the following aspects during the conducting of PSGIs:

- TSCS soil forms:

    Ka - Katspruit, and Kd - Kroonstad.

- WRB classes:

    Gleysols (Ka), and Stagnosols (Kd).

- Climatic regime:

    Variable, with kaolinite-rich soils exhibiting relatively low plasticity more prevalent in sub-humid areas with relatively high rainfall (Weinert climatic N-value between 2 and 5), and more plastic smectite-rich soils exhibiting stronger structure expected in sub-arid areas (Weinert climatic N-value of between 5 and 7.5), but absent in areas with very high rainfall.

- Parent material:

    Generally, associated with shale and sandstone, and acidic igneous rocks (e.g., granite), but not basic igneous rocks (e.g., basalt, diabase, dolerite, gabbro, etc.).

- Morphological setting:

    Predominantly, associated with wetlands, vleis, and pans along low-lying topography, but can also occur throughout the landscape in areas where enhanced infiltration of water, rather than surface flow, occurs onto an impermeable layer, or in areas with a wet climate.

- Inferred geotechnical behaviour:

    Gley horizons close to the surface are typically wet for prolonged periods of time with a “sticky” and highly plastic character with a degree of crusting during drier periods, while the presence of an overlying albic horizon indicates more periodic saturation with lateral movement of soil moisture, with the topsoil horizons being moderately to very highly acidic.

2.3.4.12 Inceptic soils - Cumulic

This group comprises relatively young soils comprising an orthic horizon underlaid by unconsolidated material that has only recently been subjected to soil formation processes, or exhibits only weak signs of soil formation, with a distinction being made between soils that are negligibly altered but with distinct stratification (regic sand and stratified alluvium), weakly altered with a luvic character (neocutanic horizon), weakly altered with a calcic character (neocarbonate horizon), weakly altered with an albic character (containing an albic / E horizon), or exhibit signs of wetness beneath a neocutanic or neocarbonate horizon. Identification of these soils are aided by assessment of the following aspects:

- TSCS soil forms:

  Ag - Augrabies, Du - Dundee, Fw - Fernwood, Kk - Kinkelbos, Mu - Montagu, Nb - Namib, Oa - Oakleaf, Tu - Tukulu, and Vf - Vilafontes.

- WRB classes:

  Arenosols (Fw & Nb), Fluvisols (Du), Acrisols / Lixisols / Arenosols / Cambisols (Kk, Oa, Tu, & Vf), and Luvisols / Lixisols / Arenosols / Cambisols (Ag & Mu).

- Climatic regime:

  Highly variable, but with the occurrence of neocarbonate horizons limited to areas exhibiting an arid climate (Weinert climatic N-value in excess of 7.5).

- Parent material:

  Typically, alluvial or colluvial deposits, with regic sand and stratified alluvium associated with aeolian and fluvial deposits, respectively.

- Morphological setting:

  Invariably, youthful landscape positions along mainly concave foot slopes and valley floors, with fluvic deposits invariably occurring along floodplains associated with regular flooding, and arenic soils present as littoral and desert dunes and leeward fluvial deposits.

- Inferred geotechnical behaviour:

  Expected to undergo moderate to significant consolidation under loading or when saturated, and it is prudent to recognise that the fluvic soil undergoes regular flooding, while the arenic soil is prone to wind erosion and poor water retention.

2.3.4.13 Inceptic soils - Lithic

This group comprises relatively young soils comprising an orthic horizon underlaid by either a hard bedrock horizon, or a luvic rock/soil mixture containing at least 70% rock fragments (lithocutanic horizon) that grades into bedrock at depth, in places overlain by an albic (E-) horizon, with the topsoil clearly associated with the underlying parent material. The occurrence of shallow rocky soils increases the cost of especially linear development (e.g., roads and pipelines), with the following aspects of importance in this regard:

- TSCS soil forms:

  Cf - Cartref, Gs - Glenrosa, and Ms - Mispah.

- WRB classes:

  Leptosols (Ms), and Leptosols / Acrisols / Lixisols / Cambisols (Cf & Gs).

- Climatic regime:

  Mainly in sub-arid (Weinert climatic N-value between 5 and 7.5) and arid areas (Weinert climatic N-value in excess of 7.5), but limited to steep slopes and very convex crests in more humid areas (Weinert climatic N-value less than 5).

- Parent material:

  Highly variable.

- Morphological setting:

  Typically, occurs along convex ridge crests and relatively steep slopes, but can extend to concave footslopes in areas where erosion and deposition are in balance.

- Inferred geotechnical behaviour:

  The presence of weathered bedrock at relatively shallow depth hampers excavatability, requiring ripping or heavy machinery, while fracture and joint planes within the bedrock could act as preferential drainage paths for the movement of soil moisture, although seasonal lateral movement of soil moisture is expected where an albic horizon is present.

2.3.4.14 Inceptic soils - Anthropic

This group comprises relatively young soils where human activities have either completely destroyed the natural soil character or formed mixtures of soil and various unnatural waste deposits. The following generalised aspects apply to the identification and assessment of these soils:

- TSCS soil form:

  Wb - Witbank.

- WRB class:

  Anthrosols and Technosols.

- Inferred geotechnical behaviour:

  Presence of deleterious compounds within the waste deposits and highly variable composition and structure considered problematic.

2.4 Evaluation of various adverse geotechnical characteristics

2.4.1 Introduction

The Department of Public Works (2007) defines problem soils as those exhibiting geotechnical characteristics that could adversely affect civil engineering development under specific conditions, necessitating the implementation of expensive or time-consuming remedial measures.

As the different adverse geotechnical characteristics have been extensively researched in the past in its' own right (for example, Paige-Green & Turner, 2008; Buttrick *et al*., 2011; and Diop *et al*., 2011), a short summary of the causes, distribution and effects of each parameter will suffice as reference material for preliminary stage assessments (i.e., excluding detailed precautionary and/or remedial measures required for design and construction purposes).

These characteristics have been grouped together into five main categories that define the primary assessment elements used during the conducting of PSGIs, and as such representing the primary focus of this study, namely:

Category 1: Poor trafficability (during and after construction).

Category 2: Material re-use potential.

Category 3: Adverse soil behaviour.

Category 4: Excavatability problems.

Category 5: Miscellaneous geological, geotechnical, and geomorphological factors.

It must be noted that the listed factors are based on the parameters proposed by Partridge *et al*. (1993) and as such should not be seen as a complete list of all adverse geotechnical effects that can be expected. However, any unspecified characteristics could readily be added to the miscellaneous category. The parameters utilised during this process correspond to the list of factors for the interpretation of pedological information for engineering purposes proposed by Paranhos *et al*. (2019). The adverse geotechnical characteristics are discussed in more detail in the following sections and associated tables.

In order to aid assessment of soil behaviour, the primary geotechnical behaviour of various transported, residual and pedogenic soils as defined by various authors (including Weinert, 1980, and Brink, 1985), based on collated and referenced information by the Department of Public Works (2007) considered sufficiently concise for the purposes of this study, are summarised in Table 2.11.

Table 2.11: Primary geotechnical properties of transported, residual and pedogenic soils of various origins (as summarised by the Department of Public Works, 2007).

Soil origin	Source rock	Material	Inferred geotechnical behaviour
TRANSPORTED SOILS			
Talus (coarse colluvium). Due to gravity action.	Any rock outcropping directly above talus deposit.	Unsorted angular gravel and boulders within sandy soil matrix.	• slope instability.
Hillwash (fine colluvium). Due to sheetwash.	Acid crystalline igneous rocks. Basic crystalline igneous rocks. Arenaceous sedimentary rocks. Argillaceous sedimentary rocks.	Clayey sand. Sand. Silt. Clay.	• potentially collapsible, • potentially expansive, and/or • potentially compressible.
Alluvium / gulley wash. Due to surface drainage along streams or gullies.	Dependent on catchment.	Gravel. Sand. Silt. Clay.	• all possible problems, including dispersivity and erosion.
Lacustrine deposits. Due to surface drainage into pans, lakes or sub-surface voids.	Usually mixed source.	Sand. Silt. Clay.	• potentially expansive, and/or • potentially compressible.
Estuarine deposits. Due to surface drainage and tidal action.	Mixed source.	Sand. Silt. Clay.	• 'quicksand'.
Aeolian deposits. Due to wind action.	Usually mixed source.	Sand.	• potentially collapsible.
Littoral deposits. Due to wave action.	Mixed source.	Beach sand.	• potentially collapsible.
RESIDUAL SOILS			
Acid Igneous rocks.	Vein quartz, pegmatite rhyolite, aplite, granite, etc.	Clayey sand/ sandy clay (often mica-rich). Clayey gravel. Corestone. Gravel, cobbles, and boulders.	• potentially collapsible, • potentially dispersive, • sand 'boils', • high permeability, • potentially erodible, and/or • good compaction and workability.
Basic Igneous rocks.	Basalt, dolerite, diabase, andesite, diorite, norite, pyroxenite, etc.	Clay (turf). Silty clay, becoming sandy clay with depth. Corestone. Gravel, cobbles, and boulders.	• potentially expansive, • low shear strength, • low / very low permeability, • poor compaction and workability, • slope instability, and/or • uneven bedrock surface.
Calcareous rocks.	Calcrete, limestone, marble, dolomite, etc.	Wad. Silty/ sandy clays. Clayey/ sandy gravel. Angular gravel, cobbles, and boulders. Large dolomite floaters.	• cavities, with associated surface instability (e.g., sinkholes, subsidences), • hard rock interbedded with loose / soft layers, • highly erodible, • highly porous, • fair to good compaction & workability, and/or • very uneven bedrock surface.

Table 2.11: (continued): Primary geotechnical properties of transported, residual and pedogenic soils of various origins (after Department of Public Works, 2007).

Soil origin	Source rock	Material	Inferred geotechnical behaviour
Argillaceous (clayey) sedimentary rocks.	Claystone, mudstone siltstone, shale, coal, etc.	Clay, silt, and silty clay.	• potentially expansive, • low shear strength, • high settlement, • slaking on exposure, • low/ very low permeability, • potentially dispersive, • poor compaction and workability; and/or • slope instability.
Arenaceous (sandy) sedimentary rocks.	Sandstone, conglomerate, tillite, chert, etc.	Clayey sand/ gravel Cobbles, boulders, and rubble.	• potentially expansive (tillite); • variable permeability, • potentially erodible, and/or • good to excellent compaction and workability.
Metamorphic rocks.	Marble, slate, hornfels, quartzite, schist, gneiss, anthracite, etc.	Clay, silt, and sand. Angular gravel, cobbles, and boulders.	• Low shear strength, • Slope instability, • Variable permeability, and/or • Poor to good compaction and workability.
PEDOGENIC SOILS			
Various.	Various.	Ferricrete (plinthite). Calcrete. Silcrete. Manganocrete. Phoscrete. Gypcrete.	• highly variable founding conditions resulting in differential settlement, • poor excavatability where hardpan pedocrete occurs, • soft pedocrete layers occurring beneath hardpan layers could undergo densification under loading, leading to differential settlement, • could be indicative of groundwater seepage, • poor to good compaction and workability, and/or • potentially dispersive (calcrete).

2.4.2 Category 1: Poor trafficability

Paige-Green (1989) states that trafficability is primarily a generalised assessment of the bearing characteristics of the soil material over which vehicles will pass. According to Müller *et al*. (2011) assessment of the trafficability of a site is a complex process based on soil capabilities, weather conditions and the technical parameters of the machinery to be utilised, and to a lesser extent geomorphological factors, e.g., steep slopes, natural vegetation, location within a flood plain or wetland, etc. Heavy precipitation over a relatively short period, typical of the Highveld region, will have a smaller impact than continuous light rain over several days, as the former results in rapid drying out of the topsoil, while the latter could lead to significant water ingress into and as such saturation of the sub-surface materials (Paige-Green, 1989). In addition to the above-mentioned parameters, the United States Army also requires documentation of the occurrence of natural obstacles, including rock outcrops, as part of trafficability assessments (United States Army, 2009). Although trafficability is deemed to be a less critical factor during civil engineering projects that rely on the movement of a variety of construction vehicles, the effects thereof on soil degradation (e.g., soil compaction, remoulding, etc.) have recently become a more pressing environmental concern (Müller *et al*., 2011).

An estimate of potential trafficability problems during a preliminary geotechnical assessment primarily focusses on three parameters, as detailed in Table 2.12, proposed as part of this research based on the available information that can be obtained from the land type maps and memoirs, namely:

- Presence of boulders at surface.
- 'Sticky'/ slippery conditions when wet.
- Loss of cohesion/ 'quicksand' conditions when wet.

Table 2.12: Proposed parameters to allow assessment of the impact of poor trafficability on development.

Parameter	Discussion
Presence of boulders at surface	The presence of boulders, comprising rock and/or hardpan pedocrete remnants, at the surface could hamper the movement of most wheeled and some tracked vehicles during and after construction (United States Army, 2009).
'Sticky'/ slippery conditions when wet	Field Manual FM 5-430-00-1 of the United States Air Force (1994) indicates that fine grained (i.e.: clayey) soil exhibiting low strength could become 'sticky' when wet (i.e., during and after heavy precipitation events), and as such could accumulate in the running gears of vehicles (both wheeled and tracked), invariably hampering steering and movement of mainly lighter vehicles. Additionally, excess water ponding on a layer of clayey soil exhibiting plastic behaviour overlying firmer soil could cause slippery conditions that would severely hamper steering of, or even immobilise, rubber-tired vehicles (United States Air Force, 1994).
Loss of cohesion when wet/ 'quicksand' conditions	Some fine-textured soils could undergo significant reduction in bearing strength under loading (e.g., directly beneath the wheels or tracks of vehicles) when saturated, while that of loose sands could increase (United States Air Force, 1994). Additionally, the formation of 'quicksand' conditions after heavy precipitation events, with excessive soil moisture present at relatively shallow depth (i.e., a perched water table and/or the ingress of storm water) within sandy topsoil overlying less permeable material (e.g., bedrock, pedocrete, or a moderately to strongly structured clayey horizon) will significantly reduce the cohesion and strength of the topsoil under loading (i.e., acting as a liquid; Júnior *et al*., 2018).

Problems with access to and trafficability on a site during and after construction are inferred to present the developer with some headaches (assumed slight impact and cost implication), as:

- either more suitable equipment will have to be sourced and utilised,

- development may have to be delayed until either more suitable conditions prevail (e.g., drier weather), and/or
- suitable site improvement measures have been implemented, and/or stricken vehicles have been recovered and repaired.

It must be noted that these parameters are in addition to those proposed by Partridge *et al*. (1993). However, these options could impact initial and ongoing project costs, and delay time-sensitive project actions.

2.4.3 Category 2: Material re-use potential

Although laboratory tests are required for the analysis of the re-use potential of site-specific soil, rock and pedogenic materials, these are generally not available during the pre-feasibility phase of development. Generalised geotechnical characteristics inferred from pedological information could provide a broad indication of the re-use potential of soil-like materials (that include saprolite underlying diagnostic soil horizons) to be excavated from trenches or landscaping earthworks during construction. This assessment is based on the following guidelines by the South African National Standards (2011 & 2012) and the Committee of State Road Authorities (1985):

- soil forms exhibiting an indicated clay content of less than 6% without significant structure, typically not classifying as USCS SC, ML, MH, CL, & CH -type material, could be suitable for use as pipe bedding material,
- relatively sandy or gravelly soils, including saprolite, but excluding those with clayey topsoil, could be suitable for re-use as fill (subgrade) and subbase material, and
- gravelly soils, including soft ferricrete horizons and relatively sandy soils underlaid by saprolite, but again excluding soils with clayey topsoil, could be suitable as selected subgrade/ gravel wearing course material.

In the light of the above-mentioned guidelines, it is evident that soils exhibiting a high clay content (including both expansive and non-expansive types) are generally unsuitable for re-use. This is mainly due to its tendency to render a compacted material with low density and resultant low strength. Relatively sandy and gravelly material (including soft ferricrete) that does not classify as USCS SC, ML, MH, CL, or CH-type material on the other hand could be potentially suitable for re-use in the construction of engineered fills (e.g., beneath foundations, access roads and paved areas) (Committee of State Road Authorities, 1985).

In general, this factor is inferred to have a slight to moderate impact on the overall cost of development, as it could require the sourcing of more suitable material from other sources in the area, or alternatively, reworking of the natural soils (e.g., washing or screening) to produce a more suitable material, albeit at greater cost.

2.4.4 Category 3: Adverse soil behaviour

Although primarily meant for the assessment of adverse soil characteristics with regard to residential development, the geotechnical parameters proposed by Partridge *et al*. (1993) that can be derived from the pedological information are deemed sufficient for most development types, and are thus grouped together as follows:

- Potentially collapsible soils.
- Groundwater seepage.
- Active/ expansive soils.
- Potentially compressible soils, including so-called ‘soft clays’.
- Potentially erodible/ dispersive soils.
- Prolonged saturation/ waterlogged soils.

The character, occurrence, and impact of each of these parameters on development are discussed in Table 2.13. In general, this factor is inferred to have a slight to severe impact on the overall cost of development. The presence of any of these parameters could either disqualify certain portions of a particular study area from development or require the implementation of basic (least expensive) to extreme (could be very expensive) precautionary and remedial measures to counter the effects of the adverse characteristic(s) on structures and infrastructure.

2.4.5 Category 4: Excavatability problems

SANS 634 (2012) refers to a classification system originally established by the authors of the now withdrawn SABS 1200DA (1988), as detailed by Table 2.14, describing the machine excavatability of materials for earthworks for the installation of bulk services during township development (Kleinhans, 2002). Partridge *et al*. (1993) proposed the following regarding the assessment of excavatability to a depth of approximately 1.5 m (Constraint F as shown by Table 2.5), namely:

Most favourable: scattered to occasional boulders comprising up to 10% of the total volume of material occurring to a depth of 1.5 m.

Intermediate: rock/ hardpan pedocrete comprising between 10 and 40% of the total volume of material occurring to a depth of 1.5 m.

Table 2.13: Assessment of the impact of various adverse geotechnical behaviour of soil, based on the parameters proposed by Partridge *et al*. (1993). Note: the abbreviation PWB denotes Partridge, Wood and Brink.

Parameter	Discussion
Potentially collapsible soils PWB Constraint 1_A and 2_A	Swartz (1985) defines a collapsible soil as an open structured, silty, sandy material exhibiting low dry density and being partially saturated, that undergoes significant densification and reduction in strength with an increase of moisture content. Schwartz (1985) states the following regarding development on potentially collapsible soil: • Leaking wet services at, or poor surface drainage around, buildings constructed on collapsible soils could trigger gradual or sudden settlement beneath foundations and/or floor slabs, resulting in structural damage that can be repaired once total settlement has occurred. • Settlement due to collapsible soil could damage roads and bulk engineering services. Diop *et al*. (2011) state that the implementation of suitable remedial measures for this problem could add up to 20% to the cost of development, although structural damage can be repaired once total settlement has occurred.
Groundwater seepage PWB Constraint 2_B to 3_B	For the purposes of this study, this factor is defined as the seasonal/ periodic and/or permanent occurrence of groundwater near the surface. Vepraskas and Lindbo (2012) and the NHBRC (2015) define a perched water table as a zone of saturation occurring above unsaturated material. The NHBRC (2015) defines a high water table as the accumulation ('ponding') of soil moisture within a more permeable layer (e.g., a sandy horizon) overlying a layer exhibiting low permeability (e.g., clay) and/or high density (e.g., rock or a cemented pedocrete), typically occurring in low-lying areas, especially in areas with high rainfall. This problem is exasperated in areas where the impermeable layer rises to the surface (such as at the transition between relatively steep mid slopes and relatively gently sloping foot slopes), allowing the groundwater to emerge as seepage, and in cases where long foundations placed in or on the impermeable layer impede the lateral flow of groundwater (NHBRC, 2015). As such, the NHBRC (2015) requires assessment of the occurrence and extent of perched groundwater levels at depths of less than 1.5 m, and less than 1 m, with the former possibly leading to structural damage due to cyclical heave/shrinkage or collapse and/or consolidation settlement, and the latter causing rising damp in walls and beneath floor slabs, as well as lowering the bearing strength of the natural soil and man-made fills beneath foundations, in addition to those already mentioned. The presence of a high groundwater table along relatively steep slopes is known to cause slope instability and slumping/ landslides that have led to significant property damage and even loss of life (e.g., Low *et al*., 1999). SANRAL (2013) state that water within sub-surface layers (more specifically: road pavement layers) could significantly reduce the strength of these layers under loading, leading to washing out or 'pumping' of weaker underlying material. Another significant effect of high groundwater levels, but one that acts over a far longer time period, is the dissolution of dolomite and limestone that leads to the sub-surface spread of voids and cavernous conditions and its associated geotechnical challenges (Table 2.15).
Active/ expansive soils PWB Constraint 1_C to 3_C	Soils that undergo volumetric changes as a result of changes in the basal spacing of certain clay minerals during interaction with water pose a more serious challenge to development (Diop *et al*., 2011, and Williams *et al*., 1985). These soils generally occur in areas with low rainfall or impeded drainage, but are expected to be less prevalent in areas with high rainfall. It is, however, the soil type that causes the most problems in Southern Africa (Kleinhans, 2002). Williams *et al*. (1985) state the following regarding the adverse effects of expansive clays on development: • Heave and shrinkage damage to buildings is triggered by periodic changes in soil moisture, especially in areas where the natural vegetation has been removed prior to development, with leaking wet services severely exasperating this problem. • Ongoing differential vertical movement leads to significant cracking of brick walls and floor slabs and may cause even small-diameter wet service pipes to rupture. • Repairs usually offer only a temporary solution, and some heavily damaged structures may eventually have to be abandoned/ demolished. • Roads constructed over expansive soils require regular maintenance, with differential movement severely degrading the ride comfort experienced by road users, while the interfaces between expansive soil and rigid structures (such as bridges and culverts) may also be problematic. Diop *et al*. (2011) note that the occurrence of expansive clays could lead to extensive structural damage if mis-identified or incorrect construction methods are applied, with costly repairs required periodically, with some structures even becoming damaged beyond economical repair.
Compressible soils, including 'soft clays' PWB Constraint 1_D to 3_D	According to Diop *et al*. (2011) a sandy soil will undergo consolidation-related settlement under loading in excess of its normal consolidation/ pre-consolidation pressures as a result of the relatively rapid densification of particles with accompanying expulsion of air and water from the inter-particle pores until a sufficient resisting strength is reached, while clayey soil could consolidate over longer periods of time due to gradual dissipation of pore water stresses. Although potentially compressible deposits are mainly expected in places along the coast, as well as along the flood plains of inland stream- and river channels, residual clays associated with weathered lavas of the Ventersdorp Supergroup and residual silty clays from weathered mudrocks of the Karoo Supergroup could also exhibit a compressible character (Diop *et al*., 2011). Jones and Davies (1985) define a special category of soils that could undergo consolidation under loading, namely 'soft clays', comprising near surface clays, which form a crust, deemed partially saturated and over-consolidated as a result of changes in the water table, or over-consolidated and saturated clays buried beneath younger deposits. This material is generally expected to exhibit undrained shear strengths between 10 and 40 kPa. 'Soft clays' predominantly occur along coastal areas, especially in estuaries along northern and southern KwaZulu-Natal and Eastern Cape, and in localised areas in and around Cape Town, with thin deposits of recently deposited 'soft clays' also present in wetland areas (Jones & Davies, 1985). According to Jones and Davies (1985), the presence of 'soft clays' could adversely affect construction projects, including the following: • require very specific and expensive foundation solutions, as the low shear strength of these materials prevents the use of more conventional shallow footings beneath structures, • differential settlement of 'soft clays' could damage large-diameter bulk engineering services, and/or • could prove problematic during the construction and long-term use of roads, due to differential settlement and the failure of embankments. Diop *et al*. (2011) state that the implementation of suitable remedial measures for this problem could add up to 20% to the cost of development.
Potentially erodible / dispersive soils PWB Constraint 1_E to 3_E	Erodible soils are defined as materials in which the surface shear strength when wet is too weak to resist the tractive forces exerted by sheetwash across the soil surface, typically along moderately steep slopes or in areas where concentrated surface flow occur (Paige-Green, 2008). Paige-Green (2008) states that dispersion entails the suspension of mainly sodium-rich clay particles in non-moving soil moisture, with dispersive soils typically being prone to sub-surface erosion in the form of pipes/ tunnels during periods of groundwater flow. Soils exhibiting a dispersive character are generally derived from granite, mudrock and shale, with sodium-enrichment of other soils also possible due to more recent geomorphological processes (Paige-Green, 2008). According to Paige-Green (2008) and Diop *et al*. (2011), degradation of the natural environment tends to be the primary effect of soils prone to erosion and/or dispersion, leading to donga formation, while localised slope failure, undercutting of foundations, silting of storm water drains, and tunnel/piping erosion in earth embankments could affect development on and in the vicinity of affected land.
Prolonged saturation/ waterlogged soils PWB Constraints 3_B and 3_L	The NHBRC (2015) defines waterlogging as instances where the groundwater level occurs at or above surface. In this light, this factor thus encompasses all adverse geotechnical aspects listed for groundwater seepage from perched- and permanent water tables, but inferred to be greatly enhanced due to the proximity of the water table to the surface as possible mitigating effects offered by a more stable overburden are absent. The occurrence of waterlogged soil is assumed indicative of a site location within the 1:50 year floodline of a water course, where development should not be attempted without very detailed studies to prevent degradation of the natural drainage regime, wetlands and water courses and its associated floodplain according to the National Water Act (Act No. 102 of 1998).

Table 2.14: Assessment of excavatability, originally developed by the authors of the now withdrawn SABS 1200DA (1988), as referenced by SANS 634 (2012).

Classification	Description
Restricted excavation	
Soft	Material which can be efficiently removed by a back-acting excavator of fly wheel power > 0.10 kW for each mm of tined bucket width.
Intermediate	Material which can be removed by a back-acting excavator having a fly wheel power > 0.10 kW for each mm of tined bucket width, or with the use of pneumatic tools before removal by a machine capable of removing soft material.
Hard Rock	Material that cannot be removed without blasting or wedging and splitting.
Non-restricted excavation	
Soft	Material which can be efficiently removed or loaded, without prior ripping, by any of the following plant: • A bulldozer or a track type front end loader having an appropriate mass of 22 tonne and a fly wheel power of 145 Kw; or • A tractor-scraper unit having an approximate mass of 28 tonne and fly wheel power of 245 kW, pushed during loading by a bulldozer equivalent to that described above.
Intermediate	Material which can be efficiently ripped by a bulldozer having an approximate mass of 35 tonne and a fly wheel power of 220 Kw.
Hard Rock	Material that cannot be efficiently ripped by a bulldozer having an approximate mass of 35 tonne and a fly wheel power of 220 Kw.
Boulder Class A	Material containing more than 40% by volume of boulders of size between 0.03 and 20 m^3, in a matrix of soft material or smaller boulders.
Boulder Class B	Material containing 40% or less by volume of boulders of size between 0.03 and 20 m^3, in a matrix of soft material or smaller boulders.

Least favourable: rock/ hardpan pedocrete comprising in excess of 40% of the total volume of material occurring to a depth of 1.5 m.

In general, this factor is inferred to have a slight to severe impact on the overall cost of development, as it dictates the level of effort required to excavate shallow foundation and deep service trenches during urban development. In this light, the presence of material readily excavatable by manual labour is deemed the least expensive. However, adverse conditions requiring the use of motorised excavators, pneumatic power tools or blasting will progressively increase the cost and difficulty of development.

2.4.6 Category 5: Miscellaneous geological, geotechnical, and geomorphological factors

Partridge *et al*. (1993), the National Department of Housing (2002), and the National Department of Human Settlements (2009) define adverse characteristics of a geological, geotechnical, and geomorphological nature that could have an adverse effect on development and/or the natural environment, but not obtainable from regional soils mapping. These adverse characteristics include the following (Table 2.15):

Table 2.15: Assessment of the impact of miscellaneous geotechnical, geological, and geomorphological characteristics of soil, broadly based on the parameters proposed by Partridge *et al*. (1993), as updated in SANS 634 (2012). Note: the abbreviation PWB denotes Partridge, Wood and Brink.

Parameter	Discussion
Undermining PWB Constraint 1_G to 3_G	According to Bell *et al*. (2000) surface and sub-surface subsidence associated with mining activities at depth could have catastrophic environmental impact, as well as causing slight to very severe damage to structures and infrastructure, and even injuries and/or loss of life. The National Department of Housing (2002) mentions the loss of positive gradients with regard to water-bearing services, and the loss of positive surface drainage as additional adverse effects of undermining. Bell *et al*. (2000) state that the effects of undermining could either be contemporaneous or occur sometime in the future after cessation of mining activities. SANS 634 (2012) classifies areas where undermining is occurring at depths in excess of 200 m below surface (excluding areas where total extraction has not occurred) as the most favourable, while areas actively being undermined at depths of up to 200 m, or where total extraction has occurred in the past, are deemed the least suitable. Areas where undermining has occurred in the past to depths of 200 m where stope closure has ceased are deemed intermediately suitable for residential development (SANS 634, 2012).
Dolomite land PWB Constraint 1_H to 3_H	Infiltration of weakly acidic rainwater, as well as percolating groundwater, along steeply dipping joints, faults, tension fractures and fissures within dolomite rock into the rock mass at depth causes karstification, whereby the zones of weakness are widened into prominent vertical slots occurring between rock pillars and/or pinnacles, that over time allows the development of a network of interconnected roughly horizontal voids and slots (Brink, 1979). Subterranean voids tend to migrate towards the surface over time, especially under the influence of a suitable triggering mechanism that weakens the overburden, to eventually manifest as surface instability features (Brink, 1979), namely: • sinkholes - the sudden appearance of roughly cylindrical and steep-sided holes in the ground in areas where the sub-surface material has eroded into voids occurring at depth; and • subsidences - the gradual formation of relatively shallow depressions, in places surrounded by concentric soil cracks, over a period of months to years, due to slumping of the upper overburden draped across a sufficiently large void, or densification of low density/ heterogeneous residuum. Sinkholes can be catastrophic due to their sudden occurrence; often resulting in injury, loss of life, and damage to property and/or infrastructure and other assets, with damage to structures on dolomite land far exceeding that of other geological formations in southern Africa (Buttrick *et al*., 2014). The NHBRC (2015) classifies dolomite land as follows: • D1: No precautionary measures required, due to adequate thickness of non-dolomitic overburden. • D2: Inferred low risk - general precautionary measures to prevent water ingress required. • D3: Inferred medium risk - general precautionary measures to prevent water ingress, as well as additional measures, required. • D4: Inferred high risk - precautionary measures deemed too costly/ impracticable to implement.
Effect of slopes PWB Constraint 1_I to 3_I PWB Constraint 1_J to 3_J	Terzaghi and Peck (1967) defines a land slip as the slow or sudden failure of a mass of soil located beneath a slope in a downward and outward manner. Sudden failures can occur without prior warning, while others are much slower, taking days to finally fail, invariably preceded by the formation of surface cracks. Slope instability is caused by various triggers, including any of the following (Terzaghi & Peck, 1967): • Excavation of a man-made cut at an angle that exceeds the angle of internal friction of the material or undercutting the foot of an existing slope. • Swelling of clayey soils after heavy precipitation events. • Hair cracking from alternate swelling and shrinking with seasonal changes in moisture content. • A sudden increase in pore water pressure either as a result of highly permeable material, or liquefaction due to a sudden shock (e.g., an earth tremor). • Deterioration of cementing material (in pedogenic soils, e.g., ferricrete). • Loss of cohesion in loose, granular soils due to vibration (e.g., traffic, etc.). Development on unstable slopes could have the following adverse effects on the meta-stability of the soil/ rock mass (Roets, 2020): • an increase in external load (e.g., under a large new building), • an increase in water content (from leaking water-bearing engineering services or ingress from poor surface drainage), • removal of a part of the soil/ rock mass by excavation, especially at slope toe, and • undermining (e.g., tunnels, or erosion due to groundwater seepage). The National Department of Housing (2002) grants additional subsidies for low-cost residential development with regard to the following adverse natural slope conditions as pertaining to the servicing of land, partially corroborating the slope classes proposed by Partridge *et al*. (1993): • The provision of water-borne sanitation, as well as site drainage, becomes problematic at slopes of less than ± 0.5˚. • Slopes of between ± 2 and 6˚ require allowance for terracing and additional masonry units in foundation walls. • Slopes in excess of ± 6˚ require terracing for houses, as well as additional earthworks to roads and storm water control measures. Note that slopes of between ± 0.5 and 2° are not deemed problematic, and as such does not require the implementation of remedial/ precautionary measures during construction.
Areas subject to seismic activity PWB Constraint 1_K to 3_K	Work conducted by Kijko *et al*. (2003) resulted in the delineation of the following seismic hazard zones within South Africa: • Zone I: Areas subject to natural seismic activity, • Zone II: Areas subject to both mining-induced and natural seismic activity. • The remainder of the country that does not exhibit a significant risk of seismic activity. SANS 10160-4 (2009) regulates provision for the seismic hazard on the hand of the following ground types based on proven site conditions: • Type 1: Rock or other rock-like geological formations, including at most 5 m of weaker material at the surface. • Type 2: Deposits of very dense sand, gravel, or very stiff clay, at least several tens of meters in thickness, characterised by a gradual increase of mechanical properties with depth. • Type 3: Deep deposits of dense/ medium dense sand, gravel, or stiff clay with thickness from several tens to many hundreds of meters. • Type 4: Deposits of loose to medium cohesionless soil (with or without some soft cohesive layers), or predominantly soft to firm cohesive soil. Additionally, SANS 10160-4 defines the importance of buildings regarding seismic events as follows: • Class I: buildings of minor importance for public safety (e.g., agricultural buildings, etc.), • Class II: ordinary buildings, not belonging to other categories, • Class III: buildings for which seismic resistance is of importance in view of consequences associated with collapse (e.g., schools, clinics, etc.), and • Class IV: buildings for which integrity during earthquakes is of vital importance for protection (e.g., hospitals, fire stations, power plants, etc.). The effects of earthquakes on structures and buried and overland engineering services and infrastructure include ground rupture, slope failure, fires, soil liquefaction and flooding (Roets, 2020).
Proximity to surface water courses PWB Constraint 2_L to 3_L	Kleinhans (2002) describes the various adverse effects of inundation/ flooding (i.e., when a surface water body overflows its natural or artificial banks to submerge the surrounding land areas or ponding of surface water in low-lying areas) on development and degradation of the natural environment. Partridge *et al*. (1993) classifies this parameter as follows in terms of its effect on development: • Intermediate: areas adjacent to a known drainage channel/ floodplain with a slope of less than ± 0.5˚. • Least favourable: areas located within a known drainage channel or floodplain. Note that where present, a most suitable condition for this parameter does not exist.
Miscellaneous factors	The following geological, pedological and climatic characteristics also impact urban development: • Slaking is defined as the process whereby some strata (primarily fine-grained sedimentary rock) degrade from a relatively competent rock mass into fractured rock pieces, chips, flakes, granular particles and/or a paste of silt or clay-sized particles possibly as a result of a build-up of internal pressure upon changes in the moisture (and to a lesser degree, temperature) regime after exposure to air (Venter, 1980). Brink (1983) notes that the various mudrock formations of the Karoo Supergroup in particular are expected to exhibit a slaking nature, and as such could undergo slope failure at angles of as little as 10˚, with structural damage possible due to differential settlement when founding upon strata that have undergone slaking. • According to Anderson (2010), 'heavy and sticky' clayey soils (containing more than 60% clay) with low bearing capacity could exhibit a self-mulching character, where the very highly expansive soil undergoes very gradual mixing and inversion as topsoil falls into wide and deep cracks that form when dry. Locally, this problem is inferred to be primarily associated with occurrences of Vertic soil horizons where excessive swelling/ shrinking over time could severely damage foundations and roads (Anderson, 2010), as well as buried infrastructure (Saadeldin, 2016), with Brink (1979) noting that pipes placed in self-mulching clays tend to work themself to the surface and that fence posts planted within the soil tilt over • The Southern Cape Coastal Condensation Problem Area is defined as an area in the Winter Rainfall Zone of South Africa that exhibits prolonged periods of rainfall during cold weather occurring between Malmesbury and Ceres in the Western Cape, extending eastwards along the southern flanks of the coastal mountain ranges and escarpment into the Eastern Cape (the Department of Human Settlements, 2009; and SANS 634, 2012). This problem manifests as rain ingress and interior surface condensation leading to mould growth that could cause respiratory health problems, including TB (The Clay Brick Association of South Africa, 2014).

- Undermining.
- Dolomite land.
- The effects of slopes (either too gentle, or too steep).
- Seismic risk.
- Proximity to surface water courses.
- Miscellaneous adverse soil and rock characteristics, including slaking, self-mulching, etc., and allowing for the 'Southern Cape Coastal Condensation Problem Area'.

These factors are inferred to have a highly variable impact on the overall cost of development, as it requires the conducting of relatively expensive investigations to quantify the extent of the problem. The results of these investigations could either disqualify certain portions of a particular study area from development or require implementation of basic (least expensive) to extreme (could be very expensive) precautionary and remedial measures to counter the effects of the adverse characteristic(s) on structures and buried and overland infrastructure.

2.5 Important contributions from the field of hydropedology

Recent studies (e.g., Van Tol & Le Roux, 2019; and Van Tol, 2020) in the relatively new field of hydropedology have expanded understanding of the presence and movement of soil moisture. Van Tol and Le Roux (2019) state that there is an interactive relationship between soil and water, with water primarily influencing the morphological character of soils, and the soil characteristics determining water flowpaths and water residence times, especially along hillslopes. As such, hydropedological studies have become an invaluable tool in environmental impact assessments, especially with regard to hydrological modelling, identification of pollution migration pathways, and wetland identification and restoration mechanisms (Van Tol & Le Roux, 2019). Work by Van Tol and Le Roux (2019) that led to the grouping of the TSCS soil forms into hydropedological soil types according to its' hydropedological behaviour. Classification of the hydropedological types is considered of importance for the purposes of this study as understanding the periodic or prolonged occurrence and movement of groundwater, or stagnation thereof, within the soil horizons greatly aids in the grouping of the various soil forms according to its contribution to the overall adverse geotechnical character of an area with regard to the cost and ease of development.

The hydropedological soil type classification allows more accurate assessment of the possible occurrence and expected duration of groundwater seepage, as well as the possibility of inundation, as discussed previously (Category 3: adverse geotechnical behaviour - Groundwater seepage, Category 3: Adverse soil behaviour - Prolonged saturation / waterlogged soils, and

Category 5: Miscellaneous geological, geotechnical, and geomorphological factors - Proximity to surface water courses). Van Tol and Le Roux (2019) defined four primary hydropedological categories, described in more detail in the following paragraphs, with the TSCS soil forms considered to exhibit characteristics corresponding to each of these categories, listed under the relevant soil groups proposed by Fey (2010), provided in Table 2.16.

2.5.1 Recharge soils

This category is characterized by the presence of either shallow or fractured rock, or deep freely draining soils, where vertical flow through and out of the material dominates. The relevant soil forms contain either of the following:

- a thick apedal or neocutanic horizon underlying a humic or orthic horizon, in places overlaid by a thin albic horizon (deep freely draining),
- a thick pedocutanic horizon overlain by a melanic or orthic horizon (deep freely draining),
- a pedocutanic horizon underlain by a lithic horizon (deep freely draining),
- thick alluvium (deep freely draining),
- a podzol horizon without signs of wetness (deep freely draining), in places with a placic pan (vertical flow into shallow or fractured rock),
- a red structured horizon (deep freely draining),
- thick regic sand (deep freely draining),
- a thin topsoil horizon overlying a lithic horizon considered not hard (vertical flow into shallow or fractured rock), or
- anthropogenic horizons (vertical flow into shallow or fractured rock).

2.5.2 Interflow soils

This character defines cases where lateral movement of soil moisture occurs along either the contact between the topsoil and sub-surface soil horizons, or between the soil / bedrock interface. The relevant soil forms comprise those containing either:

- a thick albic horizon (interflow along soil/bedrock interface),
- an albic horizon overlying various sub-surface horizons (interflow between horizons), or overlying unconsolidated material or a podzol horizon exhibiting signs of wetness (interflow along soil/bedrock interface),
- a pedocutanic horizon overlying a gley horizon (interflow along soil/bedrock interface),

Table 2.16: Soil forms according to the Taxonomical Soil Classification System (not all originally listed[^]) grouped into hydropedological categories (Van Tol & Le Roux, 2019). Soil forms arranged according to the soil groups proposed by Fey (2010).

RECHARGE		INTERFLOW		RESPONSIVE		STAGNATING
Deep presence of deep freely draining soils	**Shallow** presence of shallow or fractured rock	**A / B Horizon** lateral movement of soil moisture along contact between topsoil & sub-surface horizons	**Soil / Bedrock** lateral movement of soil moisture between soil/bedrock interface	**Shallow*** overland flow due to presence of relatively impermeable material close to surface	**Saturated** overland flow due to presence of soils that undergo prolonged saturation close to surface	outflow of soil moisture is limited or restricted
HUMIC Ia - Inanda Kp - Kranskop Lu - Lusiki Ma - Magwa Sr - Sweetwater **MELANIC** Bo - Bonheim Ik - Inhoek **DUPLEX** Sw - Swartland Va - Valsrivier **PODZOLIC** Cc - Concordia Gk - Groenkop Hh - Houwhoek Pg - Pinegrove Ts - Tsitsikamma **OXIDIC** Cv - Clovelly Gf - Griffen Hu - Hutton Sd - Shortlands **GLEYIC** Ct - Constantia **INCEPTIC - CUMULIC** Du - Dundee Nb - Namib	**HUMIC** No - Nomanci[#] **MELANIC** My - Mayo[#] Mw - Milkwood[#] **PODZOLIC** Jb - Jonkersberg **INCEPTIC - LITHIC** Gs - Glenrosa[#] Ms - Mispah[#] **INCEPTIC - ANTHROPIC** Wb - Witbank	**DUPLEX** Km - Klapmuts **09. PLINTHIC** Lo - Longlands Wa - Wasbank **GLEYIC** Cf - Cartref Kk - Kinkelbos Kd - Kroonstad Vf - Villafontes	**DUPLEX** Se - Sepane **PODZOLIC** Lt - Lamotte Wf - Witfontein **PLINTHIC** Av - Avalon Bv - Bainsvlei We - Westleigh **OXIDIC** Bd - Bloemdal Pn - Pinedene **GLEYIC** Fw - Fernwood **INCEPTIC - CUMULIC** Mu - Montagu Tu - Tukulu	**HUMIC** No - Nomanci[&] **VERTIC** Ar - Arcadia **MELANIC** My - Mayo[&] Mw - Milkwood **INCEPTIC - LITHIC** Gs - Glenrosa[&] Ms - Mispah[&]	**ORGANIC** Ch - Champagne **VERTIC** Rg - Rensburg **MELANIC** Wo - Willowbrook **GLEYIC** Ka - Katspruit	**MELANIC** Im - Immerpan Sn - Steendal **SILICIC** Gr - Garies Kn - Knersvlakte Ou - Oudtshoorn Tr - Trawal **CALCIC** Ad - Addo Ak - Askham Br - Brandvlei Cg - Coega Ky - Kimberley Mp - Molopo Py - Plooysburg Pr - Prieska **PLINTHIC** Dr - Dresden Gc - Glencoe **INCEPTIC - CUMULIC** Ag - Augrabies

^ Not listed: Es- Estcourt, Et - Etosha, Gm - Gamoep, and Ss - Sterkspruit.

* Includes soils with very low infiltration rates.

[#] Soils overlying fractured bedrock / lithocutanic B-horizons classifying as ‘not hard’, and soils with an unbleached A-horizon.

[&] Soils overlying relatively impermeable bedrock / lithocutanic B-horizons classifying as ‘hard’, and soils with a bleached A-horizon.

- various topsoil horizons overlying a soft plinthic horizon (interflow along soil/bedrock interface),
- various horizons overlying a gleyic horizon (interflow along soil/bedrock interface), or
- a neocutanic horizon overlying unconsolidated material exhibiting signs of wetness (interflow along soil/bedrock interface).

2.5.3 Responsive soils

This category describes soil conditions typically responsible for overland flow due to the presence of either relatively impermeable material, or soils that undergo prolonged saturation close to the surface. The relevant soil forms contain either:

- a relatively hard lithic horizon, covered by a humic or melanic topsoil (relatively impermeable),
- bedrock (relatively impermeable),
- a thick vertic horizon (relatively impermeable),
- an organic horizon (prolonged saturation), or
- a melanic or vertic topsoil overlying a gley horizon (prolonged saturation).

2.5.4 Stagnating soils

This category describes soil conditions where the outflow of soil moisture is limited or restricted. The relevant soil forms contain either:

- a dorbank horizon,
- a soft carbonate horizon, in places with a melanic topsoil horizon,
- a hard carbonate horizon, in places with a melanic topsoil horizon,
- a hard plinthic horizon, or
- a thick neocarbonate horizon.

2.6 Previous attempts to utilise pedological information

Although the information provided by regional pedological surveys is predominantly used by agricultural specialists and pedologists, practitioners from other fields of expertise have in the past attempted to infer generalised geotechnical properties for the different South African soil forms, predominantly on the hand of the readily available land type inventories. The most prominent of these will be discussed in more detail in the following sections.

2.6.1 Interpretation of pedological data for engineering purposes by Harmse (1977)

Harmse (1977) stated that use of pedological information could be useful for engineering purposes during the planning stage of proposed development, provided that soil maps of suitable scale and accuracy are available, with interpretation thereof based on a comprehensive databank of engineering properties for each diagnostic soil horizon yet to be established. Harmse (1977) further advocated closer cooperation and coordination between pedologists and engineering geologists in order to facilitate this process, while specifically noting that the Binomial Soil Classification System is generally incorrectly perceived as being of value only within an agricultural setting. However, Harmse (1977) cautions against the grouping of soil forms for engineering purposes only according to its pedological classification, but that additional information resulting from engineering geological studies also be considered.

In this light, Harmse (1977) listed inferred geotechnical properties for a number of soil forms based on the results of limited laboratory tests on samples of specific soil horizons, including heave / shrinkage potential and classification thereof according to the United Soil Classification System (USCS), as summary of which is provided in Table 2.17.

Table 2.17: Inferred geotechnical properties for selected soil horizons of the Binomial Soil Classification System (after Harmse, 1977), with corresponding soil groups according to Fey (2010).

Horizon	BSCS soil forms	Corresponding soil groupings (Fey, 2010)	Heave / shrinkage potential	USCS classes
Melanic	Bo - Bonheim Mw - Milkwood	Melanic soils Melanic soils	Very high Very high	CL, CH MH
Pedocutanic	Bo - Bonheim Va - Valsrivier	Melanic soils Duplex soils	High - very high Low - very high	CH CL, CH
Prismacutanic	Es - Estcourt Ss - Sterkspruit	Duplex soils Duplex soils	Very high Very high	CH MH, CH
Vertic	Ar - Arcadia Rg - Rensburg	Vertic soils Vertic soils	Very high Very high	MH, CH MH, CH
G / Gley	Rg - Rensburg	Vertic soils	Very high	MH, CH
Red apedal	Hu - Hutton	Oxidic soils	Low	ML, CL, MH
Yellow-brown apedal	Av - Avalon Cv - Clovelly	Plinthic soils Oxidic soils	Low Low	ML, CL MH
Soft plinthic	We - Westleigh	Plinthic soils	Low	ML, CL

Legend (Holtz & Kovacks, 1981):

ML: Inorganic silts and very fine sands, rock flour, silty / clayey fine sands, or clayey silts with slight plasticity.
MH: Inorganic silts, micaceous / diatomaceous fine sandy or silty soils, or elastic silts.
CL: Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, or lean clays.
CH: Inorganic clays of high plasticity, or fat clays.

2.6.2 Translating pedological information into engineering terms by Brink (1985)

Brink (1985) opinions that while there are fundamental differences between the pedological and engineering geological description of soil profiles, pedological information could be of considerable value for engineering geological investigations in support of linear and township development projects, as well as the identification of potential construction material sources, by providing useful information on the soil character down to bedrock. In particular, the following differences are of importance:

- Engineering geologists typically classify soil to include all unconsolidated material occurring down to bedrock, while pedologists are only interested in the upper 1.2 to 1.5 m of the soil profile, although in the latter case use of the Natural and Anthropogenic Soil Classification System (Soil Classification Working Group, 2018) allows inclusion and assessment of horizons occurring at depths in excess of 1.5 m.
- According to engineering geologists, the origin of a soil material is primarily derived in terms of the effects of external geological and geomorphological processes on the constituent materials. Conversely, pedologists describe soil origin in terms of the effects of internal pedological processes (Brink, 1985).

Brink (1985) further states that soil formation is strongly affected by parent material, climatic regime, and organisms occurring within a specific morphological environment over a specific period of time. Parent material typically comprise either residual soils derived from in-situ weathering of bedrock, or transported soils. Pedogenic layering occurs as a result of the movement of rainwater through the parent material that causes the removal of chemical constituents and fines particles from the upper soil profile with deposition thereof lower down in the sub-surface material, occasionally replaced by accumulated organic material from surface sources. In this light, broad pedological classes are primarily differentiated by the degree of alteration of the original parent material, except in specific cases (e.g., wind-blown sand) where the constituent material is highly resistant to weathering.

Brink (1985) arranged the various soil forms of the Binomial Soil Classification System (MacVicar *et al*., 1977) according to the degree of alteration of the parent materials, ranging from soils exhibiting well developed morphology to those with less distinct morphology. The resultant soil classes, with reference to the BSCS soil forms, parent material, and Brink’s notes on inferred geotechnical constraints, are summarised in Table 2.18, with its broad spatial distribution across Southern Africa illustrated in Figure 2.7. These classes, with reference to the corresponding soil groups proposed by Fey (2010) for the purposes of this study, are discussed in the following paragraphs.

Table 2.18: Summarized soil classes for translating pedological information into engineering terms based on Brink (1985), with mapping units as shown in Figure 2.7. Note: soil forms according to the Binomial Soil Classification System (MacVicar *et al*., 1977), and corresponding soil groups according to Fey (2010).

Mapping unit	Principal BSCS soil form equivalents (MacVicar *et al*., 1977)	Corresponding soil groupings (Fey, 2010)	Parent material	Inferred geotechnical constraints on development
PODZOLIC SOILS CLASS				
0 - Podzolic soils	Ct - Constantia, Hh - Houwhoek, Lt - Lamotte, Sp - Shepstone	Oxidic soils (Ct, Sp) Podzolic soils (Hh, Lt)	Residual sandstone of the Cape Supergroup, and derived colluvium	Potentially collapsible. Very low pH values. Low cohesion (series with less than 15% clay). Slightly impeded (for series with less than 15% clay) to impeded internal drainage.
FERRALLITIC SOILS CLASS				
1a - Mainly red ferrallitic sands	Mesotrophic & dystrophic series with < 20% clay of: Bv - Bainsvlei, Gf - Griffen, Hu - Hutton	Plinthic soils (Bv) Oxidic soils (Gf, Hu)	Residual granite, quartzite, and sandstone, and derived colluvial sands	Potentially collapsible. Low pH values. Excellent internal drainage.
1b - Mainly red ferrallitic clays	Mesotrophic & dystrophic series with > 20% clay of: Bv - Bainsvlei, Gf - Griffen, Hu - Hutton	Plinthic soils (Bv) Oxidic soils (Gf, Hu)	Residual basic igneous rocks, metalavas, phyllites, and schists	Potentially highly compressible. Low pH values. Excellent internal drainage.
1c - Mainly yellow ferrallitic sands	Mesotrophic & dystrophic series with < 20% clay of: Av - Avalon, Cv - Clovelly, Gc - Glencoe, Pn - Pinedene	Plinthic soils (Av, Gc) Oxidic soils (Cv, Pn)	Residual granite, quartzite, and sandstone, and derived colluvial sands	Potentially collapsible. Hardpan ferricrete possible at shallow depth (Gc). Good (Cv), fair (Av), slightly impeded (Pn), and impeded (Gc) internal drainage.
1d - Mainly yellow ferrallitic clays	Mesotrophic & dystrophic series with > 20% clay of: Av - Avalon, Cv - Clovelly, Gc - Glencoe, Pn - Pinedene	Plinthic soils (Av, Gc) Oxidic soils (Cv, Pn)	Residual basic igneous rocks, metalavas, phyllites, and schists	Potentially highly compressible. Hardpan ferricrete possible at shallow depth (Gc). Good (Cv), fair (Av), slightly impeded (Pn), and impeded (Gc) internal drainage.
1e - Humic ferrallitic soils	Series containing >15% clay of: Ia - Inanda, Kp - Kranskop, Ma - Magwa, No - Nomanci	Humic soils	Mainly residual dolerite, and derived colluvium	Potentially highly compressible. Low pH values. Excellent to slightly impeded internal drainage.
FERSIALLITIC SOILS CLASS				
2a - Mainly red fersiallitic sands	Eutrophic series and lime-rich series, with < 20% clay, of: Bv - Bainsvlei, Hu - Hutton	Plinthic soils (Bv) Oxidic soils (Hu)	Residual granite and sandstone, and derived colluvium	Potentially collapsible. Excellent internal drainage.
a2 - Mainly red, narrowly graded fersiallitic sands on aeolian sand	Eutrophic series and lime-rich series, with < 20% clay, of: Bv - Bainsvlei, Hu - Hutton	Plinthic soils (Bv) Oxidic soils (Hu)	Aeolian sand	Potentially collapsible. Excellent internal drainage.
2b - Mainly red fersiallitic clays	Eutrophic series and lime-rich series, with > 20% clay, of: Bv - Bainsvlei, Hu - Hutton	Plinthic soils (Bv) Oxidic soils (Hu)	Residual granite and sandstone, and derived colluvium	Potentially highly compressible. Excellent internal drainage.
2c - Mainly yellow and grey hydromorphic fersiallitic sands	Eutrophic series and lime-rich series, with < 20% clay, of: Av - Avalon, Cv - Clovelly, Gc - Glencoe, Pn - Pinedene	Plinthic soils (Av, Gc) Oxidic soils (Cv, Pn)	Residual sandstone of the Waterberg and Karoo Supergroups, and derived colluvium, as well as aeolian sands	Potentially collapsible. Hardpan ferricrete possible at shallow depth (Gc). Good (Cv), fair (Av), slightly impeded (Pn), and impeded (Gc) internal drainage.
c2 - Mainly narrowly graded fersiallitic sands	Eutrophic series and lime-rich series, with < 20% clay, of: Av - Avalon, Cv - Clovelly, Gc - Glencoe, Pn - Pinedene	Plinthic soils (Av, Gc) Oxidic soils (Cv, Pn)	Aeolian sand	Potentially collapsible. Hardpan ferricrete possible at shallow depth (Gc). Good (Cv), fair (Av), slightly impeded (Pn), and impeded (Gc) internal drainage.
2d - Mainly yellow and grey hydromorphic fersiallitic clays	Eutrophic series and lime-rich series, with > 20% clay, of: Av - Avalon, Cv - Clovelly, Gc - Glencoe, Pn - Pinedene	Plinthic soils (Av, Gc) Oxidic soils (Cv, Pn)	Residual intermediate and basic rocks and shale, and derived colluvium	Potentially highly compressible. Hardpan ferricrete possible at shallow depth (Gc). Good (Cv), fair (Av), and impeded (Gc, Pn) internal drainage.
BLACK AND RED SMECTITIC CLAYS CLASS				
3a - Mainly black smectitic clays	Ar - Arcadia (black series), Bo - Bonheim, Mw - Milkwood, My - Mayo, Tk - Tambankulu	Vertic soils (Ar) Melanic soils (Bo, My, Mw, & Tk)	Residual basic igneous rocks, and Karoo Supergroup and younger mudrocks	Moderately expansive (Mw, My, Tk). Highly expansive (Bo). Extremely expansive (Ar). Impeded - shallow (Mw, My), and impeded to severely impeded (Ar, Bo, Tk) internal drainage.
3b - Mainly red smectitic clays	Ar - Arcadia (red series), Sw - Swartland (red series), Va - Valsrivier (red series), Sd - Shortlands	Vertic soils (Ar) Duplex soil (Sw & Va) Oxidic soils (Sd)	Residual nepheline basalt, ferro-gabbro, basic igneous rocks, metalavas, and Karoo Supergroup mudrocks	Moderately expansive (Sd, Sw, Va). Extremely expansive (Ar). Good (Sd), slightly impeded (Sw, Va), and impeded (Ar) internal drainage.
SOLONETZIC AND PLANOSOLIC, AND HALOMORPHIC SOILS CLASSES				
4a - Solonetzic soils with sandy topsoil	Solonetzic soils: series containing < 15% clay in topsoil or albic horizons of: Es - Estcourt, Kd - Kroonstad, Ss - Sterkspruit	Duplex soils (Es, Ss) Gleyic soils (Kd)	Mainly residual granite, Karoo Supergroup mudrocks (in particular Elliot Formation and Beaufort Group), and alluvium	Potentially compressible when subjected to changes in moisture content. Potentially moderately dispersive and susceptible to erosion. Severely impeded internal drainage.
4b - Solonetzic and planosolic soils with sandy horizons	Solonetzic soils: series containing 15 - 35% clay of: Es - Estcourt, Kd - Kroonstad, Ss - Sterkspruit Planosolic soils: non-red series containing 15 - 35% clay of: Sw - Swartland, Va - Valsrivier	Duplex soils (Es, Sw, Ss, Va) Gleyic soils (Kd)	Mainly residual granite, Karoo Supergroup mudrocks (in particular Elliot Formation and Beaufort Group), and alluvium	Potentially compressible when subjected to changes in moisture content. Potentially moderately dispersive and susceptible to erosion. Sub-surface horizons potentially moderately expansive Impeded to severely impeded internal drainage.
4c - Solonetzic and planosolic soils with clayey horizons	Solonetzic soils: series containing > 35% clay of: Es - Estcourt, Kd - Kroonstad, Ss - Sterkspruit Planosolic soils: non-red series containing > 35% clay of: Sw - Swartland, Va - Valsrivier	Duplex soils (Es, Sw, Ss, Va) Gleyic soils (Kd)	Residual mudrocks, mainly of Malmesbury Group and Karoo Supergroup, and alluvium	Sub-surface horizons potentially moderately to severely expansive. Potentially dispersive and susceptible to piping and erosion. Impeded to severely impeded internal drainage.

Table 2.18: (continued): Summarized soil classes for translating pedological information into engineering terms based on Brink (1985), with mapping units as shown in Figure 2.7. Note: soil forms according to the Binomial Soil Classification System (MacVicar et al., 1977), and corresponding soil groups according to Fey (2010).

Mapping unit	Principal BSCS soil form equivalents (MacVicar *et al*., 1977)	Corresponding soil groupings (Fey, 2010)	Parent material	Inferred geotechnical constraints on development
ARENOSOLS CLASS				
6a - Littoral sands	Eutrophic series of: Cv - Clovelly	Oxidic soils	Dune sand	Potentially collapsible. Low cohesion implies unstable excavation sidewalls. Prone to shifting implying unstable founding surface.
6b - Mainly red arenosols	Eutrophic series of: Hu - Hutton	Oxidic soils	Aeolian sand	Potentially collapsible. Low cohesion implies unstable excavation sidewalls.
6c - Mainly yellow arenosols	Eutrophic series of: Cv - Clovelly	Oxidic soils	Aeolian sand	Potentially collapsible. Low cohesion implies unstable excavation sidewalls.
6d - Greyish hydromorphic sand (undifferentiated)	Wet series of: Fw - Fernwood Dry series of: Fw - Fernwood	Inceptic soils - Cumulic	Hydromorphic sand of low-lying areas with high groundwater table (wet series) or at > 1 m depth (dry series)	Potentially compressible when wet (“quicksand”).
6e & 6f	Series of: Cv - Clovelly, Hu - Hutton, and regic sand (Fw)	Oxidic soils (Cv, Hu) Inceptic soils - Cumulic (Fw)	Aeolian sand	Potentially collapsible. Low cohesion implies unstable excavation sidewalls.
ALLUVIAL AND WEAKLY DEVELOPED SOILS AND OTHER SOILS OF LOW LYING AREAS, AND HYDROMORPHIC SOILS CLASSES				
2c - Grey hydromorphic soils	Series with < 6% clay: Fw - Fernwood Series with < 15% clay: Cf - Cartref, Lo - Longlands, Vf - Villafontes, Wa - Wasbank	Plinthic soils (Lo, Wa) Inceptic soils - Cumulic (Fw, Vf) Inceptic soils - Lithic (Cf)	Residual granite, sandstone, and quartzite, and aeolian sand	Potentially collapsible. Low cohesion implies unstable excavation sidewalls. Impeded to severely impeded internal drainage.
c2 - Hydromorphic sands of aeolian origin	Series with < 6% clay: Cf - Cartref, Fw - Fernwood, Lo - Longlands, Wa - Wasbank	Plinthic soils (Lo, Wa) Inceptic soils - Cumulic (Fw) Inceptic soils - Lithic (Cf)	Aeolian sand	Periodic flooding (waterlogged). Moderately to highly compressible under loading when saturated. Impeded to severely impeded internal drainage.
7a - Dark alluvial sands	Du - Dundee Series with < 15% clay: Oa - Oakleaf	Inceptic soils - Cumulic (Oa, Du)	Alluvium & pedisediments	Potentially compressible. Low cohesion implies unstable excavation sidewalls. Periodic flooding. Slightly impeded internal drainage.
7b - Dark alluvial clays	Ka- Katspruit, Rg - Rensburg, Wo - Willowbrook Series with > 35% clay of: Oa - Oakleaf	Vertic soils (Rg) Melanic soils (Wo) Gleyic soils (Ka) Inceptic soils - Cumulic (Oa)	Flood plain, pan, and vlei sediments	Potentially expansive. High groundwater tables. Flooding (waterlogged). Severely impeded internal drainage.
7c - Alluvium enriched with organic material	Ch - Champagne	Organic soils	Organic alluvium	Extremely low bearing strength. Saturated conditions (waterlogged).
LITHOSOLS AND LITHOLIC SOILS, AND WEAK DEVELOPED SHALLOW SOILS CLASSES				
8b, 0a, 0b, 0d - Shallow sands	Series with less than 15% clay of: Ms - Mispah Lime-poor series with < 15% clay of: Gs - Glenrosa	Inceptic soils - Lithic	Residual granite (Ms) Sandstone / siltstone (Gs)	Bedrock or weathered rock at shallow depth
8a, 9a, 0e - Calcareous sands	Calcareous series with hard rock of: Ms - Mispah	Inceptic soils - Lithic	Calcrete covered with shallow sands	Calcrete at shallow depth
9b, 0e - Calcareous sands	Lime-rich series with < 15% clay of: Gs - Glenrosa	Inceptic soils - Lithic	Residual granite and calcareous rocks	Calcrete at shallow depth
8e - Other shallow soils	Lime-poor series with hardpan ferricrete of: Ms - Mispah	Inceptic soils - Lithic	Residual granite	Ferricrete crusts
8c, 0c, 0f, 0b - Miscellaneous shallow soils	Ms - Mispah Lime-rich series with > 15% clay of: Gs - Glenrosa	Inceptic soils - Lithic	Basic igneous rocks, metamorphic rocks, and mudrocks	Bedrock or weathered rock at shallow depth
8c and 0e, 0c - Miscellaneous shallow soils	Calcareous series with hard rock and > 15% clay of: Ms - Mispah Lime-rich series with > 15% clay of: Gs - Glenrosa	Inceptic soils - Lithic	Residual basic igneous rocks and calcrete	Bedrock or weathered bedrock / calcrete at shallow depth
8d, 0c - Miscellaneous shallow soils	Mw - Milkwood Calcareous series with hard rock and > 15% clay of: Ms - Mispah	Melanic soils (Mw) Inceptic soils - Lithic (Ms)	Residual basic igneous rocks	Bedrock at shallow depth

Figure 2.7: Map showing the broad distribution of the various pedological classes within Southern Africa (after Brink, 1985) with the primary Weinert climatic N-value contours (yellow lines). Note: not to scale - scanned and rescaled from the original.

2.6.2.1 Podzolic soils class

These soils occur predominantly in wetter winter rainfall areas, in the presence of fluvic acid that aids decomposition of clay minerals resulting in the formation of a grey, quartz-rich horizon near the surface that is substantially different in character than typical hydromorphic horizons, with the resulting soil not containing more than 15% clay.

Definition of this class relies on the following aspects:

- Parent material:
  - Residual sandstone of the Cape Supergroup, and derived colluvium.
- BSCS soil forms:
  - Ct - Constantia, Hh - Houwhoek, Lt - Lamotte, and Sp - Shepstone.
- Soil groups:
  - Podzolic soils (Hh & Lt), and
  - Oxidic soil (Ct & Sp).
- Adverse geotechnical behaviour:
  - Potentially collapsible, with very low pH values, and slightly impeded to impeded internal drainage.

2.6.2.2 Ferrallitic soils class

These soils occur predominantly in areas with an annual rainfall in excess of 800 mm, in places associated with older land surfaces and highly weathered transported deposits, with weak horizon differentiation and gradational horizon transitions, containing mainly non-plastic (i.e., 1:1 kaolinitic) clay minerals mixed with free iron and aluminium oxides, and prone to the formation of flocculated structure.

Definition of this class relies on the following aspects:

- Parent material:
  - Mainly red or yellow ferrallitic sands (mesotrophic and dystrophic series with less than 20% clay): residual granite, quartzite, and sandstone, and derived colluvial sands.
  - Mainly red or yellow ferrallitic clays (mesotrophic and dystrophic series with more than 20% clay): residual basic igneous rocks, metalavas, phyllites, and schists.
  - Humic ferrallitic soils (with more than 15% clay): mainly residual dolerite, and derived colluvium.

- BSCS soil forms:
    - Mainly red ferrallitic sands: mesotrophic and dystrophic series with less than 20% clay of Bv - Bainsvlei, Gf - Griffen, and Hu - Hutton.
    - Mainly yellow ferrallitic sands: mesotrophic and dystrophic series with less than 20% clay of Av - Avalon, Cv - Clovelly, Gc - Glencoe, and Pn - Pinedene.
    - Mainly red ferrallitic clays: mesotrophic and dystrophic series with more than 20% clay of Bv - Bainsvlei, Gf - Griffen, and Hu - Hutton.
    - Mainly yellow ferrallitic sands: mesotrophic and dystrophic series with more than 20% clay of Av - Avalon, Cv - Clovelly, Gc - Glencoe, and Pn - Pinedene.
    - Humic ferrallitic soils: series with more than 15% clay of Ia - Inanda, Kp - Kranskop, Ma - Magwa, and No - Nomanci.
- Soil groups:
    - Humic soils (Ia, Kp, Ma, & No),
    - Plinthic soils (Av, Bv, & Gc), and
    - Oxidic soil (Cv, Gf, Hu, & Pn).
- Adverse geotechnical behaviour:
    - Invariably, non-expansive and not dispersive, and considered well-suited for the construction of cuts and fills.
    - Potentially collapsible, with low pH values and excellent internal drainage: Bv, Gf, & Hu with less than 20% clay.
    - Potentially collapsible, with highly variable (good to impeded) internal drainage, and hardpan ferricrete occurring at relatively shallow depth (Gc): Av, Cv, Gc, & Pn with less than 20% clay.
    - Potentially highly compressible, with low pH values and excellent internal drainage: Bv, Gf, & Hu with more than 20% clay.
    - Potentially highly compressible, with highly variable (good to impeded) internal drainage, and hardpan ferricrete occurring at relatively shallow depth (Gc): Av, Cv, Gc, & Pn with more than 20% clay.
    - Potentially highly compressible, with low pH values and excellent to slightly impeded internal drainage: Ia, Kp, Ma, & No with more than 15% clay.

2.6.2.3 Fersiallitic soils class

These soils occur predominantly as red or yellow soils with weak to moderately developed structure in areas with moderate rainfall (i.e., annually between 450 and 800 mm), often underlaid by calcareous material especially beneath wind-blown sandy deposits, with gradational horizon transitions, albeit in places with distinct concentrations of iron oxides especially within yellow horizons, containing mainly non-plastic (i.e., 1:1 kaolinitic) clay minerals mixed with more plastic 2:1 (i.e., hydromica-vermiculite-smectite) and 2:2 (i.e., chloritic) types, with the poorly-drained grey hydromorphic horizons invariably associated with groundwater seepage especially in quartz-rich parent material.

Definition of this class relies on the following aspects:

- Parent material:
    - Mainly red fersiallitic sands (eutrophic series and series containing free lime, with less than 20% clay): residual granite and sandstone, and derived colluvium.
    - Narrowly graded, fersiallitic sand, and narrow graded, mainly red fersiallitic sands on aeolian sands (eutrophic series and series containing free lime, with less than 20% clay): aeolian sand.
    - Mainly yellow and grey hydromorphic fersiallitic sands (eutrophic series and series containing free lime, with less than 20% clay): residual sandstone of the Waterberg and Karoo Supergroups, and derived colluvium, as well as aeolian sands.
    - Mainly red fersiallitic clays, and mainly yellow and grey hydromorphic clays (eutrophic series and series containing free lime, with more than 20% clay): residual intermediate and basic rocks and shale, and derived colluvium.
- BSCS soil forms:
    - Mainly red fersiallitic sands, and narrow graded, mainly red fersiallitic sands on aeolian sands: eutrophic series and series containing free lime, with less than 20% clay, of Bv - Bainsvlei, and Hu - Hutton.
    - Mainly red fersiallitic clays: eutrophic series and series containing free lime, with more than 20% clay, of Bv - Bainsvlei, and Hu - Hutton.
    - Narrow graded fersiallitic sands, mainly yellow and grey hydromorphic fersiallitic sands: eutrophic series and series with free lime, with less than 20% clay, of Av - Avalon, Cv - Clovelly, Gc - Glencoe, and Pn - Pinedene.

  - Mainly yellow and grey hydromorphic fersiallitic clays: eutrophic series and series with free lime, with more than 20% clay, of Av - Avalon, Cv - Clovelly, Gc - Glencoe, and Pn - Pinedene.
- Soil groups:
  - Plinthic soils (Av, Bv, & Gc), and
  - Oxidic soil (Cv, Hu, & Pn).
- Adverse geotechnical behaviour:
  - Generally, considered non-expansive, with the low cohesion of the sandier material considered problematic.
  - Potentially collapsible, with excellent internal drainage: Bv & Hu with less than 20% clay.
  - Potentially collapsible, with good to impeded internal drainage, and hardpan ferricrete at relatively shallow depth (Gc): Av, Cv, Gc, & Pn with less than 20% clay.
  - Potentially highly compressible, with excellent internal drainage: Bv & Hu with more than 20% clay.
  - Potentially highly compressible, with good to impeded internal drainage, and hardpan ferricrete at relatively shallow depth (Gc): Av, Cv, Gc, & Pn with more than 20% clay.

2.6.2.4 Black and red smectitic clays class

These soils are characterised as dark or red coloured soils comprising mainly highly plastic smectitic clay minerals (i.e., 2:1 types) exhibiting well-developed structure (typically described as slickensided and shattered) with changes in moisture content, often associated with evidence of argillo-pedoturbation at the surface (e.g., surface cracks, gilgai, or self-mulching), typically occurring along low relief terrain on basic or ultrabasic igneous rocks, or on lime-rich Karoo Supergroup mudrocks, in both bottomland and upland scenarios, especially in areas with a hot and dry climate, excluding dark hydromorphic alluvial clays in areas with poor drainage and a high groundwater table (i.e., prolonged saturation).

Definition of this class relies on the following aspects:

- Parent material:
  - Mainly black smectitic clays: residual basic igneous rocks, and Karoo Supergroup and younger mudrocks.
  - Mainly red smectitic clays: residual nepheline basalt, ferro-gabbro, basic igneous rocks, metalavas, and Karoo Supergroup mudrocks.

- BSCS soil forms:
  - Mainly black smectitic clays: Ar - Arcadia (black series), Bo - Bonheim, Mw - Milkwood, My - Mayo, and Tk - Tambankulu.
  - Mainly red smectitic clays: Arcadia (red series), Sd - Shortlands, Sw - Swartland (red series), and Va - Valsrivier (red series).
- Soil groups:
  - Vertic soils (Ar),
  - Melanic soils (Bo, Mw, My, & Tk),
  - Duplex soil (Sw & Va), and
  - Oxidic soils (Sd).
- Adverse geotechnical behaviour:
  - Potentially moderately (typically red coloured, or thin dark coloured clays) to extremely (predominantly dark coloured clays) expansive, and slightly impeded to impeded internal drainage, in places at shallow depth.

2.6.2.5 Solonetzic and Planosolic soils, and Halomorphic soils classes

Solonetzic and Planosolic soils comprise soil forms containing a dark sub-surface horizon exhibiting moderately to strongly developed pedocutanic or prismacutanic characteristics, in places overlain by an E- or albic horizon, as well as soils with distinct textural differentiation between the topsoil and sub-surface horizons where the latter has undergone significant leaching (in particular with regard to sodium).

Halomorphic soil forms are generally similar to that of Solonetzic and Planosolic soils, but contain significant amounts of free salts, occurring within nearly all pans predominantly along low-lying areas, especially in the drier western and northwestern portions of South Africa.

Definition of this class relies on the following aspects:

- Parent material:
  - Solonetzic / Halomorphic soils with sandy topsoil: mainly residual granite, and mudrocks of the Elliot Formation and Beaufort Group of the Karoo Supergroup, and alluvium.
  - Solonetzic and Planosolic / Halomorphic soils with clayey topsoil: mainly residual mudrocks of the Malmesbury Group and Karoo Supergroup, and alluvium.

- BSCS soil forms:
  - Solonetzic and Planosolic / Halomorphic soils with sandy topsoil: series with < 15% clay in topsoil and E- / albic horizon of Es - Escourt, Kd - Kroonstad, and Ss - Sterkspruit.
  - Solonetzic / Halomorphic soils with sandy topsoil: series with 15 to 35% clay of Es - Escourt, Kd - Kroonstad, and Ss - Sterkspruit.
  - Planosolic / Halomorphic soils with sandy topsoil: non-red series with 15 to 35% clay of Sw - Swartland, and Va - Valsrivier.
  - Solonetzic / Halomorphic soils with sandy topsoil: series with more than 35% clay of Es - Escourt, Kd - Kroonstad, and Ss - Sterkspruit.
  - Planosolic / Halomorphic soils with sandy topsoil: non-red series with more than 35% clay of Sw - Swartland, and Va - Valsrivier.
- Soil groups:
  - Duplex soils (Es, Ss, Sw, & Va), and
  - Gleyic soils (Kd).
- Adverse geotechnical behaviour:
  - Potentially compressible when subjected to changes in moisture content, potentially moderately dispersive and susceptible to erosion, with severely impeded internal drainage: Solonetzic / Halomorphic soils with sandy topsoil.
  - Potentially compressible when subjected to changes in moisture content, potentially moderately dispersive and susceptible to erosion, and sub-surface horizons potentially moderately expansive, with impeded to severely impeded internal drainage: Solonetzic and Planosolic / Halomorphic soils with sandy topsoil.
  - Sub-surface horizons potentially moderately to severely expansive, and potentially dispersive and susceptible to piping and erosion, with impeded to severely impeded internal drainage: Solonetzic and Planosolic / Halomorphic soils with sandy topsoil.

2.6.2.6 Arenosols class

This class comprises soil profiles that have undergone little or no soil formation or horizon differentiation, typically developed on transported soils, including young sandy alluvial deposits, being red coloured in uplands areas and dune ridges, yellow in flat-lying areas, and grey in bottomlands areas and areas with impeded drainage.

Definition of this class relies on the following aspects:

- Parent material:
    - Littoral sands and mainly red or yellow arenosols: dune or aeolian sand.
    - Undifferentiated greyish hydromorphic sands: Hydromorphic sands in low-lying areas with either a high groundwater table, or one occurring at a depth in excess of 1 m.
- BSCS soil forms:
    - Littoral sands and mainly red or yellow arenosols: eutrophic series of Cv - Clovelly and Hu - Hutton.
    - Undifferentiated greyish hydromorpic sands: both wet and dry series of Fw - Fernwood.
- Soil groups:
    - Oxidic soils (Cv & Hu), and
    - Inceptic soils - Cumulic (Fw).
- Adverse geotechnical behaviour:
    - Potentially collapsible, with low cohesion implying unstable excavation sidewalls and the red littoral sands could shift, while the greyish hydromorphic soils could be potentially compressible when saturated giving rise to “quicksand” conditions.

2.6.2.7 Alluvial and weakly developed soils and other soils of low lying areas, and Hydromorphic soils classes

Alluvial soils comprise relatively young, immature soils found within marshes and along the banks and floodplains of major rivers, and dark coloured soils occurring between seif dunes, as well as in areas where surface drainage has been disrupted by relatively recent tectonic movement, where incipient soil formation is evident primarily in the form of clay movement and bioturbation.

Hydromorphic soils comprise soil forms exhibiting distinct signs of wetness (either present as a bleached sub-surface horizon overlying rock, or mottled clay that has often undergone ferruginization) where either an impervious sub-surface horizon inhibits the movement of groundwater along seepage lines, or soil formation is influenced by prolonged saturation (i.e., a nearly permanent groundwater table) along seepage lines especially in areas covered by permeable sandy deposits, typically occurring higher up in the landscape than solonetzic soils.

Definition of these classes relies on the following aspects:

- Parent material:
    - Grey hydromorphic sands: residual granite, sandstone, and quartzite, and aeolian sand.

- Hydromorphic sands of aeolian origin: aeolian sand.
- Dark alluvial sands: alluvium and pedisediments.
- Dark alluvial clays: flood plain, pan, and vlei sediments.
- Alluvium enriched with organic material: organic alluvium.

- BSCS soil forms:
  - Grey hydromorphic sands: series with less than 6% clay of Fw - Fernwood, and series with less than 15% clay of Cf - Cartref, Lo - Longlands, Vf - Villafontes, and Wa- Wasbank.
  - Hydromorphic sands of aeolian origin: series with less than 6% clay of Fw - Fernwood, Cf - Cartref, Lo - Longlands, and Wa- Wasbank.
  - Dark alluvial sands: Du - Dundee, and series with less than 15% clay of Oa - Oakleaf.
  - Dark alluvial clays: Ka- Katspruit, Rg - Rensburg, Wo - Willowbrook, and series with > 35% clay of Oa - Oakleaf.
  - Alluvium enriched with organic material: Ch - Champagne.
- Soil groups:
  - Organic soils (Ch),
  - Vertic soils (Rg),
  - Melanic soils (Wo),
  - Plinthic soils (Lo, Wa),
  - Gleyic soils (Ka),
  - Inceptic soils - Cumulic (Du, Fw, Oa, & Vf), and
  - Inceptic soils - Lithic (Cf).
- Adverse geotechnical behaviour:
  - Potentially collapsible, with low cohesion implying unstable excavation sidewalls, and impeded to severely impeded internal drainage: grey hydromorphic sands.
  - Periodic flooding (waterlogged conditions) and potentially moderately to highly compressible under loading when saturated, with impeded to severely impeded internal drainage: hydromorphic sands of aeolian origin.
  - Potentially compressible, with low cohesion implying unstable excavation sidewalls, with periodic flooding and slightly impeded internal drainage: dark alluvial sands.

- Potentially expansive, with high groundwater tables and periodic flooding (waterlogged conditions), and severely impeded internal drainage: dark alluvial clays.
- Extremely low bearing strength predominantly under saturated conditions (waterlogged): alluvium enriched with organic material.

2.6.2.8 Lithosols and litholic soils, and weakly developed shallow soils, classes

Lithosols and litholic soils are defined as skeletal soils that overlie relatively resistant bedrock or weathered rock at shallow depth, generally present along relatively steep slopes, especially in areas with a dry climate, while rapid erosion of weathering products could occur above weathered rock along steep slopes in areas with a wetter climate, with the character of the topsoil closely related to its parent material.

Weakly developed shallow soils are typically, shallow reddish to greyish brown sandy soils overlying reddish and yellowish brown sandy and clayey soil, located along the transition between semi-humid and arid areas, frequently containing a biotic stone line or pebble marker at shallow depth, and does not exhibit a hydromorphic character.

Weakly developed soils in arid areas are defined as shallow, brown to greyish brown soils, occasionally without a prominent sub-surface horizon, exhibiting properties closely associated with its parent material or underlying hardpan pedocrete, with the topsoil frequently being lime-rich, in places containing gypsum.

Definition of these classes relies on the following aspects:

- Parent material:
    - Shallow sands: residual granite, sandstone, and siltstone.
    - Calcareous sands: calcrete covered by shallow sand, and residual granite and calcareous rocks.
    - Other shallow soils: residual granite.
    - Miscellaneous shallow soils: basic igneous rocks, metamorphic rocks, calcrete, and mudrocks.
- BSCS soil forms:
    - Shallow sands: undifferentiated series with less than 15% clay of Ms - Mispah, and lime-poor series with less than 15% clay of Gs - Glenrosa.
    - Calcareous sands: lime-rich series with hard rock of Ms - Mispah, and lime-rich series with less than 15% clay of Gs - Glenrosa.

    - Other shallow soils: lime-poor series with hardpan ferricrete and less than 15% clay of Ms - Mispah.
    - Miscellaneous shallow soils: undifferentiated series of Ms - Mispah, lime-rich series with hard rock and more than 15% clay of Ms - Mispah, lime-rich series with > 15% clay of Gs - Glenrosa, and Mw - Milkwood.
- Soil groups:
    - Melanic soils (Mw), and
    - Inceptic soils - Lithic (Gs & Ms).
- Adverse geotechnical behaviour:
    - Bedrock or weathered rock at shallow depth: shallow sands.
    - Calcrete at shallow depth: calcareous sands.
    - Ferricrete crusts: other shallow soils.
    - Bedrock or weathered rock shallow depth: miscellaneous shallow soils.

2.6.3 Inferring engineering soil properties from land type inventories by Fanourakis (1990)

Fanourakis (1990) established a mathematical model to allow the determination of the engineering properties of soils from pedological data obtained from the available land type inventories without requiring any physical testing. This was deemed of importance during regional soil surveys for township proclamation purposes, as well as for the assessment of proposed road and rail routes.

The proposed mathematical model utilises the following pedological characteristics:

- pedological grading properties, and
- pedological chemical properties.

Application of this model yields the following engineering properties:

- engineering grading characteristics,
- plasticity characteristics,
- compaction characteristics,
- bearing strength characteristics, and
- swell characteristics.

Fanourakis (1990) concluded that application of this mathematical model might reduce the costs of a regional geotechnical assessment with up to 30%, dependent on the magnitude and complexity of the project. In his research, Fanourakis (1990) reached similar conclusions to that of Harmse (1977), stating that the assessment of pedological information during preliminary stage geotechnical investigations should preferably be based on a comprehensive databank of geotechnical properties for each soil horizon to be establish by geopractitioners. Additionally, he advocated use of pedological information from additional sources rather than relying only on the land type inventories.

Lambrechts and MacVicar (2004) noted that Fanourakis' work assists in the estimation of several parameters of importance in engineering applications from soil test data specifically with regard to Arcadia, Hutton, Shortlands, Swartland, and Valsrivier soil forms. In particular, it is important to note that the results of work conducted by Fanourakis (2012) clearly revealed that red apedal sub-surface horizons containing more than 12% clay exhibit a degree of plasticity, and as such could potentially undergo a degree of heave / shrinkage with changes in moisture content.

However, this promising, but complex, system was not generally accepted by the geotechnical fraternity (Paige-Green & Turner, 2007), as most of the information required for its use relied on an intimate knowledge of soil science and related tests, rather than industry-standard engineering geological methodology in regular use by geotechnical practitioners. Additionally, the determination of geotechnical soil properties by means of laboratory and/ or chemical tests is considered contrary to the desktop-level application that forms the foundation of this study.

2.6.4 Assigning engineering geological properties to soils by Hattingh (1995)

Hattingh (1995) conducted research on the relationship between engineering geological properties of soil and the different soil forms of the Taxonomical Soil Classification System (Soil Classification Working Group, 1991) from a pedological perspective. Hattingh (1995) proposed that the geotechnical behaviour of the different soil forms be assessed by means of eight properties broadly corresponding to the geotechnical parameters proposed by Partridge *et al*. (1993), namely:

- erodible soils,
- soils in which groundwater seepage occurs,
- soils affected by elevated groundwater levels,
- dispersive soils,
- shallow soils,

- compressible soils,
- collapsible soils, and
- expansive soils.

A more detailed discussion of the resultant grouping of soil forms, as well as the rationale behind each, is provided by Table 2.19. It must be noted that the soil forms comprising each group were translated to that of the Binomial Soil Classification (MacVicar *et al*., Soil Classification Working Group, 2018) for the purposes of this study to simplify integration of this information with that available through the land type maps and memoirs.

Although unpublished, the work conducted by Hattingh (1995) was invaluable in providing the foundation for the current research.

Table 2.19: Inferred geotechnical properties of various soil forms according to the Binomial Soil Classification System (adjusted from Hattingh, 1995).

Geotechnical properties	Discussion, with lists of relevant soil forms
A. Erodible soils	It is not desirable to attempt to classify the erosion potential of an area in terms of its soil cover alone, as this is influenced by several other factors (e.g., slope, vegetation cover, conservation practices, etc.). However, knowledge regarding the permeability, organic content and grading of the soil material is of importance in the assessment of the erodibility of an area.
B. Soils in which groundwater seepage occurs	The presence of an E-horizon is generally deemed to be indicative of periodic or seasonal groundwater seepage within the topsoil, except when occurring above a podzolic horizon. Cartref, Constantia, Estcourt, Kroonstad, Longlands, Shepstone, Vilafontes, Wasbank
C. Soils affected by elevated groundwater levels	Those soil types exhibiting either a G or a gleycutanic B-horizon, or material comprising predominantly organic material, are deemed affected by prolonged saturation as a result of elevated groundwater levels. Champagne, Katspruit, Kroonstad, Pinedene, Rensburg, Willowbrook
D. Dispersive soils	Soil horizons exhibiting moderately well (i.e., pedocutanic) and strongly developed structure (i.e., prismacutanic) could be strongly dispersive. Estcourt, Sterkspruit, Swartland, Valsrivier
E. Shallow soils	Soil types where the diagnostic horizons are generally underlaid by hard rock or hardpan pedocrete (e.g., ferricrete, calcrete or silcrete) tend to be relatively thin, hampering the excavation of foundation and bulk service trenches. Cartref, Glenrosa, Mayo, Milkwood, Mispah, Nomanci
F. Compressible soils	Soils comprising normally consolidated clayey material that exhibits low strength (typically defining a G-horizon), or those composed predominantly of organic material, are deemed potentially highly compressible. Hattingh (1995) noted that occurrences of these soils along the coastal belt of the country are generally more problematic than similar, but shallower, over-consolidated clayey soils deeper inland. Champagne, Katspruit, Rensburg, Willowbrook
G. Collapsible soils	Soils exhibiting loose- to soft consistency are generally prone to densification under loading. However, potentially collapsible soils (mainly sandier material with low density and a degree of colloidal cementation) undergo significant consolidation when wet. These are defined by soils with either an apedal B, neocutanic B, or E-horizon, that have undergone a degree of leaching. Constantia, Estcourt, Glencoe, Griffen, Houwhoek, Hutton, Inhoek, Kroonstad, Lamotte, Longlands, Oakleaf, Pinedene, Shepstone, Vilafontes, Wasbank
H. Expansive soils	Soils exhibiting strong structure are expected to exhibit moderate to very strong expansive properties, albeit some only when saturated. Hattingh (1995) further noted that these soils are generally only problematic when the soil profile is deep, the soil material has undergone desiccation with a risk of an increase in moisture, or when a lightly loaded structure is to be constructed upon this material. Arcadia, Bonheim, Estcourt, Inhoek, Katspruit, Kroonstad, Mayo, Milkwood, Rensburg, Shortlands, Sterkspruit, Swartland, Valsrivier, Westleigh, Willowbrook

CHAPTER 3 STUDY DESIGN AND METHODOLOGY

3.1 Introduction

Preliminary stage geotechnical investigations invariably result in the compilation of preliminary geotechnical zonation maps where portions of the study area in question exhibiting roughly similar geological, geotechnical, and geomorphological characteristics are grouped together. Experience shows that project areas at best comprise one or two terrain units (used as the basic mapping element) within the same land type, but at worst could encompass several land types comprising many terrain units exhibiting widely differing inferred geotechnical behaviour. It is therefore desirable to aggregate the results of reconnaissance-level geotechnical assessments. PSGIs primarily rely on a study of existing information enhanced by the practitioner’s own experience, and as such, decisions are invariably subjective. The generalised nature of the subject matter that encompasses such a wide field of natural materials to consider hampers standardisation, while the introduction of an unfamiliar information source, in the form of the results of pedological surveys, further complicates matters. In this light, it is evident that this study will require implementation of methods and techniques that facilitate the establishment of standardised formats to collate the information in an effective manner while still allowing personal experience that improves accuracy, and incorporating use of pedological information in a user-friendly manner without a steep learning curve. The availability of regional soils information grouped into terrain units either based on the land type maps and memoirs, or obtained from other regional soil surveys, supported by the regional geotechnical maps from the CGS and other published sources, makes this a valuable asset for utilisation in preliminary stage geotechnical investigations. However, the development of a geotechnical characterisation system, based on industry-standard principles and presented in a scientifically supportable manner, is required to facilitate utilisation thereof by engineering geologists and other geotechnical practitioners. Such a system would be greatly beneficial in the identification of inferred adverse geological, geotechnical, hydropedological, and geomorphological factors affecting the development potential of any given site.

Within this framework, the strategy used to develop a geotechnical characterisation system that utilises pedological information was based on the following methodologies, as shown diagrammatically in Figure 3.1

- The research commenced with a review of various technical publications of a legislative, geological, and geotechnical nature in order to define the framework within which the research was to be conducted, as well as revealing gaps to be addressed by the research (qualitative research).

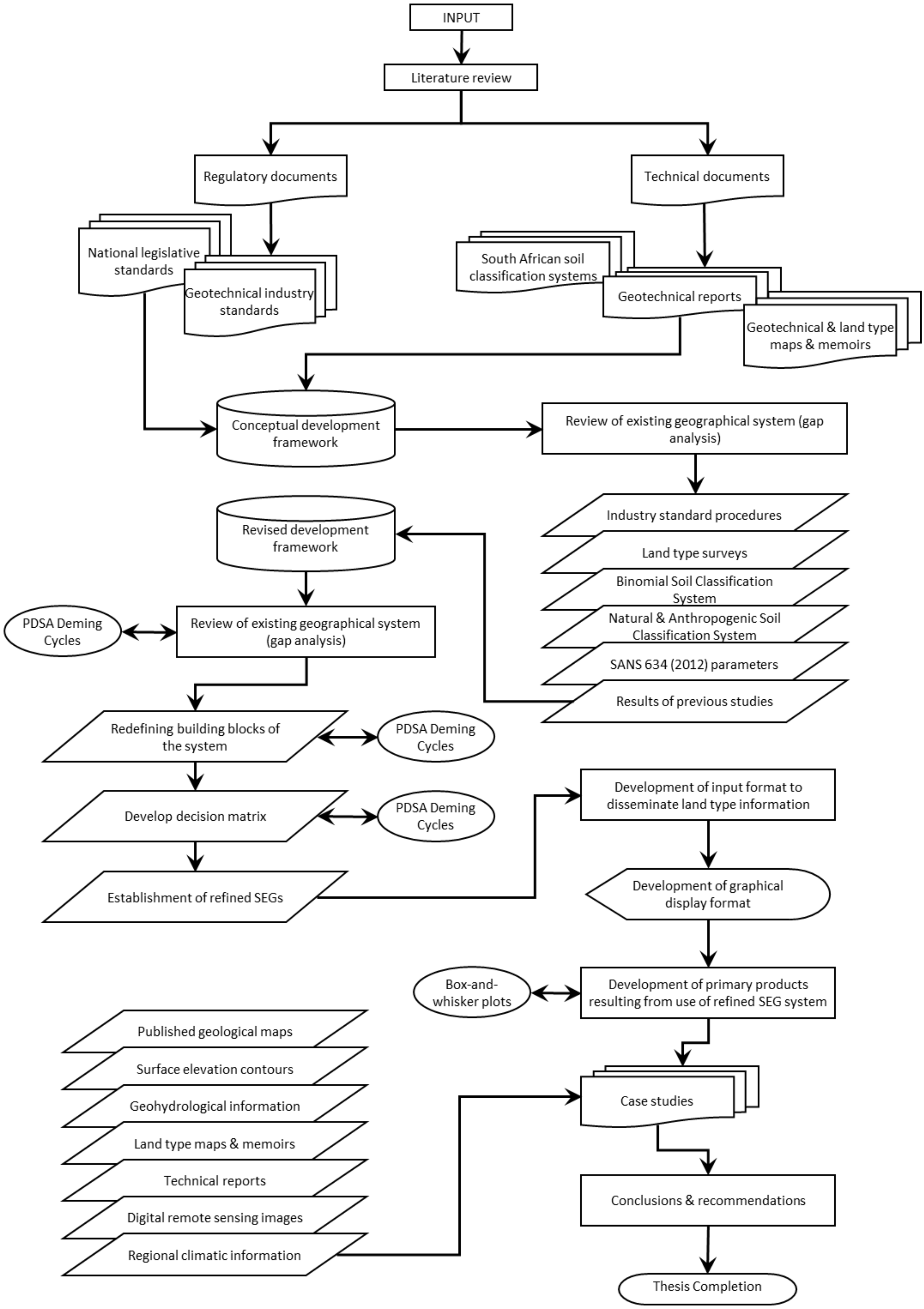


Figure 3.1: Flow diagram depicting the development framework utilised during this study.

- Information obtained by means of the literature review was subsequently utilised to review and improve an existing geotechnical characterisation system by means of Plan-Do-Study-Act (PDSA) Deming cycles, as illustrated Figure 3.2 (quantitative research).

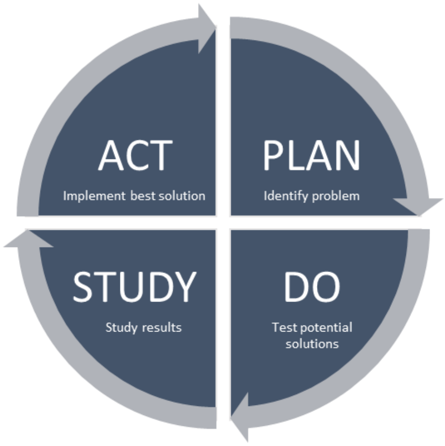


Figure 3.2: Typical Plan-Do-Study-Act Deming Cycle (after Moen, 2009, and ASQ, 2020).

This process is of particular value for the development of a new or improved process, and facilitates data collection and analysis while allowing for the implementation of changes and/ or improvements on a continuous basis (Moen, 2009 and ASQ, 2020). According to Moen (2009) the Plan phase of the cycle incorporates recognition and understanding of a research problem by analysing the available information, thus allowing the planning of a course of action. This includes the planning of relatively small-scale improvements to be made to a process as a result of anomalous results observed during a previous cycle. Implementation of the plan or improvement during the Do phase leads to the observation and documentation of results, as well as any problems or anomalies. Results are analysed in more detailed during the Study phase, at which time it is compared to the expected results and the effects of improvements noted. The process culminates with the Act phase during which a decision is made to either adopt the proposed changes or improvements, discard it, or re-run the cycle.

Various PDSA Deming cycles were run to

- conduct a review of an existing geotechnical characterisation system, including gap analysis that defined proposed improvements,
- collate and categorise the various soils information, adverse geotechnical characteristics, and reporting parameters of relevance to this study, and

  - facilitate the ranking of the resultant soil patterns and adverse geotechnical characteristics according to the inferred effect of each on the cost and ease of development.
- Analyses of the results of the research by statistical means were deemed impractical, as the research will not yield quantifiable numerical data. Additionally, the resultant geotechnical characterisation system will be unique and as such has no direct comparisons. In this light, the success of the research was rather analysed by,
  - comparing results obtained by the application of the newly refined geotechnical characterisation system with that obtained during a relevant detailed geotechnical investigation specifically noting accuracy, deviations, overestimations, and underestimations (qualitative research), and
  - by demonstrating its worth by means of suitable case studies representing typical real-world scenarios (qualitative research).

In the light of a reliance on personal experience promoted by this research, establishment of a comprehensive databank of geotechnical properties for each of the diagnostic soil horizons was considered supplemental to this study, as the scope of that task is sufficient to warrant a separate study in its own right.

3.2 Data gathering and processing

The research framework was established by a review of relevant articles, books, and other publications available online and from the NWU library, as well as the AGES corporate library. This included assessment of the following:

- standard procedures required for preliminary stage geotechnical investigations, especially with regard to the EIA process, to help define definition of the output format resultant from this research,
- the various regional soils mapping studies within the South African context to assess the suitability thereof as sources of information to either facilitate the establishment of the SEG system, or enhance the results thereof,
- the different soil forms defined by the BSCS (MacVicar *et al*., 1977), TSCS (Soil Classification Working Group, 1991), and NASCS (Soil Classification Working Group, 2018), mainly with the aim of facilitating the establishment of the soils effects groupings,
- the various adverse geological, geotechnical, and geomorphological characteristics predominantly pertaining to residential development in order to establish reference sheets to

aid decision-making during the conducting of PSGIs, and

- previous attempts to infer geotechnical characteristics from the results of regional soil mapping, to ascertain whether all or parts thereof could enhance the current research, including an initial version of a geotechnical characterisation system.

The following information sources were utilised during the development of the geotechnical characterisation system, namely:

- regional soils information provided by land type maps and accompanying memoirs, available in hard copy format from the ISCW (ARC-ISCW, 2019) and digitally via the Comprehensive Atlas Version 2 (DAFF, 2019),
- the published handbooks on all three of the South African soil classification systems, and
- published articles, books, and other publications relevant to the assessment of soil characteristics and adverse geotechnical behaviour, including a technical publication detailing the initial version of the geotechnical characterisation system under development, available online and in various libraries.

The following sources of information were collated and evaluated during the establishment of relevant case studies to facilitate assessment of the efficacy of the geotechnical characterisation system resultant from this research, namely:

- published geological, geotechnical and land type maps and associated memoirs, available in hard copy and digital formats from various sources, including the CGS and ARC,
- surface elevation contours obtained from the JAXA,
- digital remote sensing images, predominantly via Google Earth Pro (version 7.3.2.5776),
- regional climatic information obtained from online and/ or published sources,
- the results of a detailed geotechnical site investigation had been obtained using conventional geotechnical investigative methods, as reported on by means of an unpublished technical report contained in the AGES corporate library.

The collected data was subsequently processed, incorporating extraction, tabulation, and sorting thereof using a systematic formula based on principles detailed in the following sections.

Data collation and assessment during development of the geotechnical characterisation system and during the establishment of the case studies relied on use of Microsoft Excel (version 16.32).

3.3 Development of the Soils Effects Grouping system

3.3.1 A phased approach

Key considerations and steps in the development of the Soils Effects Grouping (SEG) system that constitutes the primary result of the research, by means of a phased approach, are illustrated in Figure 3.3, and discussed in more detail in the following sections.

3.3.2 Phase 1: Establishment of the first version of the SEG system

Although falling outside the scope of this study, the development process can be described by way of the following steps to provide background to this research, namely:

- Step 1: Development of the first version of the SEG system,
- Step 2: Publication of the first version, and
- Step 3: Implementation of the first version.

3.3.3 Phase 2: Critical review of the first version of the SEG system

- Step 4: Literature review:

  Refinement of the SEG system commenced with a thorough review of the latest industry standards and guidelines to define the framework within which revision of the SEG system will be undertaken.

- Step 5: Gap analyses:

  In the light of the framework established during the literature review, the SEG system was subjected to a critical review through the use of a number of PDSA Deming Cycles, resulting in a gap analysis that revealed several shortcomings and weaknesses. These included limitations of the basic decision matrix that drives the whole system that exclude assessment of some geotechnical characteristics that could adversely affect the cost and ease of development. Additionally, the NASCS was found to offer significant additional information on soil behaviour that could enhance the efficacy of the SEG system when used for preliminary stage geotechnical investigations, and as such requires re-alignment of the SEG system with the NASCS, rather than the BSCS, as basis.

  This step concluded with the definition of a series of actions required to refine the SEG system to position it at the cutting edge of the current pedological knowledge and expertise.

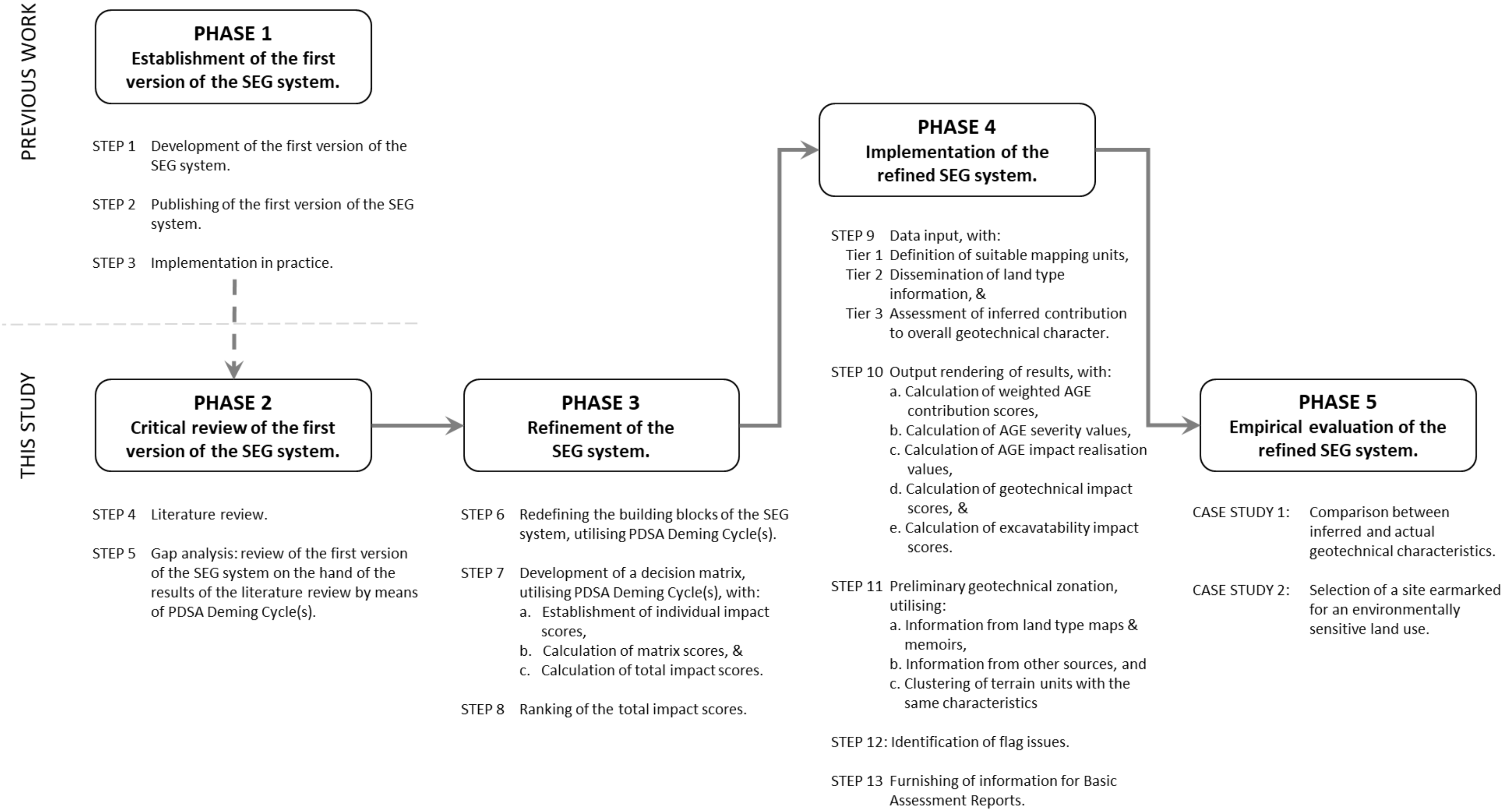


Figure 3.3: Flowchart describing the phased approach used during development of the refined SEG system.

3.3.4 Phase 3: Refinement of the SEG system

- Step 6: Redefining the buildings blocks of the SEG system:

  The refinements resulting from the critical review (Step 5) were implemented by the running of a series of iterative PDSA Deming Cycles to redefine the basic elements on which the SEG system is based, namely: Adverse Geotechnical Effects (AGEs) and Soil Type Categories (STCs). This process included the re-evaluation of the existing AGEs and the addition of new parameters identified during the literature review (Step 4).

  The 12 definitive AGEs were grouped into four broad categories focussing on different aspects of development mainly based on the parameters proposed by Partridge *et al*. (1993), updated and detailed in SANS 634 (2012), as discussed in section 2.4. The various NASCS soil forms were grouped into 12 STCs based on shared inferred primary geotechnical characteristics applicable to residential development as defined by the newly established AGEs.

  This step culminated in the establishment of lists of AGEs and STCs to be used for the establishment of the refined Soils Effects Groupings (SEGs) on which this geotechnical characterisation system rests.

- Step 7: Development of a decision matrix:

  As each AGE is expected to have a specific impact on the cost and ease of development to a lesser or greater extent, the lists of AGEs applicable to each STC (Step 6) allow ranking thereof with regard to the severity of the perceived impact as contributed by the different soil forms comprising that specific STC. This was achieved by the establishment of a rudimentary decision matrix incorporating three elements namely: the list of STCs, the list of AGEs, and individual matrix values representing the perceived severity of the impact of the different AGEs within each of the STCs. These matrix values were obtained by means of a series of PDSA Deming Cycles conducted to ensure the most accurate results that correspond with industry-standard rankings for the relevant parameters. These cycles involved the assigning of an empirically determined weight to each AGE broadly based on the ranking of various geotechnical parameters as stated by Partridge *et al*. (1993) that reflects the perceived severity of the impact on development (Table 2.5). These weights reflect an inferred increase in severity that would require the implementation of progressively costlier and complex precautionary and/ or remedial actions. A basic linear scale was devised to reflect the anticipated combined contribution of the soil forms comprising each specific STC to the overall severity of the perceived impact that each AGE could have on development.

  Individual matrix values were subsequently calculated as the product of the AGE weight, STC weight, and the corresponding STC contribution value. Soil forms that yielded matrix values significantly in variance with that of the other soils within a specific STC were then identified, and reassigned into different STCs.

At the end of each run of the cycle, a total matrix value was calculated for each STC by tabulating the individual matrix values for the relevant AGEs. The cycle was repeated until no further revisions were required, and a series of distinctly different total matrix values was obtained.

- Step 8: Ranking of the resultant total matrix values:

  The resultant total matrix values obtained during Step 7 were used to rank the STCs in terms of the overall perceived impact on development. The lowest value was considered to represent soil forms that would have the least overall impact, while the STC with the highest total matrix value represented those soil forms that would severely hamper development. The STCs were subsequently renamed to define a list of refined Soils Effects Groupings (SEGs), numbered according to the resultant rank of each STC (i.e., SEG-I to SEG-XII).

3.3.5 Phase 4: Implementation of the refined SEG system

- Step 9: Data input:

In order to allow geotechnical practitioners to utilise the refined SEG system, a data input spreadsheet utilising Microsoft Excel, version 16.32, was developed to facilitate the entering of pedological information in an intuitive and structured format primarily based on the list of SEGs. Soils information is entered separately for each terrain unit comprising a land type.

The geopractitioner is then required to allocate a prominence value for each of the relevant AGEs within the list of SEGs resulting from the data entry, based on available information and personal experience.

- Step 10: Output rendering of results:

  In order to present the entered soils information and aggregated geotechnical characteristics in an efficient and practical manner, a semi-diagrammatical reporting format was developed. The data report includes the following information:

  - aggregated prominences of the relevant SEGs with lists of constituent soil forms,
  - a graphical representation of the depth extent of the diagnostic horizons,
  - diagrammatical depictions of the prominences of the various underlying materials,
  - diagrammatical depictions of stoniness,
  - aggregated clay content for both the diagnostic topsoil and sub-surface layers (where

noted),

- o diagrammatical depiction of the aggregated geotechnical character of the soils, and
- o a list of the relevant geotechnical impact scores.

The entered soils information and allocated prominence values were subsequently used to establish a list of aggregated geotechnical characteristics comprising AGE severity scores and associated AGE impact realisation values. These two parameters describe the overall geotechnical behaviour exhibited by the soil forms occurring within that specific terrain unit and the perceived impact thereof on development. These values were obtained by various mathematical formulas built into the spreadsheet.

This process culminates with the calculation of a weighted geotechnical magnitude value (representing Category 3 Adverse soil behaviour parameters; section 2.4.4) and an excavatability magnitude value (representing Category 4 Excavatability problems parameters; section 2.4.5). These values are primarily of importance in allowing comparison between terrain units (Step 11).

- Step 11: Preliminary geotechnical zonation:

The various geotechnical characteristics exhibited by the diverse soil forms occurring within a terrain unit, as obtained from pedological information (Step 10), were classified according to the guidelines set by Partridge *et al*. (1993) through the use of the AGE severity value obtained by application of the SEG system. These characteristics specifically include only the adverse soil behaviour (Category 3; section 2.4.4) and excavatability problems (Category 4; section 2.4.5) parameters. However, this requires establishment of a series of threshold values for each rank (i.e.: 1 - most favourable, 2 - intermediate, and 3 - least favourable; Table 2.5) for those AGEs where a distinct classification cannot readily be achieved, i.e., more specifically: heave / shrinkage, consolidation potential, and erodibility / dispersion potential. This was achieved by assessment of the proven geotechnical characteristics of soils occurring at 32 locations scattered throughout South Africa where the author has personally been involved in the conducting detailed geotechnical investigations, expressed in terms of the parameters proposed by Partridge *et al*. (1993). These sites were specifically chosen to represent variations in geological, geotechnical, and climatic conditions. Results were analysed utilising standard five-number summary box-and-whisker plots as defined by Tukey (McGill *et al*., 1978), comprising the following elements (Figure 3.4):

- o Minimum : smallest value, excluding outliers,
- o Lower / 25% quartile : 25% of the values are less than this value,
- o Median / 50% quartile : 50% of the values exceed this value,

- Upper / 75% quartile : 25% of the values exceed this value,
- Maximum : greatest value, excluding any outliers, and
- Outliers : values either less than 3/2 times the lower quartile or more than 3/2 times the upper quartile.

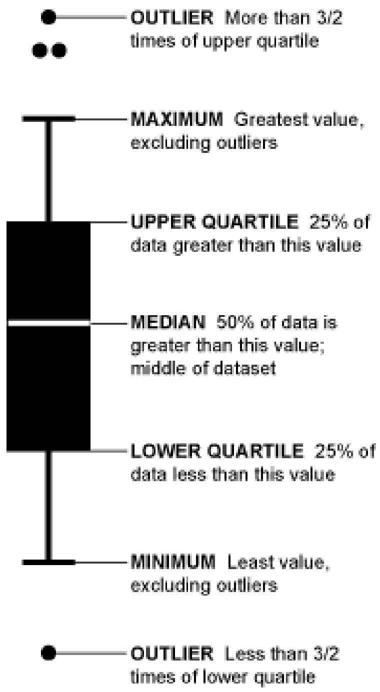


Figure 3.4: Diagrammatic depiction of a typical five-number box-and-whisker plot (Flowingdata, 2020).

Miscellaneous geological, geotechnical, and geomorphological characteristics (Category 5 parameters; section 2.4.6), as well as poor trafficability (Category 1 parameters; section 2.4.2) and material re-use potential (Category 2 parameter; section 2.4.3), are subsequently classified according to the same ranking, and combined with the previous results to define the inferred geotechnical character of each terrain unit.

Those terrain units exhibiting the same geological, geotechnical, and geomorphological characteristics can be clustered together to define preliminary geotechnical zones (the first primary product resulting from use of the refined SEG system), the spatial extent of which can be mapped out and depicted by means of a geographical information system (GIS).

- Step 12: Identification of flag issues:

The geotechnical characteristics, the majority of which are ranked according to the parameters proposed by Partridge *et al*. (1993), but also detailing other potentially adverse behaviour, exhibited by the preliminary geotechnical zones representing unique clusters of terrain units, represent flag issues to be taken into account during assessment of the development potential of a site earmarked for development (the second primary product resulting from use of the refined SEG system). The list of flag issues per zone also allow comparison between candidate sites to aid the decision-making process regarding the spatial location of a specific land use.

- Step 13: Furnishing of information for Basis Assessment Reports (BARs):

  The list of flag issues identified for each preliminary geotechnical zone furnishes environmental practitioners with appropriate geotechnical information necessary during the compilation of Basic Assessment Reports that form part of the EIA process (the third primary product resulting from use of the refined SEG system).

3.3.6 Phase 5: Empirical evaluation of the efficacy of the SEG system

Given the absence of similar geotechnical characterisation systems that rely on pedological information, evaluation of the efficacy and usefulness of the refined SEG system primarily had to be on the hand of practical examples of its use in real-world scenarios. It must be noted that these evaluations were conducted primarily utilising an empirical approach, as PSGI-type studies do not yield quantifiable data suitable for analyses by pure statistical means.

The evaluations required the conducting of several PSGIs, each focussing on a different application, namely:

- Case study 1: Comparison between inferred and actual geotechnical characteristics

  This case study focussed on the assessment of the regional geotechnical character of a site earmarked for residential development located in an area covered by a published 1:50 000 scale regional geotechnical map, and where a detailed geotechnical investigation has been conducted. This allows comparison of the inferred geotechnical characteristics for the study area obtained by means of the SEG system with that determined by means of field and laboratory testing.

- Case study 2: Selection of a site earmarked for an environmentally sensitive land use

  PSGIs, utilising the SEG system, were conducted to assess the regional geotechnical character exhibited by two candidate sites earmarked for the development of a new cemetery (deemed a land use that could adversely affect the natural environment). The PSGIs were specifically aimed at providing suitable geotechnical information to facilitate site selection by decision makers, and to inform the BAR process.

CHAPTER 4 DEVELOPMENT OF THE REFINED SOILS EFFECTS GROUPING SYSTEM

This chapter commences with a description of the origins of the Soils Effects Grouping (SEG) system, followed by the results of a recent in-depth review thereof that included a gap analysis, culminating in a detailed description of the process through which the refined SEG system was established.

4.1 Phase 1: Establishment of the first version of the SEG system

4.1.1 Conceptualisation

Although this chapter will primarily focus on the establishment of the refined version of the SEG system, a short overview of the conceptualisation and development history from the first to the refined version thereof is deemed relevant to illustrate the origins of this research (Figure 4.1).

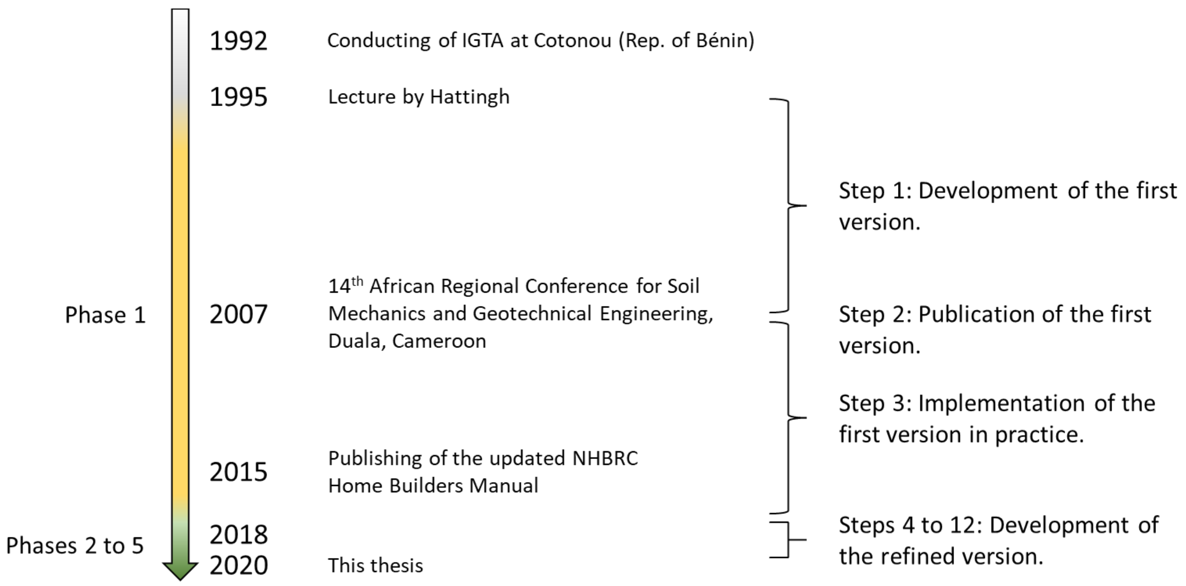


Figure 4.1: Diagrammatical overview of the development history of the SEG system. The phases and steps noted in the diagram correspond to those described in Figure 3.3.

The foundations of a system to display regional geotechnical characteristics in a graphical and/or diagrammatical format were laid during a preliminary stage geotechnical investigation conducted in 1992 around the city of Cotonou along the coast of the Republic of Bénin (Calitz, 1998). Challenges encountered during that study necessitated the adaptation of existing terrain evaluation techniques for application in engineering geological reconnaissance investigations in developing countries (Calitz, 1998). Further study, influenced by Hattingh (1995), led to the recognition of the importance of regional soils mapping contained in the South African land type maps and memoirs. However, implementation of a geographical system that relies on pedological information must take the variable nature of the different soil forms comprising any given land type into account. There is a risk that the assessment of only the behaviour of the dominant soil forms could prevent inclusion of that exhibited by less prominent, but no less important, soil forms. As an example: the waterlogged character of a localised occurrence of clayey soil that undergoes prolonged saturation could be as important to the regional assessment as the geotechnical character of a large volume of sandy apedal soils occurring in the remainder of the area. It was therefore essential to group the different soil forms into manageable clusters to facilitate the collation of the inferred soil characteristics across the area.

The inherent complexity of the data required the definition of basic assessment units to adequately simplify data entry. Development and implementation of the first version of the SEG system was conducted by means of the following steps:

- Step 1: Development,
- Step 2: Publication, and
- Step 3: Implementation.

4.1.2 Step 1: Development of the first version of the SEG system

Although considered to fall outside the scope of this research, the process followed during development of the first version of the SEG system can be summarised as follows:

- Utilising the eight geotechnical properties defined by Hattingh (1995), and incorporating the geotechnical parameters proposed by Partridge *et al*. (1993), ten soil effects groupings (SEGs) were defined by grouping together soil forms exhibiting roughly similar primary geotechnical characteristics, and allowing for the presence of scattered to extensive bedrock outcrop (not directly catered for by the BSCS). The following SEGs were defined:

    I. Apedal soils,

    II. Weakly structured clayey soils,

    III. Weakly ferruginized soils,

    IV. Bedrock outcrop,

    V. Relatively unconsolidated soils,

VI. Moderately structured clayey soils,

VII. Shallow rocky soils,

VIII. Strongly ferruginized soils,

IX. Strongly structured clayey soils, and

X. Soils that undergo saturation for prolonged periods of time.

- The perceived impacts of each of these SEGs on residential development were subsequently assessed in terms of ten adverse geotechnical effects (AGEs) based on the parameters proposed by Partridge *et al*. (1993), namely:
  - slight to moderate consolidation under loading,
  - moderate to high consolidation under loading,
  - perched water tables possible,
  - prolonged saturation,
  - slight expansiveness,
  - moderate to high expansiveness,
  - reduced mobility on terrain,
  - potentially dispersive,
  - excavatability problems: foundation trenches, and
  - excavatability problems: bulk service trenches.
- A rudimentary reporting matrix (Table 4.1) was developed that plotted the SEGs, ranked from 'least costly' to 'costliest', against the AGEs, arranged from 'least severe' to 'most severe'. This process involved the conducting of multiple PDSA Deming cycles (the details of which are considered to fall outside the scope of this study) to establish the necessary rankings as noted above. The inferred impact on development of each AGE within the different SEGs based on the rudimentary reporting matrix was indicated as follows:
  - effects expected to occur (indicated by X),
  - effects expected to occur, but only at depth (indicated by D),
  - effects expected to occur only occasionally (indicated by O), and
  - effects expected to occur in localised areas only (indicated by L).

Table 4.1: Rudimentary reporting matrix on which the first version of the SEG system was based (after Calitz & Hattingh, 2007).

SOILS EFFECTS GROUPS (least severe > … < most severe)	Soil forms	ADVERSE GEOTECHNICAL EFFECTS ON RESIDENTIAL DEVELOPMENT (< least costly … most costly >)									
		Consolidation under loading		Groundwater		Expansiveness				Excavatability problems	
		Slight to moderate	Moderate to severe	Perched water table possible	Prolonged saturation	Slight	Moderate to severe	Reduced mobility on terrain	Potentially dispersive	Foundation excavation	Bulk service trenches
I. APEDAL SOILS	Clovelly, Constantia, Griffen, Hutton, Inanda, Kranskop, Magwa,& Shepstone.	O	X						X		
II. WEAKLY STRUCTURED CLAYEY SOILS	Shortlands.	X				O		L	X		
III. WEAKLY FERRUGINIZED SOILS	Avalon, Bainsvlei, Houwhoek, Longlands, Tambankulu, & Westleigh.	X		X	D	L		L	X		O
IV. BEDROCK OUTCROP	Scattered to extensive bedrock outcrops.							L / X		X	X
V. RELATIVELY UNCONSOLIDATED SOILS	Dundee, Fernwood, Inhoek, Lamotte, Oakleaf & Villafontes.	O	X	O / L		L / D		X	X		O / D
VI. MODERATELY STRUCTURED CLAYEY SOILS	Bonheim, Swartland, Valsrivier.	X		O / L		X	O	X	X		O /D
VII. SHALLOW ROCKY SOILS	Cartref, Glenrosa, Mayo, Milkwood, Mispah, & Nomanci.	X		O / L		L		O	X	O	X
VIII. STRONGLY FERRUGINIZED SOILS	Glencoe, Mispah (Ms11 & Ms21), & Wasbank.	X		X	D			L	X	L	X
IX. STRONGLY STRUCTURED CLAYEY SOILS	Arcadia, Estcourt, Rensburg, & Sterkspruit.	X		L		O	X	X	X	O / L	O
X. SOILS THAT UNDERGO SATURATION FOR PROLONGED PERIODS OF TIME	Champagne, Katspruit, Kroonstad, Pinedene, & Willowbrook.	X		X	X	X	O	X	X		O

X Effect expected to occur
O Effect expected to occur only occasionally
D Effect expected to occur, but only at depth
L Effects expected to occur in localised areas only

4.1.3 Steps 2 and 3: Publication and implementation of the first version of the SEG system

The first version of the SEG system was formally published in 2007 (Calitz & Hattingh, 2007).

The SEG system was subsequently implemented quite successfully by Messrs. AGES during the conducting of PSGIs for urban development and Basic Assessment Reports in the Limpopo, Eastern Cape, and North-West Provinces over a period spanning more than a decade.

4.2 Phase 2: Critical review of the first version of the SEG system

4.2.1 Review elements

The refinement process commenced with the conducting of the following actions:

- Step 4: Literature review, and
- Step 5: Gap analyses.

4.2.2 Step 4: Literature review

A detailed discussion of the results of the literature review is included as Chapter 2, with the main benefits thereof summarised as follows:

- It allowed the more precise definition of the principles behind PSGIs as pertaining to the various industry standards regarding urban development and environmental impact studies.
- It allowed discussion of the different soil classification systems developed for use in South Africa, primarily focussing on the old BSCS and the new NASCS.
- It facilitated the collation and grouping of the most important geotechnical characteristics required to adequately assess the cost and ease of development on a regional scale, as well as to flag issues of a geotechnical nature of interest to environmental practitioners. In this, several parameters overlooked by the industry standard guidelines were identified.
- The results of the literature review were collated to facilitate evaluation of the efficacy of the first version of the SEG system by means of a gap analyses through the highlighting of shortcomings and/ or weaknesses in terms of the latest standards and guidelines.

4.2.3 Step 5: Gap analyses

Over time, utilisation of the first version of the SEG system in practice revealed the following issues, mainly revealed by feedback from clients, as well as evolution within the geotechnical field, namely:

- The SEG system was overtaken by the requirements of updated legislation and standards pertaining to residential development in South Africa, especially the long-awaited revision of the Home Builders Manual (NHBRC, 2015).
- Although technically falling outside the primary applications of PSGIs, decision-makers were regularly requesting assessment of additional geotechnical characteristics, including recommendations regarding the possible re-use of excavated materials in engineered fills

beneath roads or foundations, and erodibility. These requests were not directly addressed by the SEG system or the industry standards on which it was based.

- The system occasionally rendered unexpected results, with ‘severe’ AGE ratings predicted for relatively low ranked SEGs under certain conditions (as such negating the premise behind the ranking of the SEGs to a degree). This was considered the result of a less than optimal grouping of some of the BSCS soil forms within the SEGs.
- Graphical and/ or diagrammatical representation of the results of an PSGI using the SEG system was progressively proving to be a necessity to effectively convey the results thereof to non-technical decision makers.

These issues prompted a thorough review of the first version of the SEG system, conducted on the hand of a number of PDSA Deming cycles as detailed in Figure 4.2. This review revealed the following shortcomings:

- Although considered to represent an inferred low impact on development, the available soils information was not sufficiently utilised to assess the effects of mobility on terrain during and after construction (previously included as the single AGE ‘Reduced mobility on terrain’).
- Assessment of the re-use potential of the different soils, generally highly dependent upon the intended end-uses of the material requiring specialised assessments in its own right, could be addressed to a limited degree by the use of the regional soil information.
- The inferred adverse effects of prolonged saturation (including waterlogging) were found to be grouped together with those from only periodic groundwater seepage, and although not specifically accommodated as such by Partridge *et al*. (1993) should rather be assessed separately.
- Distinction between the severities of the adverse effects of some characteristics in some cases (e.g., the inferred impact of the widespread occurrence of highly collapsible soil overshadowing that presented by the localised occurrence of highly expansive material) unnecessarily complicated assessments, hampering the rendering of repeatable results.
- The impact of the presence of shallow rock in residential development projects was not adequately addressed with regard to the excavation of roads and foundation trenches where it is considered to be more problematic compared to the excavation for bulk services.
- The first iteration of the SEG system did not take the occurrence of peat and organic soil horizons and anthropogenic soils into consideration.

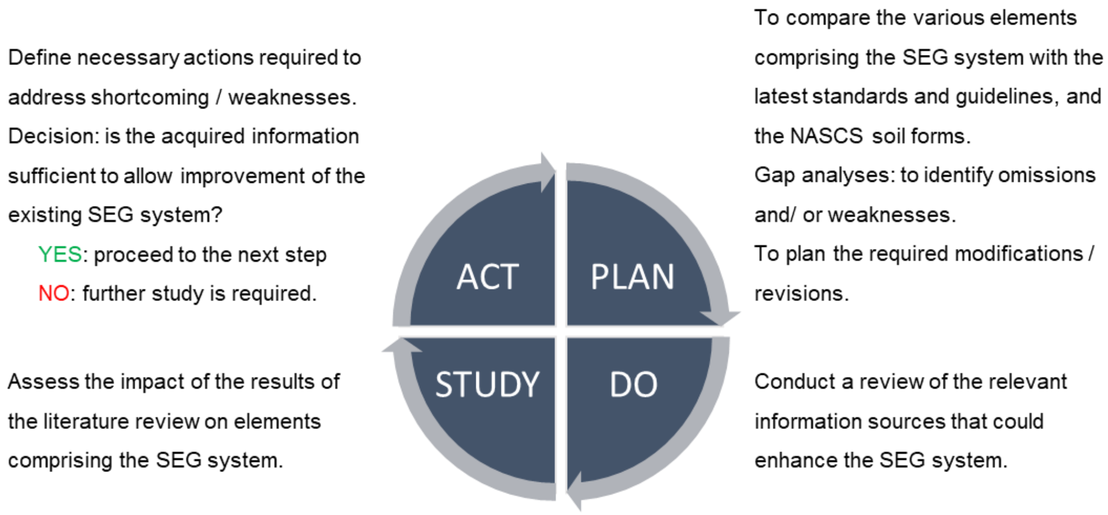


Figure 4.2: Critical review of the first version of the SEG system, representing Step 5 of the process as shown in Figure 3.3, illustrated by means of a PDSA Deming Cycle.

An assessment of each of the BSCS soil forms, as well as those of the NASCS, in terms of the results of the gap analysis revealed the following shortcomings and/ or weaknesses regarding the definition of the SEGs on which the first version (Phase 1) of the SEG system was based:

- Certain soil forms exhibit widely varying geotechnical characteristics, as catered for by differences in the soil series sub-classes, e.g., Fw31 Warrington Series of the Fernwood soil form that exhibits signs of wetness versus Fw21 Langebaan Series that does not. The variations in a soil form thus require the inclusion of certain soil forms in more than one SEG to cater for these less obvious differences in soil characteristics.
- The presence of hardpan ferricrete (including both diagnostic hard plinthite and non-diagnostic hardpan ferricrete underlying diagnostic horizons as defined by the BSCS required re-interpretation of the effects thereof on development. The presence of hardpan ferricrete is not necessarily evidence of current periodic groundwater seepage and/or inundation, but could represent remnants of paleo-climatic conditions (Le Roux & Du Preez, 2006), in which case its presence would lead only to excavatability problems.
- Utilising the presence of pedogenic layers other than ferricrete within the diagnostic soil materials as a primary classification factor was found to be superfluous, as these are generally already catered for by the series designations within certain soil forms, e.g., the presence of hardpan calcrete and silcrete beneath the orthic A-horizon generally defines different series within the Mispah soil form.

- The character of the material typically underlying the diagnostic horizons, where indicated, was generally not considered during the assessment of the inferred geotechnical characteristics of that soil form, e.g., the impact of gleyed material occurring beneath hardpan ferricrete on development was not previously taken into consideration. Additionally, the topsoil horizons of certain soil forms exhibit distinctly different primary characteristics than that of the underlying diagnostic layers and/or non-diagnostic materials. The accuracy of the application of the SEG system could be significantly impacted where preliminary stage geotechnical investigations are based solely on either the topsoil or the underlying diagnostic layer. For instance, the difference between the topsoil horizon and underlying horizons of the Bakwena soil form have a substantial difference in excavatability. The potentially highly expansive vertic A-horizon is underlaid by a soft carbonate horizon which is overlying a lithic horizon, inferred to comprise mainly weathered rock in a soil matrix, that could have a negative impact on excavatability.

4.3 Phase 3: Refinement of the SEG system

4.3.1 Refinement process

Utilising the results of the literature study and the gap analyses, the first version of the SEG system was progressively refined by means of a process that comprised the following steps:

- Step 6: Redefining the building blocks,
- Step 7: Development of a decision matrix, and
- Step 8: Ranking of the resultant total impact scores.

4.3.2 Step 6: Redefining the buildings blocks of the SEG system

Refinement of the first version of the SEG system commenced with a reassessment of the different AGEs as defined in Step 1 (Section 4.1.2) and the establishment of a series of soil type categories (STCs) based on the older SEGs of the first version. This was achieved by the conducting of a number of PDSA Deming Cycles (Figure 4.3), through which definitive lists of adverse geotechnical effects and soil type categories were established. These progressive alterations involved the allocation of inferred primary geotechnical characteristics to the different NASCS soil forms according to parameters proposed by Partridge *et al*. (1993), but also including perceived impacts on trafficability and re-use potential, based on personal experience and the results of the literature study. Those characteristics considered to have a similar effect on the cost and ease of development were grouped into a number of AGEs.

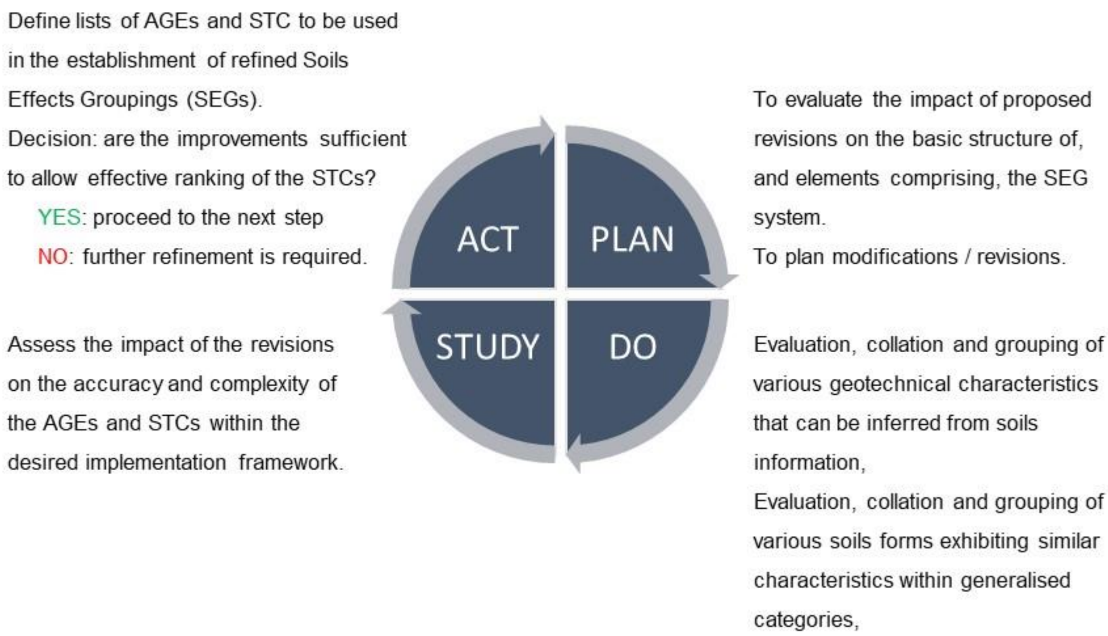


Figure 4.3: Refinement of the basic elements comprising the SEG system, representing Step 6 of the process as shown in Figure 3.3, illustrated by means of a PDSA Deming Cycle.

Soil forms considered to exhibit similar characteristics, mainly based on the primary inferred geotechnical character of its constituent horizons as proposed by Hattingh (1995) and expanded upon by Calitz and Hattingh (2007), rather than pedological characteristics of mainly the topsoil horizon used by Fey (2010), were subsequently grouped together in STCs. A specific distinction was made between soils that exhibit a gleyed character and those that do not. The results of each cycle were studied to ascertain whether that iteration of the AGEs and STCs could be attained by application of the soils information obtainable from the land type maps and memoirs without undue complexity and reworking thereof. This process eventually culminated in definitive lists of AGEs and STCs sufficiently differentiated to allow ranking of the STCs in terms of its' perceived impact on the cost and ease of development. These lists define the building blocks of the refined version of the SEG geotechnical characterisation system, as summarised in the following sections.

4.3.2.1 Adverse geotechnical effects (AGEs)

The inferred generalised adverse geotechnical characteristics comprising Category 1: Poor trafficability, Category 2: Material re-use potential, Category 3: Adverse soil behaviour and Category 4: Excavatability problems parameters were grouped into the following 12 definitive AGEs (Table 4.2):

Table 4.2: List of definitive adverse geotechnical effects (AGEs) broadly based on the parameters defined in Partridge *et al*. (1993) as supplemented.

AGEs	Inferred impacts on development
Category 1: Poor trafficability	
Boulders at the surface	Could hamper the movement of most wheeled and some tracked vehicles during and after construction. Could delay development until removed.
'Sticky'/ slippery conditions when wet	Could hamper the steering and movement of most wheeled- and some tracked vehicles. Could delay development until conditions improve, or temporary remedial measures implemented.
Loss of cohesion when wet/ 'quicksand' conditions	Fine-textured soils could undergo significant reduction in bearing strength under loading when saturated, hampering the movement of most wheeled and some tracked vehicles. The bearing strength of loose sands could increase under loading, benefiting the movement of some wheeled and tracked vehicles. 'Quicksand' conditions after heavy precipitation events could significantly reduce topsoil cohesion and strength under loading, severely hampering movement of some wheeled- and tracked vehicles. Could delay development until conditions improve, or temporary remedial measures implemented.
Category 2: Material re-use potential	
Soil-like natural materials	Clay-poor soils exhibiting little or no structure could be suitable for use as pipe bedding material. Relatively sandy or gravelly soils, including saprolite, but excluding those with clayey topsoil, could be suitable for re-use as fill (subgrade) and subbase material. Gravelly soils, including soft ferricrete horizons and relatively sandy soils underlaid by saprolite, but excluding soils with clayey topsoil, could be suitable as selected subgrade/ gravel wearing course material. The absence of suitable materials will increase the cost of development and could cause delays while suitable materials are sourced elsewhere.
Category 3: Adverse soil behaviour	
Collapse settlement	Gradual or sudden settlement could occur beneath foundations and/or floor slabs, due to leaking wet services at, or poor surface drainage around, buildings, requiring use of more specialised and costly foundation solutions. Collapse settlement could damage roads and bulk engineering services, requiring more regular maintenance.
Shallow groundwater/ seepage	Could lead to structural damage due to cyclical heave/ shrinkage. Could lead to structural damage due to collapse- and/or consolidation settlement. Could cause rising damp in walls and beneath floor slabs. Could reduce the bearing strength of the natural soil and man-made fills beneath foundations and compacted engineered fills. Could cause slope instability. Could contribute to the sub-surface spread of voids and cavernous conditions in dolomite land. Implementation of precautionary measures is inferred to impact development costs and could lead to more regular maintenance.
Heave/ shrinkage	Differential vertical movement during cyclic wetting and drying will damage brick walls and floor slabs, and rupture buried and overland engineering service infrastructure. Could severely affect durability of roads. Could over time lead to damage beyond economical repair. Implementation of precautionary measures is inferred to impact development costs and could lead to regular and costly maintenance.
Consolidation settlement/ 'soft clays'	Exhibits low shear strength requiring very specific and expensive foundation solutions. Differential settlement of 'soft clays' could damage large-diameter bulk engineering services. Could lead to differential settlement and failure of embankments, adversely affecting construction and long-term use of roads, as well as requiring implementation of precautionary measures during cut-and-fill construction. Implementation of precautionary measures is inferred to impact development costs and could lead to more regular maintenance.
Erodibility and/or dispersion	Leads to degradation of the natural environment. Could cause localised slope failure. Could cause undercutting of foundations. Could cause silting of storm water drains. Could cause tunnel/ piping erosion in earth embankments. Requires implementation of costly precautionary and/or remedial measures.
Waterlogged	Encompasses all adverse geotechnical impacts aspects listed for groundwater seepage from perched and permanent water tables, but without the mitigating effects of a more stable overburden. Invariably located within the 1:50 year floodline of a water course, or within a wetland, where development is expected to lead to severe degradation of the natural environment. Could prohibit development or require the implementation of very costly precautionary measures.
Category 4: Excavatability problems	
Engineering service trenches	• Bulk services: Generally placed at greater depth than those for internal reticulation at individual stands, and as such are at greater risk of intercepting bedrock at depth, especially in more arid regions. Less restricted access allows use of pneumatic power tools, ripping and/or blasting in lieu of more conventional mechanical excavators, with economy of scale limiting its impact on the cost of development to a degree. • Internal reticulation at individual stands: Typically, at relatively shallow depth, where bedrock, hardpan pedocretes and/or boulders could severely hamper excavation by hand or light mechanical excavator, with restricted nature of excavations limit options regarding alternative excavation techniques, e.g., blasting on a stand located between existing structures.
Roads & foundation trenches	Typically, prevalent in more arid regions. Restricted placement and nature of excavations limits options regarding alternative excavation techniques. The presence of bedrock, hardpan pedocretes and/or boulders at shallow depth could prevent or hamper the excavation of trenches or road works by hand or light mechanical excavator, requiring the use of pneumatic power tools and/or slowly expanding chemicals.

- Boulders at surface,
- ‘Sticky’/ slippery conditions when wet,
- Loss of cohesion when wet/ ‘quicksand’ conditions,
- Poor re-use potential,
- Collapse settlement,
- Shallow groundwater/ seepage,
- Heave/ shrinkage,
- Consolidation settlement/ ‘soft clays’,
- Erodibility and/or dispersion,
- Waterlogged,
- Excavatability problems: engineering service trenches, and
- Excavatability problems: roads, and foundation trenches.

4.3.2.2 Soil type categories (STCs)

The following 12 STCs, each representing a grouping of soil forms inferred to exhibit an analogous primary soil character, were defined (Table 4.3):

- Anthrosols and Technosols,
- Apedal soils,
- Dual-character soils (not gleyed),
- Moderately to strongly structured soils,
- Outcrops/ sub-outcrops of rocks or hardpan pedocrete,
- Peat and organic soils,
- Pedogenic soils,
- Relatively unconsolidated soils,
- Shallow lithic soils,
- Soils that undergo periodic saturation,
- Soils that undergo prolonged saturation, and
- Weakly structured soils (not gleyed).

Table 4.3: List of definitive soil type categories (STCs) based on the soil groupings defined by Fey (2010), generalised geotechnical, and hydropedological principles, with relevant soil horizons as used in the Natural and Anthropogenic Soil Classification System (Soil Classification Working Group, 2018).

STCs	Description
Anthrosols and Technosols	Man-made, disturbed, or contaminated soils, regardless of its geotechnical characteristics, on which development is generally not allowed due to significant adverse geotechnical characteristics and socio-environmental impacts.
Apedal soils	Soil forms defined as follows not exhibiting prominent characteristics that require classification into another grouping: • HUMIC SOILS, with a humic horizon underlaid by a red apedal or yellow-brown apedal horizon, without the presence of a soft plinthite horizon, in places overlying a gleyic horizon, • PODZOLIC SOILS, with an orthic horizon underlaid by a podzol horizon, without the presence of a soft carbonate horizon, in places overlying a lithic horizon, and • OXIDIC SOILS, with an orthic horizon underlain by a red apedal or yellow-brown apedal horizon not occurring above a neocutanic horizon, in places overlying a gleyic horizon. Hydropedological character: mainly, Recharge - Deep, and occasionally, Interflow - Soil / Bedrock.
Dual-character soils (not gleyed)	Soil forms exhibiting distinct variation in geotechnical characteristics between the topsoil and sub-surface diagnostic layers: • HUMIC SOILS overlying PLINTHIC SOILS, with a humic horizon underlaid by a neocutanic horizon overlying a soft plinthic horizon, • VERTIC SOILS overlying CALCIC SOILS, with a vertic horizon underlaid by a soft carbonate horizon, • VERTIC SOILS overlying INCEPTIC SOILS - CUMULIC, with a vertic horizon underlaid by a thick alluvial horizon, • MELANIC SOILS, with a melanic horizon underlaid by a pedocutanic horizon overlying an alluvial horizon, • DUPLEX SOILS overlying INCEPTIC SOILS - CUMULIC, with an orthic horizon underlaid by a pedocutanic or prismatic horizon overlying an alluvial horizon, and • OXIDIC SOILS overlying INCEPTIC SOILS - CUMULIC, with an orthic horizon underlaid by a red apedal or yellow-brown apedal horizon, overlying a neocutanic horizon. Hydropedological character: mainly, Recharge - Deep, and occasionally Responsive - Shallow, Interflow - Soil / Bedrock, and Stagnating.
Moderately to strongly structured soils	Soil forms comprising any of the following horizons exhibiting significant structure that defines its primary character: • HUMIC SOILS, with a humic horizon underlaid by a pedocutanic horizon, • VERTIC SOILS, with a vertic horizon underlaid by a lithic, pedocutanic, or hard rock horizon, • MELANIC SOILS, with a melanic horizon underlaid by a neocutanic, pedocutanic, or red structured horizon, not overlying an alluvial horizon, in places overlying a lithic horizon, and • DUPLEX SOILS, with an orthic horizon underlaid by neocutanic, prismacutanic, or pedocutanic horizon, not overlying an alluvial horizon, in places overlying a lithic or gleyic horizon. Hydropedological character: varies, Recharge - Deep, and Recharge - Shallow, and occasionally, Interflow - A / B Horizon, Interflow - Soil / Bedrock, and Responsive - Shallow.
Outcrops/ sub-outcrops of rock or hardpan pedocrete	Scattered to extensive bedrock outcrops, grading from loose boulders to discontinuous or extensive sheets of fairly competent rock at the surface, encompassing the following soil forms: • HUMIC SOILS, with a humic horizon underlaid by hard rock, • VERTIC SOILS, with a vertic horizon underlaid by hard rock, or a hard carbonate horizon without the presence of a soft carbonate horizon, • MELANIC SOILS, with a melanic horizon underlaid by hard rock, • PLINTHIC SOILS, with an orthic horizon underlaid by an albic horizon overlying a hard plinthic horizon, and • INCEPTIC SOILS - LITHIC, with an orthic horizon underlaid by hard rock, in places with an albic horizon, and in other with hard rock at surface. Hydropedological character: varies, Recharge - Shallow, and Responsive - Shallow, and occasionally, Interflow - A / B Horizon.
Peat and Organic soils	Soils comprising an organic or peat horizon, regardless of its geotechnical characteristics, on which development is generally not allowed or desired due to the risk of environmental degradation.
Pedogenic soils	Soil forms with a distinctly plinthic (i.e., ferruginized) character, excluding those with a hard plinthic horizon relatively close to the surface, or those exhibiting a stagnating hydropedological character, namely: • HUMIC SOILS, with a red apedal or yellow-brown apedal horizon underlaid by a soft plinthic horizon, and • PLINTHIC SOILS, with an orthic horizon either directly underlain by a soft plinthic horizon, or by a yellow-brown apedal or albic horizon underlaid by a soft plinthic horizon, in places overlying a gleyic horizon, or a red apedal horizon underlaid by a soft or hard plinthic horizon. Hydropedological character: mainly, Interflow - Soil / Bedrock, and occasionally, Interflow - A / B Horizon.
Relatively unconsolidated soils	Relatively young soil forms, excluding unconsolidated material horizons with signs of wetness: • MELANIC SOILS, with a melanic horizon underlaid by a thick alluvial horizon, and • INCEPTIC SOILS - CUMULIC, with an orthic horizon underlaid by a thick albic, alluvial, or regic sand horizon, or a neocarbonate horizon overlaid by an albic horizon, without the presence of a neocutanic horizon, in places underlaid by a gleyic horizon. Hydropedological character: • mainly, Recharge - Deep, and occasionally, Interflow - A / B Horizon, and Interflow - Soil / Bedrock.
Shallow lithic soils	Characterised by the presence of a lithic horizon relatively close to the surface, without the presence of other prominent soil horizons exhibiting prominent characteristics that require classification into another grouping: • HUMIC SOILS, with a humic horizon directly underlaid by a lithic horizon, • MELANIC SOILS, with a melanic horizon directly underlaid by a lithic horizon, and • INCEPTIC SOILS - LITHIC, with an orthic horizon underlaid by a lithic horizon, in places separated by an albic horizon. Hydropedological character: varies, Recharge - Shallow, and Responsive - Shallow.
Soils that undergo periodic saturation	Soil forms exhibiting stagnating hydropedological characteristics are defined as follows: • MELANIC SOILS, with a melanic horizon underlaid by a soft carbonate or hard carbonate horizon, and • SILICIC SOILS, with a dorbank horizon, • CALCIC SOILS, with an orthic horizon underlaid by a neocarbonate, soft carbonate, hard carbonate, or gypsic horizon, without the presence of a neocutanic horizon, • PLINTHIC SOILS, with an orthic horizon either directly underlaid by a hard plinthic horizon, or separated by a yellow-brown apedal horizon, • INCEPTIC SOILS - CUMULIC, with an orthic horizon directly underlaid by a neocarbonate horizon, not overlying unconsolidated material with wetness. Hydropedological character: Stagnating.
Soils that undergo prolonged saturation	Soil forms exhibiting distinct signs of long-term saturation: • VERTIC SOILS, with a vertic horizon underlaid by a gley horizon, • MELANIC SOILS, with a melanic horizon underlaid by a gley horizon, • CALCIC SOILS, with an orthic horizon underlaid by a soft carbonate horizon overlying either a gley or podzol horizon, or unconsolidated material with wetness, • GLEYIC SOILS, with an orthic horizon underlaid by a gley horizon, in places separated by an albic horizon, and • INCEPTIC SOILS - CUMULIC, with an orthic horizon underlaid by unconsolidated material with wetness, in places separated by a neocutanic or neocarbonate horizon. Hydropedological character: mainly, Recharge - Deep, and occasionally, Interflow - A / B Horizon, and Interflow - Soil / Bedrock.
Weakly structured soils (not gleyed)	Defined as those soil forms exhibiting a degree of structure, but not exhibiting a stagnating hydropedological character or including a gley horizon: • HUMIC SOILS, with a humic horizon underlaid by a neocutanic horizon, but without the presence of a soft plinthic horizon, • CALCIC SOILS, with an orthic horizon underlaid by a neocutanic horizon overlying either a soft carbonate, hard carbonate, or gypsic horizon, • OXIDIC SOILS, with an orthic horizon underlaid by a red structured horizon, and • INCEPTIC SOILS - CUMULIC, with an orthic horizon underlaid by a neocutanic horizon, without the presence of a red apedal or yellow-brown apedal horizon, and not overlying unconsolidated material with wetness. Hydropedological character: variable, Recharge - Deep, and Recharge - Shallow, and occasionally, Interflow - A / B Horizon.

Definition of the various STCs were primarily influenced by the following:

- soil groups defined by Fey (2010a),
- adverse geotechnical characteristics inferred to be exhibited by specific soil forms proposed by Harmse (1977), Brink (1985), and Fanourakis (1990),
- soil groups based on inferred geotechnical properties as proposed by Hattingh (1995),
- primary geotechnical characteristics as proposed by Partridge *et al*. (1993), and
- classification of the various soil forms according to hydropedological principles.

4.3.3 Step 7: Development of the elements of a decision matrix

In order to allow ranking of the STCs in terms of the AGEs with regard to its inferred impact on ease and cost of development, a decision matrix comprising two primary elements describing the inferred impact of the various soil forms and the inferred importance of the various AGEs on the cost and ease of development, had to be established. It must be noted that residential development does not typically occur in areas characterised by the presence of anthrosols and technosols, with this STC thus excluded from further assessment.

The decision matrix was established by means of three successive calculations, comprising Steps 7a to 7c, refined by means of PDSA Deming Cycles (Figure 4.4), detailed in the following sections.

4.3.3.1 Step 7a: Calculation of individual impact values

This step commenced with a representation of the prominence with regard to the inferred impact of the different AGEs collectively exhibited by the different soil forms comprising each STC on the cost and ease of development. These individual impacts were graded on a linear scale ranging between 0 and 5 (as detailed in Table 4.4), with a value of 0 allocated to AGEs not expected to be exhibited by any of the soil forms, increasing in prominence to a value of 5 that indicates invariable occurrence.

These inferred values allow incorporation of less prominent geotechnical characteristics exhibited by diagnostic horizons comprising the soils within a STC, even when present only in relatively small volumes or inferred to have a smaller impact on development. The resultant matrix of individual impact scores per AGE within each STC are presented in Table 4.5.

4.3.3.2 Step 7b: Calculation of weighted individual impact scores

The next step was the allocation of weights to each of the different AGEs in terms of the progression of parameters broadly arranged according to Partridge *et al*. (1993) (Table 4.2) in order to depict its inferred importance with regard to the cost and ease of development.

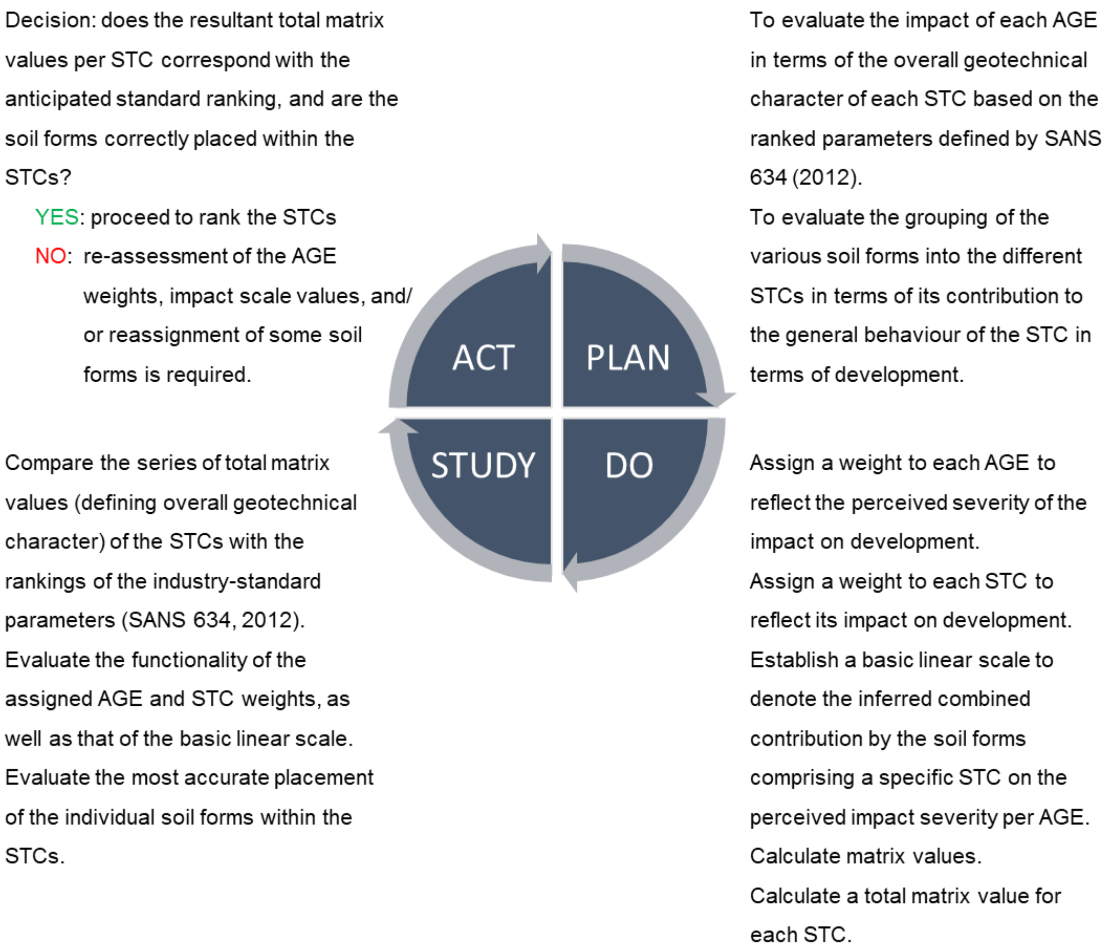


Figure 4.4: Refinement of the basic elements comprising the SEG system, representing Step 7 of the process as shown in Figure 3.3, illustrated by means of a PDSA Deming Cycle.

Table 4.4: Prominence values for the calculation of individual impact values.

Inferred prominence	Values
Effect exhibited by none of the soils in the specific STC:	0
Effect exhibited by only a very few of the soils within the specific STC/ occurs very occasionally:	1
Effect exhibited by some soils within the specific STC/ occurs infrequently:	2
Effect exhibited by around half of the soils within the specific STC/ occurs occasionally:	3
Effect exhibited by most of the soils within the specific STC/ occurs frequently:	4
Effect exhibited by all of the soils within the specific STC/ invariably occurs:	5

Table 4.5: Matrix of individual impact values per adverse geotechnical effect within each soil type category (in alphabetical order).

Matrix		Adverse geotechnical effects											
		Category 1: Poor trafficability			Category 2: Material re-use	Category 3: Adverse soil behaviour						Category 4: Excavatability problems	
		Boulders at surface	Sticky/ slippery conditions when wet	Loss of cohesion when wet/ quicksand conditions	Poor material re-use potential	Collapse settlement	Shallow groundwater / seepage	Heave/ shrinkage	Consolidation settlement/ soft clays	Erodibility and/or dispersion	Waterlogged	Engineering service trenches	Foundation trenches
Soil type categories	Apedal soils	0	1	3	3	2	1	0	3	2	0	3	1
	Dual-character soils (not gleyed)	0	3	4	4	2	1	3	4	2	0	3	1
	Moderately to strongly structured soils	0	5	4	5	0	1	5	3	2	0	3	1
	Outcrops/ sub-outcrops of rock and hardpan pedocretes	2	2	1	4	1	1	1	1	1	0	5	5
	Peat and organic soils	0	0	5	5	2	5	1	5	0	5	3	1
	Pedogenic soils	0	2	3	4	2	0	2	4	3	0	3	1
	Relatively unconsolidated soils	0	1	5	4	2	1	1	5	3	0	2	1
	Shallow lithic soils	0	2	2	5	1	1	2	2	2	0	5	3
	Soils that undergo periodic saturation	0	1	5	4	1	5	3	4	2	0	3	1
	Soils that undergo prolonged saturation	0	2	4	4	1	5	3	4	2	1	3	1
	Weakly structured soils (not gleyed)	0	3	3	5	0	0	5	4	3	0	2	1

These weights are listed in Table 4.6, and illustrated diagrammatically in Figure 4.5. Note that the fractional weights allocated to the three AGEs comprising Category 1 parameters imply a relatively small impact on the ease and cost of development as a whole with a resultant combined weight of 3. The parameters in Categories 2 to 4 were weighted on a more robust linear scale from 4 to 12, with the occurrence of waterlogged soil considered to have the greatest impact. These weights were subsequently used to calculate weighted individual impact scores (obtained from Step 7a), obtained by the multiplication of the individual impact value for each specific AGE within a STC with the allocated weight of the AGE itself.

Table 4.6: Allocated weights to the adverse geotechnical effects (AGEs) with regard to the cost and ease of development.

AGEs	Weights
Category 1: Poor trafficability	
Boulders at surface:	0.5
‘Sticky’/ slippery conditions when wet:	1
Loss of cohesion when wet/ ‘quicksand’ conditions:	1.5
Category 2: Material re-use potential	
Natural soil and rock materials:	4
Category 3: Adverse soil behaviour	
Collapse settlement:	5
Shallow groundwater/ seepage:	6
Heave/ shrinkage:	7
Consolidation settlement/ ‘soft clays’:	8
Erodibility and/or dispersion:	9
Category 4: Excavatability problems	
Engineering service trenches:	10
Roads and foundation trenches:	11
Category 3: Adverse soil behaviour	
Waterlogged:	12

As an example: the inferred impact of the potentially expansive topsoil horizon of the Mayo soil form (comprising a moderately structured clayey topsoil overlying shallow bedrock), representing one of four soil forms within the SEG lithic soils (thus classifying as ‘*some of the soils within the specific SEG*’), can be expressed as follows:

Allocated individual impact value within the STC:	2	(from Table 4.5) . . . . *a*
Allocated weight for the AGE heave/ shrinkage :	7	(from Table 4.6) . . . .*b*
Calculated weighted individual impact score :	14	(a x b).

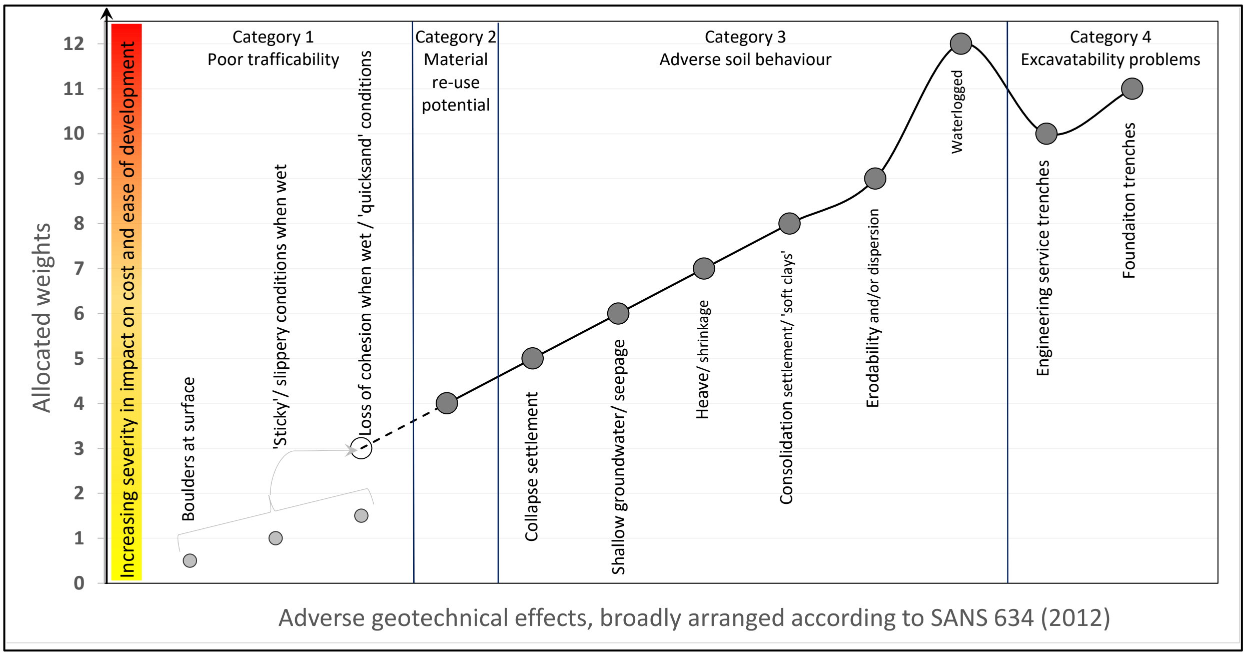


Figure 4.5: Diagrammatical depiction of the weighting of the adverse geotechnical effects (AGEs) with regard to the cost and ease of development.

4.3.3.3 Step 7c: Calculation of total impact scores

The weighted individual impact scores (obtained from Step 7b) for the list of AGEs within each STC were subsequently plotted on a decision matrix (Table 4.7). This facilitated calculation of a total impact score for each STC by tabulating the individual scores for each AGE therein. This resulted in a series of 11 values, ranging between:

116.5 for the STC apedal soils, and

215.5 for the STC peat and organic soils.

4.3.4 Step 8: Ranking of the resultant total impact scores

The ranking process culminated with rearrangement of the STCs according to their total impact score (obtained from Step 7; Section 0) to define the definitive series of refined SEGs, numbered from SEG-I to SEG-XI, as indicated by the last column of Table 4.7. A diagrammatical depiction of the refined SEGs based on the resultant total impact scores (Figure 4.6) clearly indicates that those soil forms comprising SEG-I apedal soils are inferred to have the least severe impact on development, requiring implementation of the least expensive remedial and/or mitigation measures. Conversely, the peat and organic soils (SEG-XI) are expected to have the most severe impact on development, represent conditions typically requiring very expensive and advanced precautionary and/or remedial measures.

Table 4.7: Decision matrix: weighted individual impact scores per AGE within each STC, ranked according to the total impact scores used to define the definitive list of SEGs.

	ADVERSE GEOTECHNICAL CHARACTERISTICS	ADVERSE GEOTECHNICAL CHARACTERISTICS (AGEs)												TOTAL IMAPCT SCORES	RESULTANT SOILS EFFECTS GROUPINGS (SEGs)
		Boulders at surface	Slippery conditions when wet	Loss of cohesion when wet	Poor material re-use potential	Collapse settlement PWB A1-2	Periodic Seepage PWB B1-2	Heave / shrinkage PWB C1-3	Consolidation / soft clays PWB D1-3	Erodability PWB E1-3	Excavatability problems: engineering service trenches PWB F3	Excavatability problems: road & foundation trenches PWB F1-2	Waterlogged PWB B2-3 & L2-3		
	ALLOCATED WEIGHTS:	*0.5*	*1*	*1.5*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*		
SOIL TYPE CATERGORIES (STCs)	***APEDAL SOILS***		1	4.5	12	10	6		24	18	30	11		**116.5**	**I**
	RELATIVELY UNCONSOLIDATED SOILS		1	7.5	16	10	6	7	40	27	20	11		**145.5**	**II**
	PEDOGENIC SOILS		2	4.5	16	10		14	32	27	30	11		**146.5**	**III**
	WEAKLY STRUCTURED SOILS (NOT GLEYED)		3	4.5	20			35	32	27	20	11		**152.5**	**IV**
	DUAL-CHARACTER SOILS (NOT GLEYED)		3	6	16	10	6	21	32	18	30	11		**153.0**	**V**
	MODERATELY TO STRONGLY STRUCTURED SOILS		5	6	20		6	35	24	18	30	11		**155.0**	**VI**
	OUTCROPS / SUB-OUTCROPS OF ROCK & HARD PEDOCRETES	1	2	1.5	16	5	6	7	8	9	50	55		**160.5**	**VII**
	SHALLOW LITHIC SOILS		2	3	20	5	6	14	16	18	50	33		**167.0**	**VIII**
	SOILS THAT UNDERGO PERIODIC SATURATION		1	7.5	16	5	30	21	32	18	30	11		**171.5**	**IX**
	SOILS THAT UNDERGO PROLONGED SATURATION		2	6	16	5	30	21	32	18	30	11	12	**183.0**	**X**
	PEAT & ORGANIC SOILS			7.5	20	10	30	7	40		30	11	60	**215.5**	**XI**

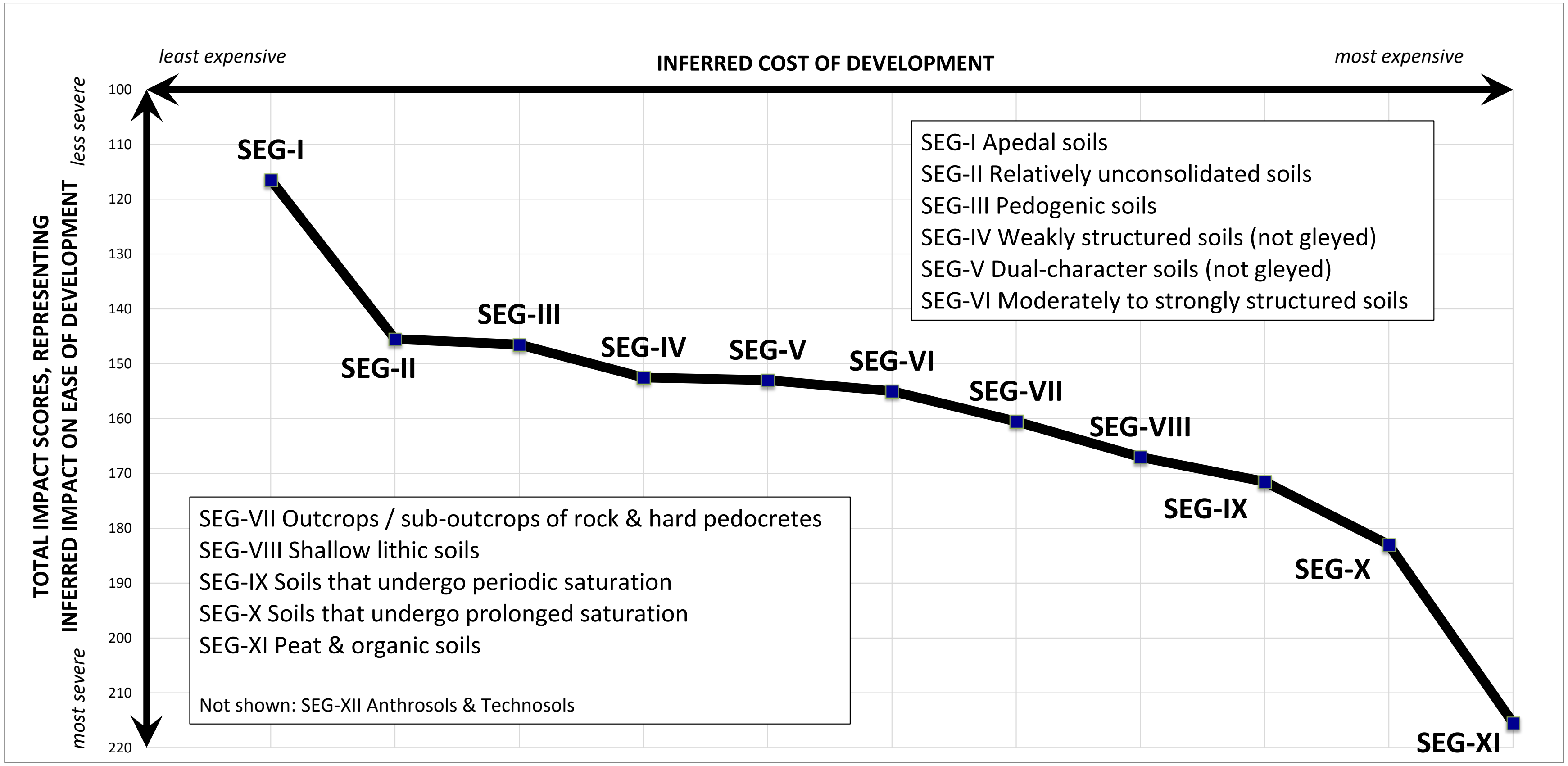


Figure 4.6: Diagrammatical ranking of the total impact scores for the STCs that define the refined SEGs.

The following refined soils effects groupings resulted from this process:

- SEG-I Apedal soils,
- SEG-II Relatively unconsolidated soils,
- SEG-III Pedogenic soils,
- SEG-IV Weakly structured soils (not gleyed),
- SEG-V Dual-character soils (not gleyed),
- SEG-VI Moderately to strongly structured soils,
- SEG-VII Outcrops/ sub-outcrops of rocks or hardpan pedocrete,
- SEG-VIII Shallow lithic soils,
- SEG-IX Soils that undergo periodic saturation,
- SEG-X Soils that undergo prolonged saturation,
- SEG-XI Peat and organic soils, and
- SEG-XII Anthrosols and technosols.

These SEGs act as the foundation for the implementation of pedological information from the land type maps and memoirs or the results of other soil surveys required to improve the efficacy of preliminary stage geotechnical investigations during the pre-feasibility and feasibility phases of proposed development, as well as specialist inputs during the EIA process. Note that although considered to be unsuitable for development, the various Anthrosols and Technosols are catered for by a separate group defining SEG-XII.

Appendix A provides lists of both the BSCS, TSCS, and NASCS soil forms comprising each SEG. Included in these lists is basic information regarding the climatic regime, parent material, morphology, hydropedology, corresponding WRB classes, and inferred generalised geotechnical characteristics for each SEG, provided in the form of a series of fact sheets.

CHAPTER 5 IMPLEMENTATION OF THE REFINED SOILS EFFECTS GROUPING SYSTEM (PHASE 4)

This chapter details the process whereby pedological data is processed into meaningful geotechnical information by application of the refined SEG system, representing Phase 4 of the study (Figure 3.3).

5.1 Introduction to the implementation process

The proposed implementation of the refined SEG system relies on the efficient collation of pedological information either from land type maps and memoirs, or from the results of more detailed soil mapping surveys. The implementation process involves five steps as discussed below:

- Step 9: Data input, where the raw soils information is disseminated by means of progressive refinement and weighting,
- Step 10: Output rendering of results, including the calculation of AGE severity and AGE realisation values,
- Step 11: Reworking of the disseminated information to facilitate geotechnical clustering and delineation of preliminary geotechnical zones,
- Step 12: Identification of flag issues, and
- Step 13: Furnishing of information for Basic Assessment Reports (BARs).

A flow diagram illustrating the above-mentioned implementation process is given in Figure 5.1, with the various constituent elements discussed in more detail in the following sections.

5.2 Step 9: Data input

This inherent complexity of the pedological information requires the use of a tiered system to properly disseminate the different elements during data input, namely:

- Tier 1: Definition of suitable mapping units,
- Tier 2: Dissemination of pedological information, and
- Tier 3: Assessment of the inferred contribution to the overall geotechnical character.

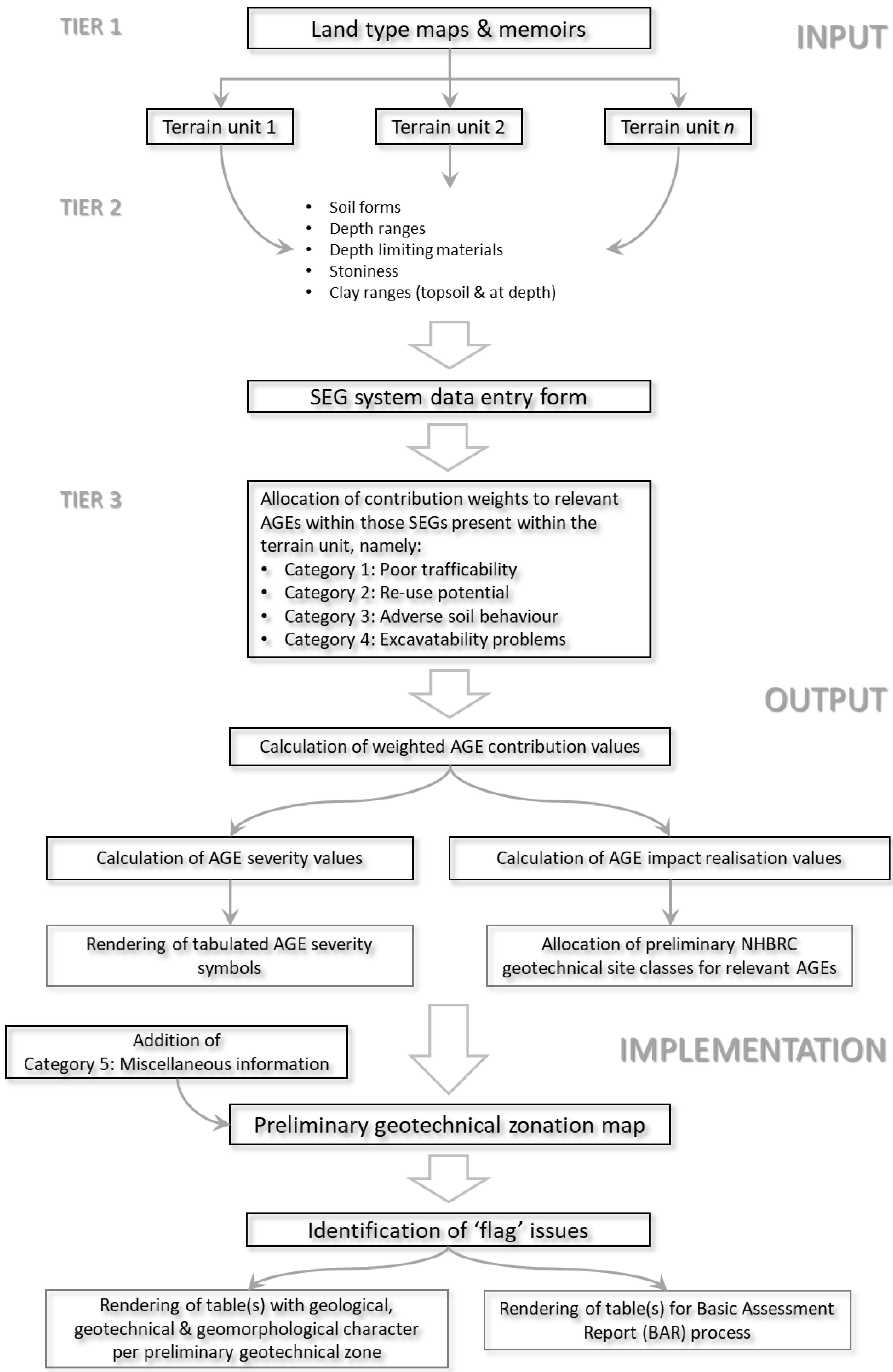


Figure 5.1: Flow diagram depicting the utilisation of the refined SEG system, comprising steps 9 to 11, in the conducting of PSGIs. Note: this diagram depicts the use of pedological information from land type maps and memoirs.

5.2.1 Tier 1: Definition of suitable mapping units

In order to properly disseminate the pedological information, it is important that a suitable mapping unit be defined for which the relevant soils information can be entered. These units should be readily mappable during the conducting of a preliminary stage geotechnical investigation using the available remote sensing images and/ or stereopair aerial photographs. The terrain units as defined in Figure 2.1 under which lists of various soil forms with relative spatial prominences are provided by the land type memoirs (Figure 2.3-D), define ideal mapping units for this purpose.

The land type memoir typically provides an indication of the prominence of each terrain unit within a specific land type, expressed as a percentage of the total surveyed area (Figure 2.3-A). However, it must be noted that the published prominence values are only applicable to very large sites, as smaller-scale development could be located wholly within only one or two terrain units, requiring a reassessment of the prominence thereof, e.g., by means of mapping utilising remote sensing images or stereopair aerial photographs. In order to simplify assessment of the inferred spatial prominences of each terrain unit within the land type as provided by the land type memoirs, a simple classification index, as shown in Table 5.1, was devised. The limits selected for the various categories represent empirically derived values reflecting the following premises:

- less than 10%: only sparse occurrences of the terrain unit within the land type,
- 10 to 19%: infrequent occurrences of the terrain unit within the land type,
- 20 to 39%: frequent occurrences of the terrain unit within the land type,
- 40 to 69%: prevalent occurrences of the terrain unit within the land type, and
- 70% or more: abundant occurrences of the terrain unit, dominating the land unit.

Although these values are not used in the dissemination of the pedological information, it does provide guidance in the application of the results of the SEG process during the delineation of preliminary geotechnical zones by the geopractitioner.

5.2.2 Tier 2: Dissemination of pedological information

The dissemination of the pedological information for each relevant terrain unit (Figure 2.3-B) defines the second tier of data input. This information typically comprises lists of soil forms or soil/ rock complexes with associated characteristics for each terrain unit (Figure 2.3-C), and is disseminated as follows:

- the occurrence of the various soil forms and soil/ rock complexes, expressed as a percentage of the total surface area within the specific terrain unit (Figure 2.3-D), entered as separate entities under the relevant SEG as defined in the fact sheets included as Appendix A,
- soil depth range, including both the stated minimum and maximum depths (Figure 2.3-E),
- the depth limiting material(s) underlying the diagnostic horizons (Figure 2.3-F), where noted,
- the stoniness of the soil (Figure 2.3-G), representing the volume of coarse particles and/or clasts within the soil matrix, and
- the minimum and maximum clay content for the topsoil and sub-surface layers respectively (Figure 2.3-H), where noted.

The SEG prominence percentages resulting from this process can be categorised as follows (Table 5.1):

- less than 10%: very highly localised pockets of these SEGs occur within the terrain unit,
- 10 to 19%: highly localised pockets of these SEGs occur within the terrain unit,
- 20 to 39%: localised pockets of these SEGs occur within the terrain unit,
- 40 to 69%: the terrain unit mainly comprises these SEGs, and
- 70% or more: the terrain unit predominantly comprises this SEG.

Table 5.1: Various prominence categories and weights utilised to aid dissemination and assessment of regional soils information.

Prominence categories pertaining to the spatial extent of terrain units within a land type	
Sparse	Comprises less than 10% of the land type.
Infrequent	Comprises between 10 and 19% of the land type.
Frequent	Comprises between 20 and 39% of the land type.
Prevalent	Comprises between 40 and 69% of the land type.
Abundant	Comprises 70% or more of the land type.
Prominence categories pertaining to the spatial extent of SEGs within terrain units	
Very highly localised pockets of	Comprises less than 10% of the terrain unit.
Highly localised pockets of	Comprises between 10 and 19% of the terrain unit.
Localised pockets of	Comprises between 20 and 39% of the terrain unit.
Mainly	Comprises between 40 and 69% of the terrain unit.
Predominantly	Comprises 70% or more of the terrain unit.

The following principles must be considered during the capture of pedological information:

- Multiple instances of the same soil form, albeit representing different soil series and/or characteristics, are entered separately to allow incorporation of these variations in the assessment of the relevant SEG.
- In cases where a soil form is indicated to be underlaid by more than one type of material (e.g., both saprolite and bedrock), the stated occurrence percentage is divided equally between the different underlying material types (rounded to the nearest 0.5%).
- In cases where information on the underlying material is not provided, or not readily discernible, the occurrence percentage is entered under 'Unspecified'.
- In cases where two or more soil forms from the same SEG (e.g., Clovelly and Hutton soil forms), or in more complex cases, where soil forms sharing some characteristics, but from different SEGs (e.g., a soil complex comprising Oakleaf soil from SEG-II, and Dundee soil from SEG-IV) have been grouped together, the occurrence percentage is divided equally between the different soil forms (rounded off to the nearest 0.5%). Different series of the same soil form within a soil complex are also grouped together.
- In cases where the underlying material is specified as 'B2', the occurrence percentage is entered under 'Miscellaneous soil layers'.
- Where occurrence percentages for non-soil-related land coverages (e.g., stream channels, dongas or pans) are provided, these are noted separately, and the associated underlying material and/ or stoniness (where indicated) entered as separate items beneath that of the soil forms and soil/ rock complexes.
- The occurrence percentages and associated characteristics are subsequently aggregated for each SEG, thereby providing a depiction of the prominences and character of all SEGs applicable to a specific terrain unit.

5.2.3 Tier 3: Assessment of the inferred contribution to the overall geotechnical character

After dissemination of the basic information, the geopractitioner is required to assess the contribution of the various AGEs within the relevant SEGs to the overall geotechnical character of the soils and/ or soil-rock complexes comprising each terrain unit. This is achieved by the allocation of scores reflecting either an inferred temporal (i.e., time-dependent), spatial (i.e., distribution over the surface area), or fractional (i.e., proportional to the whole) importance within the terrain unit (Table 5.2).

The scores for the AGEs in categories 1, 3 and 4 are ranked as follows:

- 1 - nearly neglectable,
- 2 - very slight contribution,
- 3 - slight contribution,
- 4 - moderate contribution,
- 5 - strong contribution,
- 6 - significant contribution, and
- 7 - very significant contribution.

Table 5.2: Various prominence categories and weights utilised to aid dissemination and assessment of regional soils information.

AGE contribution scores			
Contribution scores	**Temporal**	**Spatial**	**Fractional**
Category 1: Poor Trafficability **Category 3: Adverse soil behaviour** **Category 4: Excavatability Problems**			
1 - nearly neglectable	Very occasionally.	Highly localised, but at depth only.	A very small portion of the terrain unit only.
2 - very slight	Occasionally.	Very highly localised.	-
3 - slight	Sporadically.	Highly localised.	A small portion of the terrain unit/ to a lesser degree.
4 - moderate	-	Localised, but at depth only.	-
5 - strong	Regularly.	Localised.	A significant portion of the terrain unit/ to a degree.
6 - significant	-	Widespread, but at depth only.	-
7 - very significant	Always.	Widespread.	The whole terrain unit
Category 2: Material re-use potential			
1	Possibly suitable.		
2	Marginally suitable.		
3	Unlikely to be suitable.		
4	Unsuitable.		

The perceived re-use potential of the natural materials (category 2) is ranked as follows:

- 1 - possibly suitable,
- 2 - marginally suitable,
- 3 - unlikely to be suitable, and
- 4 - unsuitable.

It is essential to note that this assessment is highly dependent on the personal experience of the geopractitioner, both with regard to the expected behaviour of the different soil types, and the geotechnical character of soils occurring in the area in which the site is located. Therefore, use of the SEG system by someone with no geotechnical background cannot be expected to yield accurate results.

Although the above-mentioned process sounds complex, the conducting of tier 2 and 3 actions by means of a basic spreadsheet provides a highly structured framework through which land type information can be effectively disseminated in a repeatable and scientifically sound manner.

5.2.4 An example of the data entry process

As an example, the collation of land type information for an area comprising a valley floor that comprises approximately 0.5% of Land Type Af28 (i.e., sparse coverage) is used to explain the data entry process in more detail.

The valley floors are indicated to be mainly covered by Katspruit (60%) and Mispah (40%) soil forms, exhibiting the following characteristics (using the BSCS nomenclature) (Table 5.3):

- The Katspruit soil form comprises an orthic A-horizon overlying a G-horizon, and as such it is expected that 60% of the valley floors will be underlaid from between 0.1 and 0.3 m by gleyed material, with the topsoil containing little or no stones. The topsoil horizon of this soil form exhibits a clay content of between 20 and 50%, increasing slightly to between 25 and 50% at depth. This soil form classifies under SEG-X Soils that undergo prolonged saturation.
- The Mispah soil form covering the remainder of this terrain unit comprises an orthic A-horizon between 0.1 and 0.25 m thick overlying hardpan calcrete, representing shallow soil on rock stoniness, with the topsoil exhibiting a clay content of between 4 and 8%. This soil form classifies under SEG-VII Outcrop / sub-outcrops of rock and/ or hardpan pedocrete.

After dissemination of the relevant pedological information (tier 3 actions), AGE contribution scores were subsequently allocated to the above-mentioned soil forms by a geopractitioner (tier 3 actions; Table 5.4) as the end-product of the data entry process, namely:

Table 5.3: An example of the data entry process, in this case for soil forms indicated to occur along valley floors within Land Type Af28. Refer to Figure 2.2 for the relevant land type information sheet. The relevant data sources are referenced for each parameter.

Land type:	**Af28**						**Terrain unit:**				**5 - valley floor**				**Prominence category of terrain unit within land type:**													**sparse (0.5%)**			
Soil forms Figure 2.3-C Table 2.9	**Occurrence, entered as% per SEG** Figure 2.3-D Appendix A										**Depth, in m** Figure 2.3-E		**Depth limiting material** Figure 2.3-F										**Stoniness** Figure 2.3-G					**Clay content, entered as%** Figure 2.3-H			
	SEG-I Apedal soils	SEG-II Relatively unconsolidated soils (not gleyed)	SEG-III Pedogenic soils	SEG-IV Weakly structured soils (not gleyed)	SEG-V Dual-character soils (not gleyed)	SEG-VI Moderately to strongly structured soils	SEG-VII Outcrops/ sub-outcrops of rock or hardpan pedocrete	SEG-VIII Shallow lithic soils	SEG-IX Soils that undergo periodic saturation	SEG-X Soils that undergo prolonged saturation	Minimum	Maximum	Hardpan ferricrete	Hardpan pedocrete (other)	Lithic/ saprolite	Soft pedocretes	Moderately to strongly structured	Gleyed/ wet material	Unconsolidated material	Organic-rich subsoil	Miscellaneous soil layers	Unspecified	MB0 - no mechanical limitations	MB1 - many stones, but ploughable	MB2 - large stones& boulders, unploughable	MB3 - shallow soil on rock	MB4 – lack of soil	Topsoil - minimum	Topsoil - maximum	At depth - minimum	At depth - maximum
Katspruit Ka20										60	0.10	0.30						60					60					20	50	25	50
Mispah Ms22							40				0.10	0.25		40												40		4	8	-	-

Table 5.4: An example of the allocation of contribution scores to the different AGEs for each relevant SEG to complete the data entry process. In this case for soil forms indicated to occur along valley floors within Land Type Af28.

Soils effects groupings (SEGs):	**SEG-I** Apedal soils	**SEG-II** Relatively unconsoli-dated soils	**SEG-III** Pedogenic soils	**SEG-IV** Weakly structured soils (not gleyed)	**SEG-V** Dual-character soils (not gleyed)	**SEG-VI** Moderately to strongly structured soils	**SEG-VII** Outcrops/ sub-outcrops of rock or hardpan pedocrete	**SEG-VIII** Shallow lithic soils	**SEG-IX** Soils that undergo periodic saturation	**SEG-X** Soils that undergo prolonged saturation
Soil forms:							Mispah			Katspruit
Total prominence % per SEG:							**40**			**60**
Adverse geotechnical effects (AGEs):										
Boulders at surface:										
'Sticky'/ slippery conditions when wet:										7
Loss of cohesion when wet/ 'quicksand' conditions:							5			7
Material re-use potential:							3			4
Collapse settlement:							5			
Shallow groundwater/ seepage:										7
Heave/ shrinkage:										5
Consolidation settlement/ 'soft clays':							2			7
Erodibility and/or dispersion:							2			3
Waterlogged:										5
Excavatability problems - engineering service trenches:							7			6
Excavatability problems - Roads, and foundation trenches:							5			1

- It is inferred that the Katspruit soil form will exhibit the following geotechnical characteristics, with associated contribution weights:
  - potentially moderately to strongly expansive, affecting the following AGEs:
    - ‘Sticky’ / slippery conditions when wet: score 7 - very significant contribution, and
    - Heave / shrinkage: score 5 - strong contribution.
  - potentially moderately compressible, affecting the following AGEs:
    - Loss of cohesion when wet / ‘quicksand’ conditions: score 7 - very significant contribution, and
    - Consolidation settlement / ‘soft clays’: score 7 - very significant contribution.
  - seasonal inundation and groundwater seepage, affecting the following AGEs:
    - Shallow groundwater / seepage: score 7 - very significant contribution, and
    - Waterlogged: score 5 - strong contribution.
  - potentially slightly erodible and/ or dispersive, affecting the following AGE:
    - Erodibility and/or dispersion: score 3 - slight contribution.
  - expected occurrence of depth-limiting material at depth, but generally beyond conventional founding depths, affecting the following AGEs:
    - Excavatability problems - service trenches: score 6 - significant contribution, and
    - Excavatability problems - roads, and foundation trenches: score 1 - nearly neglectable contribution.
  - the clayey horizons are expected to be unsuitable for re-use, due to an expected high plasticity and a predominance of fines particles (i.e., silt and clay), thus ranking as follows:
    - score 4 - unsuitable.
- The relatively thin sand topsoil and hardpan calcrete of the Mispah soil form are expected to contribute as follows to the overall geotechnical character of this terrain unit:
  - relatively competent bedrock close to the surface, affecting the following AGEs:
    - Excavatability problems - service trenches: score 7 - very significant contribution, and
    - Excavatability problems - roads, and foundation trenches: score 5 - strong contribution.
  - it is expected that stormwater could infiltrate into the relatively permeable sandy topsoil overlying impermeable bedrock, thus leading to ‘quicksand’ conditions, affecting the

following AGE:

  - Loss of cohesion when wet / ‘quicksand’ conditions: score 5 - strong contribution.

- although relatively thin, the topsoil could be potentially slightly compressible and/ or collapsible, affecting the following AGEs:
  - Collapse settlement: score 5 - strong contribution,
  - Consolidation settlement / ‘soft clays’: score 2 - very slight contribution.
- potentially slightly erodible, affecting the following AGE:
  - Erodibility and/or dispersion: score 2 - very slight contribution.
- the sandy topsoil could potentially yield suitable backfill material after reworking to remove the silt and clay fraction thereof, but then only in very small volumes, ranking as follows:
  - score 3 - unlikely to be suitable.

5.3 Step 10: Output rendering of results

Pedological information disseminated during the data input phase (Step 9; Section 5.2) requires reworking thereof to allow aggregation and expression of the overall geotechnical character of the various soil forms occurring within a specific terrain unit to a reasonable degree of accuracy. This is primarily achieved by weighing and aggregating the various AGE contribution scores in several ways that allow rendering of the highly diverse information in a diagrammatical manner. The required values are obtained by means of the following cumulative calculations:

- Step 10a: calculation of weighted AGE contribution scores,
- Step 10b: calculation of AGE severity values, and
- Step 10c: calculation of AGE impact realisation values.

5.3.1 Step 10a: Calculation of weighted AGE contribution scores

This process commenced with the weighing of individual AGE contribution scores per SEG based on the prominence percentage of the relevant SEG within the terrain unit. This allows the proper depiction of the relative importance of the geotechnical characteristics exhibited by the various soil forms comprising each SEG within a specific terrain unit. The weighted values are calculated as the product of the allocated AGE contribution score (section 5.2.3) and the relevant SEG prominence percentage (section 5.2.2).

As an example, the weighting of allocated geotechnical characteristics of the soil forms indicated to occur along valley floors within Land Type Af28 are provided in Table 5.5, calculated as follows:

Table 5.5: Calculation of weighted AGE contribution scores, representing Step 10a, in this case for soil forms indicated to occur along valley floors within Land Type Af28.

	Adverse geotechnical effects (AGEs)	AGE weights	AGE contribution scores										Weighted AGE contribution scores										AGE severity	AGE impact realisation
	Soils effects groupings (SEGs):		I	II	III	IV	V	VI	VII	VIII	IX	X	I	II	III	IV	V	VI	VII	VIII	IX	X		
	Total prominence% per SEG:								40			60												
Category 1	Boulders at surface:	0.5																						
Category 1	'Sticky'/ slippery conditions when wet:	1										7										4.2		
Category 1	Loss of cohesion when wet / 'quicksand' conditions:	1.5							5			7							2.0			4.2		
Cat.2	Material re-use potential:	4							3			4							1.2			2.4		
Category 3	Collapse settlement:	5							5										2.0					
Category 3	Shallow groundwater/ seepage:	6										7										4.2		
Category 3	Heave/ shrinkage:	7																						
Category 3	Consolidation settlement/ 'soft clays':	8							2										0.8					
Category 3	Erodibility and/or dispersion:	9							2										0.8					
Category 3	Waterlogged:	12										5										3.0		
Category 4	Excavatability - engineering service trenches:	10							7			6							2.8			3.6		
Category 4	Excavatability - roads, and foundation trenches:	11										1							2.0			0.6		

Mispah soil form:
AGE contribution score: 7
SEG prominence percentage: 40%
Weighted AGE contribution score:
7 x 40% = 2.8

Katspruit soil form:
AGE contribution score: 6
SEG prominence percentage: 60%
Weighted AGE contribution score:
6 x 60% = 3.6

- The excavation of service trenches within occurrences of the Mispah soil form, comprising approximately 40% of the terrain unit, is expected to be problematic, with an allocated AGE contribution score 7 (out of a maximum score of 7). The weighted AGE contribution score is thus calculated as follows:

Allocated AGE contribution score:	7	(from Table 5.4). . . . . a
SEG prominence percentage:	40	(%, from Table 5.3) . . . . . b
Weighted AGE contribution score:	(a x (b / 100)) = 2.8	

- The excavation of service trenches within occurrences of the Katspruit soil form, comprising approximately 60% of the terrain unit, is expected to be slightly less problematic, with an allocated AGE contribution score 6 (out of a maximum score of 7). The weighted AGE contribution score is thus calculated as follows:

Allocated AGE contribution score:	6	(from Table 5.4). . . . . *c*
SEG prominence percentage:	60	(%, from Table 5.3) . . . . . *d*
Weighted AGE contribution score:	(*c* x (*d* / 100)) = 3.6	

5.3.2 Step 10b: Calculation of AGE severity values

In order to obtain a total contribution score for each AGE, the weighted AGE contribution scores were tabulated for each AGE across all of the SEGs (Table 5.6). The resultant values were subsequently expressed as a percentage of the maximum contribution score (Table 5.2), i.e., a maximum value of 7 for Categories 1, 3 and 4 parameters, and a maximum value of 4 for the Category 2 parameter (as detailed in section 5.2.3) to define a series of AGE severity values. As an example, the relevant calculations for the AGE Excavatability - engineering service trenches are as follows:

Maximum score for this AGE in category 4:	7	(from Table 5.2). . . . . *e*
Weighted AGE contribution score for SEG VII:	2.8	(from Table 5.5) . . . .*f*
Weighted AGE contribution score for SEG X:	3.6	(from Table 5.5) . . . .*g*
Total weighted AGE contribution score:	(*f* + g) = 6.4 . . . . *h*	
AGE severity value:	(*h* / *e*) (as %) = (6.4 / 7) = 91%	

Each resultant AGE severity value describes the expected level, expressed as a percentage, at which the impact of that specific AGE on the cost and ease of development has been realised by all the different soil forms indicated to occur within that specific terrain unit.

Table 5.6: Calculation of AGE severity values, representing Step 10b, in this case for soil forms indicated to occur along valley floors within Land Type Af28.

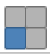
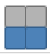
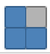
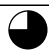
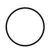
			AGE contribution scores										Weighted AGE contribution scores										AGE severity (as %)	AGE impact realisation
	Soils effects groupings (SEGs):		I	II	III	IV	V	VI	VII	VIII	IX	X	I	II	III	IV	V	VI	VII	VIII	IX	X		
	Total prominence: % per SEG:								40			60												
	Adverse geotechnical effects (AGEs)	AGE weights																						
Category 1	Boulders at surface:	0.5																					0	
	'Sticky'/ slippery conditions when wet:	1										7										4.2	60	
	Loss of cohesion when wet / 'quicksand' conditions:	1.5							5			7							2.0			4.2	89	
Cat.2	Material re-use potential:	4							3			4							1.2			2.4	90	
Category 3	Collapse settlement:	5							5										2.0				29	
	Shallow groundwater/ seepage:	6										7										4.2	60	
	Heave/ shrinkage:	7																				3.0	43	
	Consolidation settlement/ 'soft clays':	8																	0.8			4.2	71	
	Erodibility and/or dispersion:	9																	0.8			1.8	37	
	Waterlogged:	12																				3.0	43	
Category 4	Excavatability - engineering service trenches:	10							7			6							2.8			3.6	91	
	Excavatability - roads, and foundation trenches:	11							5			1							2.0			0.6	37	

<u>AGE Excavatability - engineering service trenches</u>:
AGE contribution score for SEG-VII: 2.8
AGE contribution score for SEG-X: 3.6
Maximum score for an AGE in Category 4: 7
Total weighted AGE contribution score:
(2.8 + 3.6) = 6.4
AGE severity score = 6.4 / 7 = 91.4% (integer: 91)

A diagrammatical reporting format was subsequently devised using square and round symbols each divided into four segments that conveys the AGE severity values in a simplified, yet intuitive, manner for use in PSGIs. The number of coloured segments within each symbol depicts the inferred level of severity, ranked as follows (Table 5.7):

- Category 1: Poor trafficability, Category 3: Adverse soil behaviour, and Category 4: Excavatability problems:
    - No symbol : not applicable,
    - One coloured segment : slight risk, with a severity value of less than 25%,
    - Two coloured segments : could occur, with a severity value of between 25 and less than 50%,
    - Three coloured segments : expected to occur, with a severity value of between 50 and less than 75%, and
    - All four segments coloured: high risk, with a severity value of 75% or more.

Table 5.7: List of symbols depicting the AGE severity values for each terrain unit within a land type.

AGE category	Ranges of AGE severity values	Assessment description	Symbol
Category 1: Poor trafficability **Category 3: Adverse soil behaviour** **Category 4: Excavatability problems**	0	(Not applicable.)	
	> 0 and < 25	Slight risk.	
	25 to < 50	Could occur.	
	50 to < 75	Expected to occur.	
	75 to 100	High risk.	
Category 2: Material re-use potential	0	Possibly suitable.	
	> 0 to < 25	Marginally suitable.	
	25 to < 75	Probably unsuitable.	
	75 to 100	Unsuitable.	

- Category 2 Material re-use potential:
    - No coloured segments : unsuitable, with a severity value of 75% or more,
    - One coloured segment : probably unsuitable, with a severity value of between 25 and less than 75%,
    - Two coloured segments : marginally suitable, with a severity value of more than 0 and less than 25%, and
    - Three coloured segments : possibly suitable, with a severity value of 0, and
    - Four coloured segments : an option requiring the colouring of all four segments is not defined for this parameter.

An example of the classification of the AGE severity values as discussed above for the soil forms occurring along valley floors within Land Type Af28 is provided in Table 5.8, with the resultant AGE severity values noted in Table 5.6 classifying as follows:

- Parameters exhibiting a high risk of occurrence (four coloured segments):
    - Loss of cohesion when wet / 'quicksand' conditions, and
    - Excavatability problems: service trenches,
- Parameters expected to occur (three coloured segments):
    - Slippery / 'sticky' conditions when wet,
    - Shallow groundwater / seepage, and
    - Consolidation settlement / 'soft clays'.
- Parameters that could occur (two coloured segments):
    - Collapse settlement,
    - Heave / shrinkage,
    - Erodibility / dispersion,
    - Waterlogged, and
    - Excavatability problems: roads and foundation trenches.
- Parameters exhibiting a low risk of occurrence (one coloured segment):
    - None.

- Parameters not expected to occur (no coloured segments):
    - Boulders at surface.
- Material re-use potential:
    - Probably unsuitable (one coloured segment).

Table 5.8: An example of tabulated AGE severity symbols defining the aggregated inferred geotechnical character, in this case for valley floors with Land Type Af28.

Land type	
Af28	
Terrain unit: 5 - Valley floors	**Prominence within land type: Sparse (0.5%)**

AGE severity values	
Category 1: Poor trafficability	
Boulders at surface:	
‘Sticky’ slippery conditions when wet:	Expected to occur.
Loss of cohesion when wet/ ‘quicksand’ conditions:	High risk.
Category 2: Material re-use potential	
Soil-like natural materials:	Probably unsuitable.
Category 3: Adverse soil behaviour	
Collapse settlement:	Could occur.
Shallow groundwater/ seepage:	Expected to occur.
Heave/ shrinkage:	Could occur.
Consolidation settlement/ ‘soft clays’:	Expected to occur.
Erodibility and/or dispersion:	Could occur.
Waterlogged:	Could occur.
Category 4: Excavatability problems	
Engineering service trenches:	High risk.
Roads, and foundation trenches:	Could occur.

5.3.3 Step 10c: Calculation of AGE impact realisation values

In order to express the inferred impact of the various geotechnical characteristics resulting from the application of the refined SEG system on the cost and ease of development, it is necessary to calculate the realisation value, expressed as the fraction of the total inferred severity value based on the AGE realisation value, for each AGE. This is expressed as the product of the AGE severity value resulting from step 10b (section 5.3.2) and the specific AGE weight (Figure 5.2).

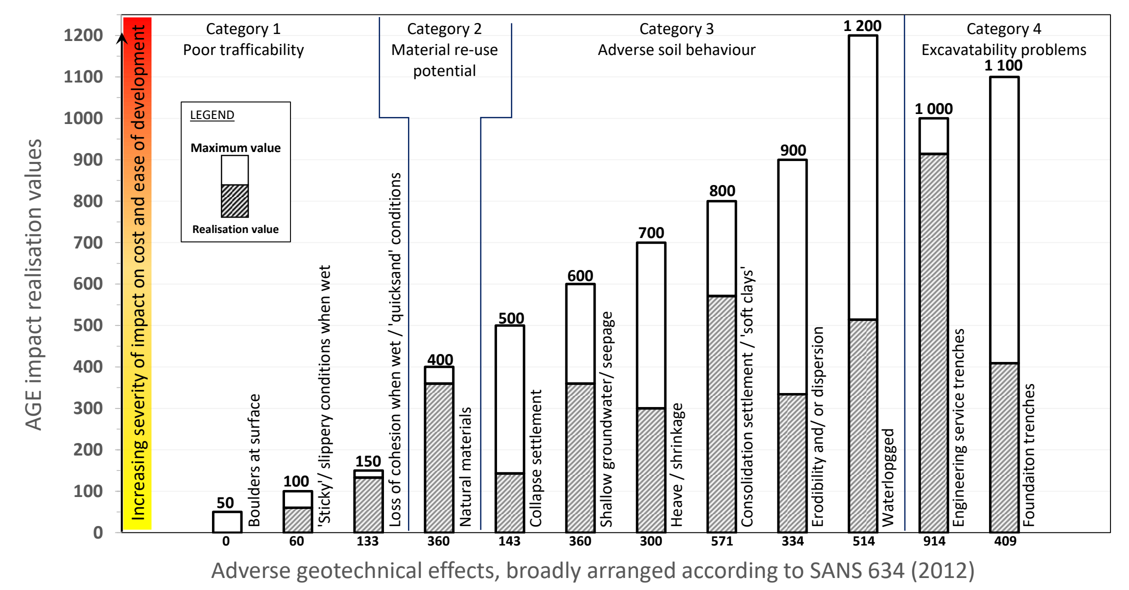


Figure 5.2: Diagrammatical depiction of the level of realisation (cross-hatched bars) of the maximum inferred impact (outlined bars) for each AGE, in this case for valley floors with Land Type Af28 (from Table 5.9).

An example of this calculation for the AGE Excavatability - engineering service trenches is provided in Table 5.9, expressed as follows:

AGE weight:	10 (from Table 4.6). . . . . *i*
AGE severity value (non-integer):	91.4% (from Table 5.6). . . . . . . *j*
AGE impact realisation value:	(*i* x *j*) = 914
Maximum AGE impact value:	(*i* x 100%) = 1 000

The resultant list of values details the overall inferred geotechnical character of the soil forms comprising a specific terrain unit, expressed as the level of realisation of the maximum inferred impact of each AGE on development. This is shown in diagrammatical format in Figure 5.2 where the length of bar for each AGE depicts its' maximum impact value (i.e., 100% realisation of this parameter), and the hatched portion reflecting the perceived level of realisation thereof as provided by the calculated AGE impact realisation value.

In this light it is evident that a low level of realisation indicates a relatively small impact by that AGE on the overall geotechnical character of the soil and/ or soil/ rock complexes occurring within a terrain unit. Conversely, a severe impact is represented by a high level of impact realisation.

Table 5.9: Calculation of AGE impact values, representing Step 10c, in this case for soil forms indicated to occur along valley floors within Land Type Af28.

			AGE contribution scores										Weighted AGE contribution scores										AGE severity values	AGE impact realisation values
	Soils effects groupings (SEGs):		I	II	III	IV	V	VI	VII	VIII	IX	X	I	II	III	IV	V	VI	VII	VIII	IX	X		
	Total prominence:% per SEG:								40			60												
	Adverse geotechnical effects (AGEs)	AGE weights																						
Category 1	Boulders at surface:	0.5																					0	0
Category 1	'Sticky'/ slippery conditions when wet:	1										7										4.2	60	60
Category 1	Loss of cohesion when wet / 'quicksand' conditions:	1.5							5			7							2.0			4.2	89	133
Cat.2	Material re-use potential:	4							3			4							1.2			2.4	90	360
Category 3	Collapse settlement:	5							5										2.0				29	143
Category 3	Shallow groundwater/ seepage:	6										7										4.2	60	360
Category 3	Heave/ shrinkage:	7										5											43	300
Category 3	Consolidation settlement/ 'soft clays':	8							2			7											71	571
Category 3	Erodibility and/or dispersion:	9							2			3											37	334
Category 3	Waterlogged:	12										5										3.0	43	514
Category 4	Excavatability - engineering service trenches:	10							7			6							2.8			3.6	91	914
Category 4	Excavatability - roads, and foundation trenches:	11							5			1							2.0			0.6	37	409

AGE Excavatability - engineering service trenches:
Weight allocated to AGE: 10
AGE severity value (non-integer): 91.4%
AGE impact value: 91.4 x 10 = 914

5.4 Step 11: Preliminary geotechnical zonation

Given that terrain units define basic geotechnical mapping elements, it is prudent to establish a mechanism that will allow comparison between terrain units within a specific study area, or between two or more study areas, based on the aggregated geotechnical characteristics of each as obtained from land type information. Adverse soil behaviour (Category 3 parameters) and excavatability problems (Category 4 parameters), are primarily associated with the spatial occurrence of the various soils within the landscape, and as such can typically be directly linked to the relevant terrain unit through the use of pedological information. Information on parameters grouped within Category 1 Poor trafficability, Category 2 Materials re-use potential and Category 5 Miscellaneous geological, geotechnical, and geomorphological factors represent characteristics that are generally of short-term duration, exhibit relatively low-level impacts, can be attributed to non-soil-like material (e.g., dolomitic strata), or can be attributed to non-morphological factors (e.g., climatic regime), is obtained from other sources.

The establishment of preliminary geotechnical zones based on the geological, geotechnical, and geomorphological character of the terrain units was achieved by collation of the following:

- Step 11a: information obtained from pedological surveys, including land type inventories,
- Step 11b: information from other sources, and
- Step 11c: clustering of terrain units exhibiting the same characteristics.

5.4.1 Step 11a: Utilising pedological information

The inferred geotechnical characteristics of each terrain unit readily obtainable from pedological information through the use of the refined SEG system were classified according to Partridge *et al*. (1993) (Table 2.5), based on the impact realisation values for the relevant AGEs in Categories 3 and 4, within the following guidelines:

- Partridge *et al*. (1993) parameter A - Collapsible soil:

  Potentially collapsible soil is expected to be present where dissemination of pedological information indicates the presence of soil material exhibiting a clay content of up to 6%, predominantly represented by soil forms within SEG-I, SEG-II and SEG-V (although the topsoil of other soil forms could also qualify). Differentiation of the impact of this parameter is predominantly based on the thickness of the potentially collapsible layer, with the following classes allocated:

- 1_A most favourable : layer thickness of less than 0.75 m (representing NHBRC site classes C and C1),
- 2_A intermediate : layer thickness in excess of 0.75 m (representing NHBRC site class C2), and
- 3_A least favourable : a least favourable condition is not applied to this parameter.

- Partridge *et al*. (1993) parameter B - Seepage:

  The presence of an albic horizon (exhibited by various soil forms in several SEGs) deemed indicative of the seasonal or occasional movement of excessive soil moisture, or gleyed characteristics (that could include some plinthic horizons) as a result of prolonged exposure to groundwater (predominantly representing soil forms within SEG-IX, SEG-X and SEG-XI), are considered to indicate groundwater seepage. The following classes are allocated (NOTE: this parameter is not specifically classified by the NHBRC):

  - 1_B most favourable : inherent constraints associated with pedological information based on the BSCS typically does not allow identification of seepage at depths in excess of 1.5 m, preventing allocation of a most favourable condition,
  - 2_B intermediate : seepage associated with permanent or perched water tables expected at a depth of less than 1.5 m, and
  - 3_B least favourable : swamps and/ or marshy areas, typically identified on the hand of the presence of specific soil types indicated to undergo periodic waterlogging present within the cluster of terrain units, e.g., soils containing an organic topsoil horizon, or the presence of a gleyed horizon at very shallow depth (representing NHBRC site class $P^{\text{marshy areas}}$).

- Partridge *et al*. (1993) parameter C - Active soil:

  Those soil forms exhibiting moderate to strong structure (mainly grouped into SEG-VI and SEG-X) are invariably expected to exhibit moderate to significant risk of heave. Additionally, some of the weakly structured soils in SEG-IV and SEG-V could be potentially slightly to moderately expansive, depending on the thickness of the relevant horizon, while the thin melanic or vertic topsoil horizons of some soils in SEG-VII and SEG-VIII could also exhibit a degree of heave. Based on detailed geotechnical results regarding the presence of potentially expansive soils obtained for 32 sites throughout South Africa, assessed by means of a box-and-whisker plot (Figure 5.3), classification of the AGE impact realisation values for this parameter is made utilising the following limits:

- 1_C most favourable : a value of up to 55 (representing NHBRC site class H and H1),
- 2_C intermediate : a value in excess of 55 and up to 280 (representing NHBRC site class H2), and
- 3_C least favourable : a value in excess of 280 (representing NHBRC site class H3).

- Partridge *et al*. (1993) parameter D - Highly compressible soil:

  Soil forms exhibiting an unconsolidated character (SEG-II), or those comprising a thick succession of relatively young clay-rich sub-soil material (SEG-IV and SEG-V) are expected to undergo consolidation under loading or when saturated. Based on detailed geotechnical results regarding the consolidation potential of soils encountered at 32 sites throughout South Africa, assessed by means of a box-and-whisker plot (Figure 5.4), the AGE impact realisation values for this parameter are classified within the following limits:

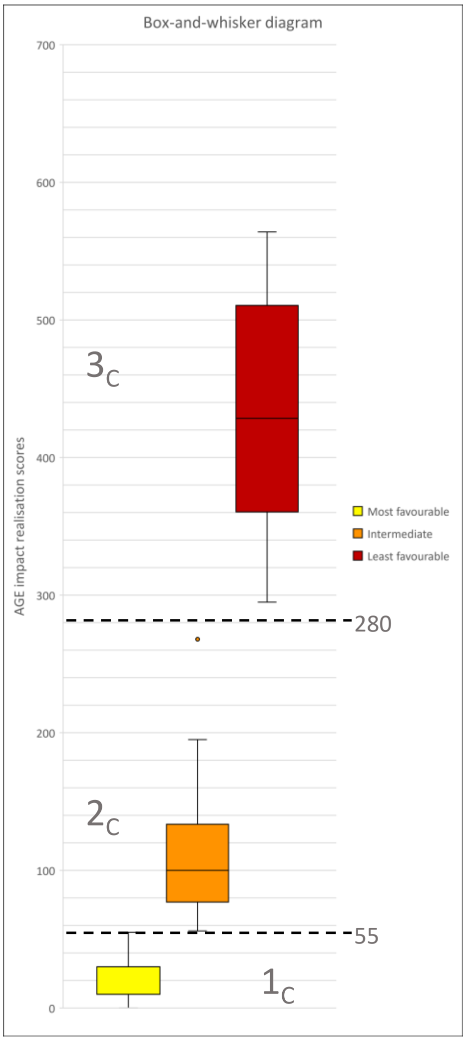
  - 1_D most favourable : a value of up to 100 (representing NHBRC site class S),
  - 2_D intermediate : a value in excess of 100 and up to 300 (representing NHBRC site class S1), and
  - 3_D least favourable : a value in excess of 300 (representing NHBRC site class S2).

- Partridge *et al*. (1993) parameter E - Erodibility of soil:

  It is inferred that soil erosion will readily occur along steeply sloping areas covered by soils exhibiting relatively low cohesion (e.g., sandy topsoil or unconsolidated material; SEG I, SEG-II, SEG-V, SEG-VII and SEG-VIII). However, more clayey soils exhibiting signs of a high sodium-content (i.e., those with a prismacutanic horizon; SEG-VI) could be potentially dispersive, and as such more prone to removal even when occurring in areas exhibiting fairly gentle slopes, or located in areas where significant sheet wash occurs. Based on the inferred erodibility made during detailed geotechnical investigations at 32 sites throughout South Africa, assessed by means of a box-and-whisker plot (Figure 5.5), the following limits were defined for the classification of AGE impact realisation values for this parameter (NOTE: this parameter is not specifically classified by the NHBRC):

  - 1_E most favourable : a value of up to 135,
  - 2_E intermediate : a value in excess of 135 and up to 355, and
  - 3_E least favourable : a value in excess of 355.

SAMPLE LOCATIONS Location	 Land type	 Terrain unit	IGTA RESULTS AGE impact realisation scores	DETAILED SITE INVESTIGATION RESULTS NHBRC site classification (2015)	 Corresponding SANS 634 (2012) classification
Thohoyandou	Ab179	Mid slope	100	H2	2_C
Tzaneen	Ab96	Mid slope	0	H1	1_C
Tzaneen	Ab96	Foot slope	104	H2	2_C
Polokwane (Ster Park)	Ae225	Mid slope	30	not significantly expansive	
Polokwane (Central)	Ae225	Foot slope	55	H1	1_C
Polokwane (Ivy Park)	Ae229	Ridge crest	0	not significantly expansive	
Polokwane (Ivy Park)	Ae229	Mid slope	0	not significantly expansive	
Marble Hall	Ae24	Mid slope	30	H1	1_C
Koekenaap	Ae373	Mid slope	0	not significantly expansive	
Vryburg	Ag10	Foot slope	69	H2	2_C
Schweizer-Reneke	Ah18	Ridge crest	0	not significantly expansive	
Schweizer-Reneke	Ah18	Mid slope	96	H2	2_C
Schweizer-Reneke	Ah18	Foot slope	494	H3	3_C
Taung	Ah21	Foot slope	56	H2	2_C
Heidelberg	Ba29	Ridge crest	0	not significantly expansive	
Heidelberg	Ba29	Foot slope	100	H2	2_C
Lydenburg	Ba66	Mid slope	295	H3	3_C
Pretoria (Zwavelpoort)	Ba9	Mid slope	317	H3	3_C
Pretoria (Zwavelpoort)	Ba9	Foot slope	375	H3	3_C
Wolmaranstad	Bc21	Foot slope	268	H2	2_C
Klerksdorp (Flamwood)	Bc23	Mid slope	84	H2	2_C
Potchefstroom (Central)	Bc25	Foot slope	447	H3	3_C
Coligny	Bc33	Mid slope	10	not significantly expansive	
Coligny	Bc33	Valley floor	564	H3	3_C
Molteno	Db92	Mid slope	410	H3	3_C
Ladysmith	Db251	Mid slope	195	H2	2_C
Devon	Ea20	Ridge crest	163	H2	2_C
Devon	Ea20	Valley floor	560	H3	3_C
Rustenburg (Bokamoso)	Ea3	Ridge crest (2nd phase)	0	not significantly expansive	
Polokwane (Ster Park)	Fa538	Foot slope	70	H2	2_C
Bona-Bona	Fc1	Valley floors	0	not significantly expansive	
Cape Town (Bishop Lavis)	Ga15	Foot slope	0	not significantly expansive	



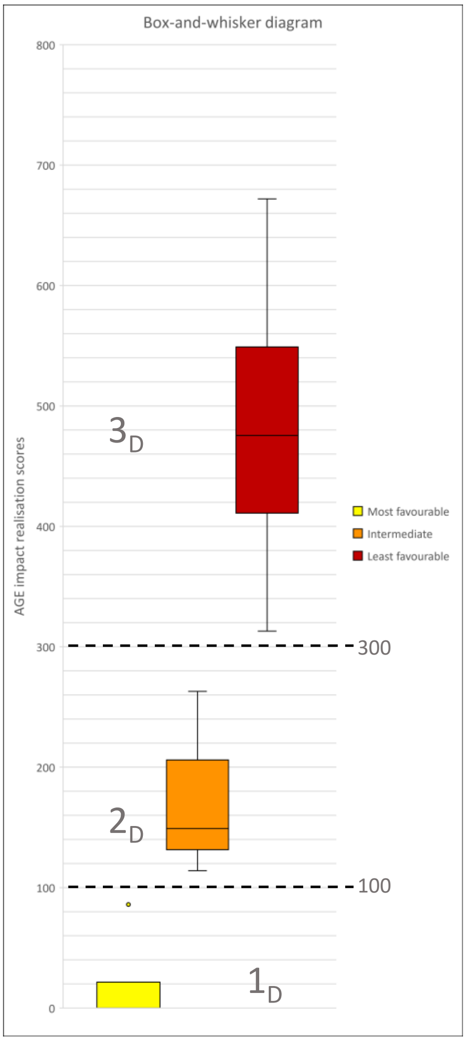
ANALYSIS	Most favourable	Intermediate	Least favourable
Minimum:	0	56	295
Lower quartile (Q_1):	10	77	360.5
Median (Q_2):	30	100	428.5
Upper quartile (Q_3):	30	133.5	510.5
Maximum:	55	268	564

Mean :	25.0	118.6	432.8
Range:	55	212	269
Interquartile range (IQR):	20	56.5	150

Figure 5.3: Determination of limits for the classification of AGE impact realisation values with regard to active soils by means of a box-and-whisker plot. The sites are arranged in alphabetical order according to the land type designation.

NOTE: Upper whisker = maximum value, bottom whisker = minimum value, upper box line = third quartile, centre line = median, bottom line = first quartile, and single dots = outliers.)

SAMPLE LOCATIONS			IGTA RESULTS	DETAILED SITE INVESTIGATION RESULTS	
Location	Land type	Terrain unit	AGE impact realisation scores	NHBRC site classification (2015)	Corresponding SANS 634 (2012) classification
Thohoyandou	Ab179	Mid slope	463	S2	3_D
Tzaneen	Ab96	Mid slope	571	S2	3_D
Tzaneen	Ab96	Foot slope	576	S2	3_D
Polokwane (Ster Park)	Ae225	Mid slope	549	S2	3_D
Polokwane (Central)	Ae225	Foot slope	583	S2	3_D
Polokwane (Ivy Park)	Ae229	Ridge crest	320	S2	3_D
Polokwane (Ivy Park)	Ae229	Mid slope	457	S2	3_D
Marble Hall	Ae24	Mid slope	411	S2	3_D
Koekenaap	Ae373	Mid slope	547	S2	3_D
Vryburg	Ag10	Foot slope	469	S2	3_D
Schweizer-Reneke	Ah18	Ridge crest	490	S2	3_D
Schweizer-Reneke	Ah18	Mid slope	518	S2	3_D
Schweizer-Reneke	Ah18	Foot slope	665	S2	3_D
Taung	Ah21	Foot slope	571	S2	3_D
Heidelberg	Ba29	Ridge crest	389	S2	3_D
Heidelberg	Ba29	Foot slope	463	S2	3_D
Lydenburg	Ba66	Mid slope	417	S2	3_D
Pretoria (Zwavelpoort)	Ba9	Mid slope	495	S2	3_D
Pretoria (Zwavelpoort)	Ba9	Foot slope	537	S2	3_D
Wolmaranstad	Bc21	Foot slope	482	S2	3_D
Klerksdorp (Flamwood)	Bc23	Mid slope	313	S2	3_D
Potchefstroom (Central)	Bc25	Foot slope	549	S2	3_D
Coligny	Bc33	Mid slope	462	S2	3_D
Coligny	Bc33	Valley floor	672	S2	3_D
Molteno	Db251	Mid slope	86	C	1_D
Ladysmith	Db92	Mid slope	411	S2	3_D
Devon	Ea20	Ridge crest	263	S1	2_D
Devon	Ea20	Valley floor	640	S2	3_D
Rustenburg (Bokamoso)	Ea3	Ridge crest (2nd phase)	114	S1	2_D
Polokwane (Ster Park)	Fa538	Foot slope	350	S2	3_D
Bona-Bona	Fc1	Valley floors	149	C2	2_D
Cape Town (Bishop Lavis)	Ga15	Foot slope	320	C2	3_D



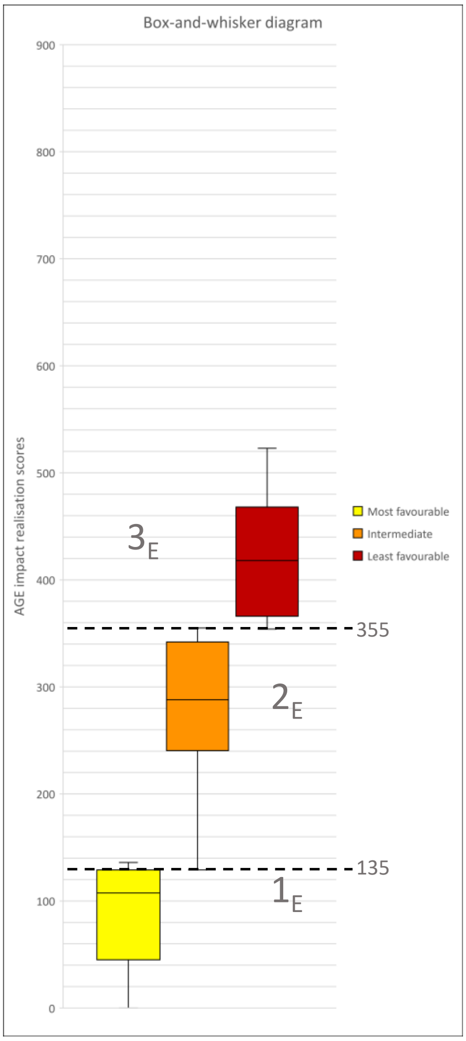
ANALYSIS	Most favourable	Intermediate	Least favourable
Minimum:	0	114	313
First quartile (Q_1):	0	131.5	411
Median (Q_2):	0	149	475.5
Third quartile (Q_3):	21.5	206	549
Maximum:	86	263	672

Mean :	21.5	175.3	477.7
Range:	86	149	359
Interquartile range (IQR):	21.5	74.5	138

Figure 5.4: Determination of limits for the classification of AGE impact realisation values with regard to highly compressible soil by means of a box-and-whisker plot. The sites are arranged in alphabetical order according to the land type designation.

NOTE: Upper whisker = maximum value, bottom whisker = minimum value, upper box line = third quartile, centre line = median, bottom line = first quartile, and single dots = outliers.)

SAMPLE LOCATIONS			IGTA RESULTS	DETAILED SITE INVESTIGATION RESULTS	
Location	Land type	Terrain unit	AGE impact realisation scores	NHBRC site classification (2015)	Corresponding SANS 634 (2012) classification
Thohoyandou	Ab179	Mid slope	341	-	2_E
Tzaneen	Ab96	Mid slope	129	-	1_E
Tzaneen	Ab96	Foot slope	134	-	1_E
Polokwane (Ster Park)	Ae225	Mid slope	360	-	2_E
Polokwane (Central)	Ae225	Foot slope	347	-	2_E
Polokwane (Ivy Park)	Ae229	Ridge crest	257	-	2_E
Polokwane (Ivy Park)	Ae229	Mid slope	257	-	2_E
Marble Hall	Ae24	Mid slope	270	-	2_E
Koekenaap	Ae373	Mid slope	366	-	3_E
Vryburg	Ag10	Foot slope	179	-	2_E
Schweizer-Reneke	Ah18	Ridge crest	336	-	2_E
Schweizer-Reneke	Ah18	Mid slope	343	-	2_E
Schweizer-Reneke	Ah18	Foot slope	351	-	3_E
Taung	Ah21	Foot slope	355	-	2_E
Heidelberg	Ba29	Ridge crest	129	-	1_E
Heidelberg	Ba29	Foot slope	161	-	2_E
Lydenburg	Ba66	Mid slope	418	-	3_E
Pretoria (Zwavelpoort)	Ba9	Mid slope	6	-	1_E
Pretoria (Zwavelpoort)	Ba9	Foot slope	77	-	1_E
Wolmaranstad	Bc21	Foot slope	523	-	3_E
Klerksdorp (Flamwood)	Bc23	Mid slope	123	-	2_E
Potchefstroom (Central)	Bc25	Foot slope	195	-	1_E
Coligny	Bc33	Mid slope	288	-	3_E
Coligny	Bc33	Valley floor	468	-	3_E
Molteno	Db251	Mid slope	86	-	1_E
Ladysmith	Db92	Mid slope	354	-	3_E
Devon	Ea20	Ridge crest	129	-	1_E
Devon	Ea20	Valley floor	103	-	2_E
Rustenburg (Bokamoso)	Ea3	Ridge crest (2nd phase)	0	-	1_E
Polokwane (Ster Park)	Fa538	Foot slope	129	-	1_E
Bona-Bona	Fc1	Valley floors	58	-	1_E
Cape Town (Bishop Lavis)	Ga15	Foot slope	0	-	1_E



ANALYSIS	Most favourable	Intermediate	Least favourable
Minimum:	0	129	354
First quartile (Q_1):	45	240.5	366
Median (Q_2):	107.5	288	418
Third quartile (Q_3):	129	342	468
Maximum:	136	355	523

Mean :	84.4	276.5	425.8
Range:	136	226	169
Interquartile range (IQR):	84	101.5	102

Figure 5.5: Determination of limits for the classification of AGE impact realisation values with regard to erodibility of soil by means of a box-and-whisker plot. The sites are arranged in alphabetical order according to the land type designation.

NOTE: Upper whisker = maximum value, bottom whisker = minimum value, upper box line = third quartile, centre line = median, bottom line = first quartile, and single dots = outliers.

- Partridge *et al*. (1993) parameter F - Difficulty of excavation to 1.5 m depth:

  The AGE impact realisation values regarding the presence of bedrock and/ or hardpan pedocrete in engineering service trenches based on the disseminated pedological information can be classified as follows:

  - 1_F most favourable : a maximum value of less than 100 implying that hard rock and/ or hardpan pedocrete comprises less than 10% of the material to a depth of 1.5 m (not warranting classification as NHBRC site class R),
  - 2_F intermediate : a maximum value of between 100 and 400 implying that hard rock and/ or hardpan pedocrete comprises between 10 and 40% of the material to a depth of 1.5 m (can be classified as NHBRC site class (R) indicating highly localised conditions), and
  - 3_F least favourable : a maximum value in excess of 400 implying that hard rock and/ or hardpan pedocrete comprises in excess of 40% of the material to 1.5 m (representing NHBRC site class R).

Dissemination of the pedological information allows assessment of the Category 1 Poor trafficability and Category 2 Materials re-use potential parameters, although Partridge *et al*. (1993) contains no mention thereof. As these could potentially affect the cost and ease of development, suitable guidelines for the ranking of these parameters must be established to allow flagging of these potential problems during the conducting of an PSGI prior to development.

The following supplemental parameters are proposed based on the Partridge *et al*. (1993) ranking system used for the other parameters:

- Supplemental parameter - Boulders at surface:

  The presence of boulders is considered primarily as a result of bedrock outcrops (represented by SEG-VII) and can be identified by the dissemination of pedological information through the use of the refined SEG system. This information is typically supplemented by the study of remote sensing imagery, with the following proposed ranking regarding the severity of its impact on development:

  - 1 most favourable : a most favourable condition is not applied to this parameter,
  - 2 intermediate : areas where boulders could occur at the surface associated with scattered bedrock outcrops with an AGE impact realisation value of less than 25 (representing 50% of the total value of 50), and

- 3 least favourable : areas where large swathes or rock associated with extensive bedrock outcrops are expected with an AGE impact realisation value of 25 or more.

- Supplemental parameter - 'Sticky' / slippery conditions when wet:

  It is inferred that topsoil containing a significant amount of potentially plastic clay (particularly soils in SEG-VI and SEG-X, and to a lesser extent within SEG-IV, SEG-V, SEG-VII and SEG-VIII) could hamper the movement of especially wheeled vehicles during and for a period after rainfall events, or on a more continuous basis if waterlogged. As such, the following ranking is proposed to assess the impact of this parameter on development:

  - 1 most favourable : a most favourable condition is not applied to this parameter,
  - 2 intermediate : hazardous conditions could occur or are expected to occur during and after rainfall events, with an AGE impact realisation value of less than 75 (representing 75% of the total value of 100), and
  - 3 least favourable : high risk of hazardous conditions, with an AGE impact realisation value of 75 or more.

- Supplemental parameter - Loss of cohesion / 'quicksand' conditions when wet:

  It is expected that soil moisture from rainfall events or leaking wet services could accumulate within relatively permeable gravelly, sandy or silty topsoil that overlies denser material, including moderately to strongly structured clayey soil, hardpan pedocrete or bedrock (mainly applicable to soil forms within SEG-V, SEG-VII, SEG-VIII and SEG-IX, and to a lesser extent in SEG-I, SEG-II, SEG-IV, SEG-VI and SEG-X). In some instances (particularly with regard to some of the soil forms comprising SEG-II, SEG-V, SEG-VII and SRG-VIII) loads applied by passing wheeled and tracked vehicles could force the moisture towards the surface where it could lead to liquefaction and/ or a reduction in the cohesion (and as such the bearing strength) of the topsoil, severely affecting trafficability of a site. It is proposed that the severity of this parameter be ranked as follows:

  - 1 most favourable : a most favourable condition is not applied to this parameter,
  - 2 intermediate : hazardous conditions could occur or are expected to occur during and after rainfall events, or when becoming saturated due to other reasons, with an AGE impact realisation value of less than 112.5 (representing 75% of the total value of 150), and
  - 3 least favourable : high risk of hazardous conditions during and after rainfall events, with an AGE impact realisation value of 112.5 or more.

- Supplemental parameter - Material re-use potential:

  The on-site availability of natural materials suitable for re-use as backfill material or in the construction of compacted engineered fills is expected to reduce development costs to a degree. However, soil forms comprising material with a clay content in excess of 6% (applicable to all SEGs) will require significant effort and cost to render more suitable for re-use, while those with very thin soil-like overburden (especially those of SEG-VII) could yield only very small volumes of possibly suitable material. In this light, the following ranking of the severity of the impact of this parameter is proposed, namely:

  - 1 most favourable : localised pockets of possibly suitable material with/ without reworking occur, with an AGE impact realisation value of less than 100 (representing 25% of the total value of 400),
  - 2 intermediate : very small volumes of material possibly suitable for re-use with/ without reworking occur, with an AGE impact realisation value of between 100 and up to 300 (representing 75% of the total value of 400), and
  - 3 least favourable : most or all of the natural materials are deemed unsuitable for re-use, with an AGE impact realisation value in excess of 300.

5.4.2 Step 11b: Utilising information obtained from other sources

In addition to the ranking of Category 3 and Category 4 parameters discussed in the previous section, Partridge *et al*. (1993) also allows ranking of some Category 5 parameters, albeit requiring information from other sources than land type maps and memoirs, namely:

- Partridge *et al*. (1993) parameter G - Undermining:

  This factor is typically assessed only in broad terms on the hand of the available geological and land use information, but could require the conducting of a specialised investigation that falls outside the scope of the PSGI for more accurate verification. Where possible, the following classes are allocated:

  - 1_G most favourable : undermining at a depth greater than 200 m below surface, except in instances where total extraction mining has not occurred,
  - 2_G intermediate : areas where mining activities have occurred in the past at a depth of less than 200 m, and where stope closure has ceased, and

- 3_G least favourable : mining within 200 m of the surface, or where total extraction mining has taken place (representing NHBRC site class $P^{\text{mining subsidence}}$).

- Partridge *et al*. (1993) parameter H - Dolomite land:

  An indication of the occurrence of dolomite land is generally based on published geological maps, technical reports, and/ or the results of walk-over surveys to observe outcrops in the area. However, assessment of the inherent hazard class (IHC) exhibited by dolomitic strata underlying a site requires specialised technical information only obtainable through the conducting of specialised field surveys (the results of which are not always available in the public domain). As such, IHCs for PSGI purposes are assessed in terms of the known characteristics of the specific geological formation (e.g., the Monte Christo Formation typically represents a greater hazard - IHC 6 to 8 - than that of the Oaktree Formation - IHC 5) and/ or the personal experience of the geopractitioner. The following classes are allocated:

  - 1_H most favourable : possibly stable areas where the dolomitic strata are covered by Karoo Supergroup sediments or sill intrusions in excess of 60 m (non-dewatered areas) or 100 m (dewatered areas) as defined by SANS 1936 (2012), or where Black Reef Formation strata occur, anticipated to classify as IHC 1 (representing NHBC site class $P^{\text{dolomitic area}}$: D1),
  - 2_H intermediate : areas potentially exhibiting a risk of instability with an IHC of 2 to 5 (representing NHBRC site class $P^{\text{dolomitic area}}$: D2 or D3), based on information from the Council for Geoscience, including the 1:50 000 scale geotechnical series maps, reports in corporate libraries, and/ or an absence of obvious evidence of surface instability visible on remote sensing images, and
  - 3_H least favourable : areas where sinkholes and/ or subsidences have occurred, based on information from the Council for Geoscience, including the 1:50 000 scale geotechnical series maps, reports in corporate libraries and/ or evidence of surface instability visible on remote sensing images, classifying as IHC 6 to 8 (representing NHBC site class $P^{\text{dolomitic area}}$ / D4).

- Partridge *et al*. (1993) parameter I - very gently sloping to nearly flat lying area / steep slopes:

  Average slopes as a result of topographical features present in and around a site are generally assessed by means of the available surface elevation contours either obtained on a regional scale from various web-based sources (e.g., JAXA), or resulting from site-specific surveys conducted for the project. The results of these slope analyses are classified as follows:

  - 1_I most favourable : natural slopes of between 2 and 6°,
  - 2_I intermediate : natural slopes of less than 2°,
    natural slopes of between 6 and 18° (KwaZulu-Natal and Western Cape Provinces), or slopes of between 6 and 12° (all other provinces), and
  - 3_I least favourable : natural slopes in excess of 18° (KwaZulu-Natal and Western Cape Provinces), or slopes in excess of 12° (all other provinces).

  Note that assessment of this parameter is typically conducted under parameter B - Seepage.

- Partridge *et al*. (1993) parameter J - unstable natural slopes:

  The possible occurrence of unstable slopes in an area is generally dependent on slope angles and the character of the soil and rock occurring at the surface. As such, this parameter is typically assessed by means of specialised field and laboratory tests. However, an assessment of the potential for slope instability on PSGI-level focusses predominantly on the known characteristics of the strata underlying and the soils covering moderately steep to steep slopes within a site, based on the results of a slope analysis utilising surface elevation contours either obtained on a regional scale from various web-based sources (e.g., JAXA). A study of remote sensing imagery could identify evidence of historical landslides in the area. The results of this assessment are classified as follows:

  - 1_J most favourable : areas exhibiting a low risk of slope instability,
  - 2_J intermediate : areas exhibiting an intermediate risk of slope instability, and
  - 3_J least favourable : areas exhibiting a high risk of slope instability, especially if subject to seismic risk (representing NHBRC site class $P^{landslip}$).

- Partridge *et al*. (1993) parameter K - seismicity:

  Assessment of this parameter on PSGI-level relies on the regional seismic hazard information provided in Part 4 of SANS 10160 (2009), as precise assessment of this parameter again requires a specialist investigation. Results are classified as follows:

- 1_K most favourable : areas exhibiting a 10% probability of a seismic event with a peak ground acceleration of up to 100 cm/s^2 within 50 years,
- 2_K intermediate : areas exhibiting a risk of mining-induced seismicity with a peak ground acceleration in excess of 100 cm/s^2, and
- 3_K least favourable : areas exhibiting natural seismicity with a peak ground acceleration in excess of 100 cm/s^2.

- Partridge *et al*. (1993) parameter L - Areas subject to flooding:

  In instances where the pedological information indicates the presence of soils that could undergo waterlogging (primarily those soil forms comprising SEG-XI, but also in instances where soil horizons exhibiting a gleyed character occurs at very shallow depth above hardpan pedocrete or weathered bedrock), it is inferred that the terrain unit is at risk of periodic flooding, and as such the following class is allocated:

  - 1_L most favourable : a most favourable condition is not applied to this parameter,
  - 2_L intermediate : periodic flooding could occur in areas with slopes of less than 1% (approximately 0.5°) occurring in close proximity to known drainage channels or flood plains, and
  - 3_L least favourable : areas located within known drainage channel or floodplain.

  Note that this parameter is not specifically catered for by the NHBRC (2015).

The available geological and geotechnical information typically assessed during the conducting of an PSGI allows identification of other adverse factors not included in any of the previously-mentioned parameters, accommodated as follows:

- Supplemental parameter - Other adverse characteristics:

  Soils exhibiting a self-mulching character (predominantly falling in SEG-VI and SEG-X), strata known to slake after exposure to water or air, or areas located within 'Southern Cape Coastal Condensation Problem Area' could adversely affect the development potential of a site. It is proposed that the severity of this parameter be ranked as follows:

  - 1 most favourable : a most favourable condition is not applied to this parameter,
  - 2 intermediate : soil/ strata exhibiting other adverse characteristics could occur in localised areas, and
  - 3 least favourable : the widespread occurrence of soil/ strata exhibiting other adverse characteristics is expected.

5.4.3 Step 11c: Clustering of terrain units

Terrain units exhibiting the same geotechnical classification based on those parameters proposed by Partridge *et al*. (1993) obtainable from pedological information and other sources (excluding the supplemental parameters not mentioned by Partridge *et al*., 1993), are subsequently grouped together using the built-in sorting function of Microsoft Excel, version 16.32, to define geotechnical clusters. Table 5.10 provides an example of the preliminary classification of the geotechnical characteristics exhibited by soils occurring at 32 sites within South Africa resulting from the refined SEG process, with clustering of terrain units exhibiting the same classification.

Combining these clusters with the available geospatial distribution of the various terrain units within a given study area by means of a Geographical Information System (GIS) enables the geopractitioner to define preliminary geotechnical zones for which remedial and/ or precautionary measures required to alleviate the inferred adverse geotechnical characteristics can then be defined. The resultant zonation map defines the first of three primary products of an PSGI.

5.5 Step 12: Identification of flag issues

The list of geological, geotechnical and geomorphological characteristics exhibited by the natural materials occurring within the preliminary geotechnical zones, each representing a geotechnical cluster as defined in Step 11 (section 5.4), represents flag issues that summarise the perceived impact thereof on the ease and cost of development primarily based on the requirements of SANS 634 (2012), as well as other adverse characteristics proposed by this study. The following flag issues are defined (Table 5.11):

- Category 1 - Poor trafficability:
  - boulders at the surface,
  - ‘sticky’ / slippery conditions when wet, and
  - topsoil expected to lose cohesion when saturated / ‘quicksand’ conditions
- Category 2 - Materials re-use potential:
  - natural soil-like materials.
- Category 3 - Adverse soil behaviour:
  - collapse settlement,
  - groundwater seepage and/ or waterlogging,
  - heave / shrinkage, compressibility / ‘soft clays’, and
  - erodibility.

Table 5.10: Geotechnical clustering illustrated on the hand of an assessment of the inferred geotechnical characteristics of the soils occurring at 32 sites in South Africa through application of the refined SEG system. The preliminary geotechnical classification was obtained by means of the principles explained in section 5.4.

AGE IMPACT REALISATION VALUES (SEG SYSTEM)

LOCALITY	LAND TYPE: Land type	LAND TYPE: Terrain unit	Category 3 parameters: A - Collapsible soil (maximum value: 500)	Overall thickness of collapsible horizons (mm)	B - Seepage (maximum value: 600)	C - Active soil (maximum value: 700)	D - Highly compressible soil (maximum value: 800)	E - Erodability of soil (maximum value: 900)	L - Areas subject to flooding (waterlogged) (maximum value: 1 200)	Category 4 parameters: F - Difficulty of excavation to 1.5 m (maximum value: 1 000)
Wolmaranstad	Bc21	Foot slopes	149	650	46	268	482	523		597
Marble Hall	Ae24	Mid slopes			9	30	411	270		689
Coligny	Bc33	Mid slopes			21	10	462	288		709
Potchefstroom (Central)	Ae225	Foot slopes				55	583	347		814
Potchefstroom (Central)	Ae225	Mid slopes				30	549	129		829
Ladysmith	Db251	Mid slopes			5	195	95	86		304
Polokwane (Ster Park)	Fa538	Foot slopes	41	1200	41	70	350	129		601
Bona-Bona	Fc1	Valley floors	236	900			149	58		857
Pretoria (Zwavelpoort)	Ba9	Mid slopes			6	317	495	6		415
Devon	Ea20	Ridge crests			17	163	263	129		689
Pretoria (Zwavelpoort)	Ba9	Foot slopes			139	375	537	77	34	282
Heidelberg (Gauteng)	Ba29	Ridge crests					389	129		379
Tzeneen	Ab96	Mid slopes				100	571	129		0
Tzeneen	Ab96	Foot slopes				104	576	134		3
Cape Town (Bishop Levis)	Ga15	Foot slopes	223	1500	321		320		129	34
Taung	Ah21	Foot slopes	329	1200		56	571	355		69
Lydenburg	Ba66	Mid slopes			13	295	417	418		50
Koekenaap	Ae373	Mid slopes	339	1200			547	366		576
Schweizer-Reneke	Ah18	Mid slopes	139	1200	82	96	518	343		641
Schweizer-Reneke	Ah18	Foot slopes	26	950	31	494	665	351		630
Potchefstroom (Central)	Bc25	Foot slopes	22	1200	85	447	549	136	31	641
Schweizer-Reneke	Ah18	Ridge crests	180	1200			490	336		636
Vryburg	Ag10	Foot slopes			6	69	469	179		878
Klerksdorp (Flamwood)	Bc23	Mid slopes			15	84	313	224		880
Thohoyandou	Ab197	Mid slopes			4	100	463	341		314
Molteno	Db92	Mid slopes			4	410	411	354		729
Heidelberg (Gauteng)	Ba29	Foot slopes			21	100	463	161	17	164
Rustenburg (Bokamoso)	Ea3	Ridge crests (2nd phase)					114			1000
Devon	Ea20	Valley floors			343	560	640	309	411	457
Polokwane (Ivy Park)	Ae229	Ridge crests					320	257		914
Polokwane (Ivy Park)	Ae229	Mid slopes					457	257		829
Coligny	Bc33	Valley floors			312	564	672	468	267	383

GEOTECHNICAL CLUSTERING (classification according to SANS 634:2012)

LOCALITY	1 - Most favourable: A - Overall thickness < 0.75 m	C - Impact realisation value ≤ 55	D - Impact realisation value ≤ 100	E - Impact realisation value ≤ 135	F - Impact realisation value < 100	Result	2 - Intermediate: A - Overall thickness > 0.75 m	B - Seepage expected at depth of < 1.5 m	C - Impact realisation value > 55 and ≤ 280	D - Impact realisation value > 100 and ≤ 300	E - Impact realisation value > 135 and ≤ 355	F - Impact realisation value ≥ 100 and ≤ 400	Result	3 - Least favourable: C - Impact realisation value > 280	B - Seepage when waterlogging expected	D - Impact realisation value > 300	E - Impact realisation value > 355	F - Impact realisation value > 400	L - Presence of waterlogged soils inferred	Result	RESULTANT PRELIMINARY GEOTECHNICAL CLASSIFICATION	CLUSTERS
Wolmaranstad	A					1A		B	C				2BC			D	E	F		3DEF	1A 2BC 3DEF	1
Marble Hall		C				1C		B			E		2BE			D		F		3DF	1C 2BE 3DF	2
Coligny		C				1C		B			E		2BE			D		F		3DF	1C 2BE 3DF	
Potchefstroom (Central)		C				1C					E		2E			D		F		3DF	1C 2E 3DF	3
Potchefstroom (Central)		C		E		1CE										D		F		3DF	1CE 3DF	4
Ladysmith			D	E		1DE		B	C			F	2BCF								1DE 2BCF	5
Polokwane (Ster Park)				E		1E	A	B	C				2ABC			D		F		3DF	1E 2ABC 3DF	6
Bona-Bona				E		1E	A			D			2AD					F		3F	1E 2AD 3F	7
Pretoria (Zwavelpoort)				E		1E		B					2B	C		D		F		3CDF	1E 2B 3CDF	8
Devon				E		1E		B	C	D			2BCD					F		3F	1E 2BCD 3F	9
Pretoria (Zwavelpoort)				E		1E						F	2F	C	B	D			L	3CBDL	1E 2F 3CBDL	10
Heidelberg (Gauteng)				E		1E						F	2F			D				3D	1E 2F 3D	11
Tzeneen				E	F	1EF			C				2C			D				3D	1EF 2C 3D	12
Tzeneen				E	F	1EF			C				2C			D				3D	1EF 2C 3D	
Cape Town (Bishop Levis)					F	1F	A						2A		B	D			L	3BDL	1F 2A 3BDL	13
Taung					F	1F	A		C		E		2ACE			D				3D	1F 2ACE 3D	14
Lydenburg					F	1F		B					2B	C		D	E			3CDE	1F 2B 3CDE	15
Koekenaap							A						2A			D	E	F		3DEF	2A 3DEF	16
Schweizer-Reneke							A	B	C		E		2ABCE			D		F		3DF	2ABCE 3DF	17
Schweizer-Reneke							A	B			E		2ABE	C		D		F		3CDF	2ABE 3CDF	18
Potchefstroom (Central)							A				E		2AE	C	B	D		F	L	3CBDFL	2AE 3CBDFL	19
Schweizer-Reneke							A				E		2AE			D		F		3DF	2AE 3DF	20
Vryburg								B	C		E		2BCE			D		F		3DF	2BCE 3DF	21
Klerksdorp (Flamwood)								B	C		E		2BCE			D		F		3DF	2BCE 3DF	
Thohoyandou								B	C		E	F	2BCEF			D				3D	2BCEF 3D	22
Molteno								B			E		2BE	C		D		F		3CDF	2BE 3CDF	23
Heidelberg (Gauteng)									C		E	F	2CEF		B	D			L	3BDL	2CEF 3BDL	24
Rustenburg (Bokamoso)										D			2D					F		3F	2D 3F	25
Devon											E		2E	C	B	D		F	L	3CBDFL	2E 3CBDFL	26
Polokwane (Ivy Park)											E		2E			D		F		3DF	2E 3DF	27
Polokwane (Ivy Park)											E		2E			D		F		3DF	2E 3DF	
Coligny												F	2F	C	B	D	E		L	3CBDEL	2F 3CBDEL	28

Table 5.11: List of flag issues, obtained from the use of pedological information through application of the refined SEG system and from other source, resultant from the conducting of an PSGI based on principles explained in section 5.4.

FLAG ISSUES		INFERRED IMPACTS ON DEVELOPMENT **According to** Partridge *et al.* (1993)**, supplemented where indicated, based on AGE severity values.**		
		1 - Most favourable	2 - Intermediate	3 - Least favourable
CATEGORY 1 - POOR TRAFFICABILITY	**Occurrence of boulders at the surface,** hampers movement of all types of vehicle.	A most favourable condition is not defined for this parameter.	2_{supp}: Boulders expected at the surface / scattered bedrock outcrops expected to occur.	3_{supp}: Extensive bedrock outcrops expected.
	'Sticky' / slippery conditions when wet, hampers movement of mainly wheeled vehicles.	A most favourable condition is not defined for this parameter.	2_{supp}: 'Sticky' / slippery conditions expected after rain.	3_{supp}: 'Sticky' / slippery conditions expected at all times.
	Topsoil expected to lose cohesion when saturated / 'quicksand' conditions, e.g., liquefaction or 'quicksand' conditions will hamper movement of all types of vehicle.	1_{supp}: Topsoil expected to lose cohesion in localised areas after rain.	2_{supp}: Topsoil expected to lose cohesion when saturated.	3_{supp}: Quicksand conditions expected after rain / in inundated areas.
CATEGORY 2 - MATERIALS RE-USE POTENTIAL Natural soil-like overburden.		1_{supp}: Localised pockets of natural materials could be suitable for re-use with / without reworking.	2_{supp}: Very small volumes of natural material could possibly be suitable for re-use with / without reworking.	3_{supp}: Most to all natural materials expected to be unsuitable for re-use.
CATEGORY 3 - ADVERSE SOIL BEHAVIOUR	**Collapse settlement,** under loading or when saturated.	Class 1_A: Potentially collapsible material < 0.75 m thick expected to occur.	Class 2_A: Potentially collapsible material > 0.75 m thick expected to occur.	A least favourable condition is not defined for this parameter.
	Groundwater seepage and/ or waterlogging.	A most favourable condition is not defined for this parameter.	Class 2_B: Seepage associated with permanent or perched water tables expected at a depth of < 1.5 m.	Class 3_B: Swamps and marshes, including soil inferred to be waterlogged.
	Heave / shrinkage, with changes in moisture content.	Class 1_C: Low soil-heave expected, with an AGE impact realisation value of ≤ 55.	Class 2_C: Moderate soil-heave expected, with an AGE impact realisation value of > 55 and ≤ 280.	Class 3_C: High soil-heave expected, with an AGE impact realisation value of > 280.
	Compressibility / 'soft clays', under loading or when saturated.	Class 1_D: Low soil compressibility expected, with an AGE impact realisation value of ≤ 100.	Class 2_D: Moderate soil compressibility expected, with an AGE impact realisation value of > 100 and ≤ 300.	Class 3_D: High soil compressibility expected, with an AGE impact realisation value of > 300.
	Erodibility / dispersion, dispersive soils / non-cohesive material along steep slopes or within areas where concentrated surface flow occurs.	Class 1_E: Low, with an AGE impact realisation value of ≤ 135.	Class 2_E: Intermediate, with an AGE impact realisation value of > 135 and ≤ 355.	Class 3_E: High, with an AGE impact realisation value of > 355.
CATEGORY 4 - EXCAVATABILITY PROBLEMS To a depth of 1.5 m.		Class 1_F: Pockets of bedrock / hardpan pedocrete expected to comprise < 10% of total profile up to 1.5 m, with an AGE impact realisation value of < 100.	Class 2_F: Pockets of bedrock / hardpan pedocrete expected to comprise between 10 and 40% of total profile up to 1.5 m, with an AGE impact realisation value of ≥ 100 and ≤ 400.	Class 3_F: Bedrock / hardpan pedocrete expected to comprise > 40% of total profile up to 1.5 m, with an AGE impact realisation value of > 400.
CATEGORY 5 - MISCELLANEOUS GEOLOGICAL, GEOTECHNICAL & GEOMORPHOLOGICAL FACTORS	**Undermining,** risk of surface instability / differential settlement.	Class 1_G: Undermining at a depth > 200 m, except in areas where total extraction mining has not occurred.	Class 2_G: Areas where mining activities have occurred in the past at a depth of < 200 m, where stope closure has ceased.	Class 3_G: Areas where mining is occurring at a depth of < 200 m, or where total extraction mining has taken place.
	Dolomite land, risk of sinkholes and/or subsidences, with details regarding Inherent Hazard Classes (IHC) provided in Part 2 of SANS 1936 (2012).	Class 1_H: Possibly stable: areas of dolomite covered by sufficiently thick layers of Karoo sediments or sill intrusions, anticipated to classify as IHC 1.	Class 2_H: Potentially unstable, anticipated to classify as IHC 2 to 5.	Class 3_H: Areas where sinkholes / subsidences have occurred, anticipated to classify as IHC 6 to 8.
	Very gentle slopes to nearly flat-lying areas, periodic ponding of surface water possible, wet engineering services prone to blockage.	A most favourable condition is not defined for this parameter.	Class 2_I: Slopes of < 2˚.	A least favourable condition is not defined for this parameter.
	Steep slopes, more complex construction work indicated.	Class 1_I: Slopes of between 2 and 6˚.	Class 2_I: Slopes of between 6 and 18˚ (KwaZulu-Natal and Western Cape Provinces), or slopes of between 6 and 12˚ (all other provinces).	Class 3_I: Slopes of > 18˚ (KwaZulu-Natal and Western Cape Provinces), or slopes of > 12˚ (all other provinces).
	Unstable natural slopes, based on the results of a slope analysis, risk of possible slope failure.	Class 1_J: Low risk.	Class 2_J: Intermediate risk.	Class 3_J: High risk, especially in areas subject to seismic activity.
	Seismicity, details regarding seismic hazard provided in Part 4 of SANS 10160 (2009).	Class 1_K: Areas exhibiting a 10% probability of a seismic event with a peak ground acceleration of < 100 cm/s^2 within 50 years.	Class 2_K: Area exhibiting a risk of mining-induced seismicity with a peak ground acceleration of > 100 cm/s^2.	Class 3_K: Areas exhibiting a risk of natural seismic activity with a peak ground acceleration of > 100 cm/s^2 expected.
	Periodic flooding, mainly based on geospatial setting of the area.	A most favourable condition is not defined for this parameter.	Class 2_L: Periodic flooding could occasionally occur due to proximity to surface water courses in areas with slopes of less than 1% (± 0.5°).	Class 3_L: Periodic flooding expected due to location within surface water courses.
	Other adverse characteristics (soil and/ or strata), e.g., self-mulching, slaking, 'Southern Cape Condensation Problem Area', etc.	A most favourable condition is not defined for this parameter.	2_{supp}: Soil / strata exhibiting adverse characteristics could occur in localised areas.	3_{supp}: Widespread occurrence of soil / strata exhibiting adverse characteristics expected.

- Category 4 - Excavatability problems:
  - excavations to a depth of ± 1.5 m.
- Category 5 - Miscellaneous geological, geotechnical and geomorphological factors:
  - undermining,
  - dolomite land,
  - very gentle slopes to nearly flat-lying areas,
  - steep slopes,
  - unstable natural slopes,
  - seismicity,
  - periodic flooding, and.
  - other adverse characteristics.

The above-mentioned list of flag issues represents the second primary product of an PSGI useful for the assessment, ranking and comparison of the development potential of the sites by geopractitioners, town planners, engineers, developers, and governmental authorities. It is evident that the PSGIs utilising pedological information yield collated results in a scientifically verifiable manner that not only meet, but greatly exceed, the industry standards for this type of investigation.

As an example, assessment of the geological, geotechnical, and geomorphological characteristics exhibited by a site wholly located within a valley floor within Land Type Af28 with a preliminary geotechnical classification of $1_{A,K}$ $2_{E,I}$ $3_{B,C,D,F,L}$ (AGE realisation values provided in Table 5.9 and taking its location within a nearly flat lying floodplain into account, classified using the principles defined in section 5.4) yields the following list of flag issues (Table 5.12), namely:

- Most favourable:
  - 1_A - collapse settlement.
- Intermediate:
  - 2_{supp} - topsoil expected to lose cohesion when saturated.
  - 2_E - erodibility / dispersion,
  - 2_I - very gentle slopes to nearly flat-lying areas, and 2_K - seismicity

Table 5.12: An example of flag issues identified for a site wholly located on a valley floor covered by soils of Land Type Af28.

FLAG ISSUES		INFERRED IMPACTS ON DEVELOPMENT According to Partridge *et al.* (1993), supplemented where indicated, based on AGE severity values.		
		1 - Most favourable	2 - Intermediate	3 - Least favourable
CATEGORY 1 - POOR TRAFFICABILITY	**Occurrence of boulders at the surface,** hampers movement of all types of vehicle.			
	'Sticky' / slippery conditions when wet, hampers movement of mainly wheeled vehicles.			3_{supp}: 'Sticky' / slippery conditions expected at all times.
	Topsoil expected to lose cohesion when saturated / 'quicksand' conditions, e.g., liquefaction or 'quicksand' conditions will hamper movement of all types of vehicle.		2_{supp}: Topsoil expected to lose cohesion when saturated.	
CATEGORY 2 - MATERIALS RE-USE POTENTIAL	Natural soil-like overburden.			3_{supp}: Most to all natural materials expected to be unsuitable for re-use.
CATEGORY 3 - ADVERSE SOIL BEHAVIOUR	**Collapse settlement,** under loading or when saturated.	Class 1_A: Potentially collapsible material < 0.75 m thick expected to occur.		
	Groundwater seepage and/ or waterlogging.			Class 3_B: Swamps and marshes, including soil inferred to be waterlogged.
	Heave / shrinkage, with changes in moisture content.			Class 3_C: High soil-heave expected, with an AGE impact realisation value of > 280.
	Compressibility / 'soft clays', under loading or when saturated.			Class 3_D: High soil compressibility expected, with an AGE impact realisation value of > 300.
	Erodibility / dispersion, dispersive soils / non-cohesive material along steep slopes or within areas where concentrated surface flow occurs.		Class 2_E: Intermediate, with an AGE impact realisation value of > 135 and ≤ 355.	
CATEGORY 4 - EXCAVATABILITY PROBLEMS	To a depth of 1.5 m.			Class 3_F: Bedrock / hardpan pedocrete expected to comprise > 40% of total profile up to 1.5 m, with an AGE impact realisation value of > 400.
CATEGORY 5 - MISCELLANEOUS GEOLOGICAL, GEOTECHNICAL & GEOMORPHOLOGICAL FACTORS	**Undermining,** risk of surface instability / differential settlement.			
	Dolomite land, risk of sinkholes and/or subsidences, with details regarding Inherent Hazard Classes (IHC) provided in Part 2 of SANS 1936 (2012).			
	Very gentle slopes to nearly flat-lying areas, periodic ponding of surface water possible, wet engineering services prone to blockage.		Class 2_I: Slopes of < 2°.	
	Steep slopes, more complex construction work indicated.			
	Unstable natural slopes, based on the results of a slope analysis, risk of possible slope failure.			
	Seismicity, details regarding seismic hazard provided in Part 4 of SANS 10160 (2009).	Class 1_K: Areas exhibiting a 10% probability of a seismic event with a peak ground acceleration of < 100 cm/s^2 within 50 years.		
	Periodic flooding, mainly based on geospatial setting of the area.			Class 3_L: Periodic flooding expected due to location within surface water courses.
	Other adverse characteristics (soil and/ or strata), e.g., self-mulching, slaking, 'Southern Cape Condensation Problem Area', etc.			

- Least favourable:
  - 3_{supp} - ‘sticky’ / slippery conditions when wet,
  - 3_{supp} - materials re-use potential,
  - 3_B - groundwater seepage and waterlogging,
  - 3_C - heave / shrinkage,
  - 3_D - compressibility / ‘soft clays’,
  - 3_F - excavatability problems, and
  - 3_L - periodic flooding.

5.6 Step 13: Furnishing of information for Basic Assessment Reports (BARs)

The third and final primary product of an PSGI is the furnishing of information of a geotechnical nature in a sufficiently concise format to assist environmental practitioners in the compilation of Basic Assessment Reports (BARs) that form part of the EIA process. This information is generally rendered as specialist inputs by a geopractitioner in terms of the Environmental Impact Assessment Regulations as detailed by NEMA (Act No. 107 of 1988, as amended) and the Western Cape Provincial Department of Environmental Affairs & Development Planning (DEA&DP, 2020). Experience shows that these inputs are typically requested only during the later stages of the BAR process with resultant severe time constraints. In this light, the conducting of an PSGI is ideal for this purpose as results that can be trusted by the environmental practitioner is typically available within hours to a few days at most.

However, comparison of the list of flag issues resulting from a PSGI with the requirements of a BAR shows that reduction of the former is necessary to provide unambiguous responses to the aspects that need to be addressed. It is therefore prudent for the geopractitioner to compile a secondary set of collated flag issues already in the relevant format as required for the compilation of BARs. Responses to the issues raised during the BAR process can be formulated as follows, based on the list of flag issues (detailed in section 5.5) and details forthcoming from the dissemination of pedological information (section 5.2.2 and Figure 2.3-H), namely:

- Shallow water table (less than 1.5 m deep):

  The presence of a water table at a depth of less than 1.5 m is indicated by the flagging of any or all of the following issues:

  - intermediate condition for the category 3 parameter ‘Groundwater seepage and/ or waterlogging’, classifying as 2_B, or

- least favourable condition for the category 3 parameter ‘Groundwater seepage and/ or waterlogging’, classifying as 3_B.

- Dolomite, sinkhole or doline areas:

  The presence of dolomite land is indicated by the flagging of any of the following issues:

  - any condition within the category 5 parameter ‘Dolomite land’, classifying as either 1_H, 2_H, or 3_H.

- Seasonally wet soils (often close to water bodies):

  The presence of seasonally wet soils is indicated by the flagging of any or all of the following issues:

  - least favourable condition for the category 3 parameter ‘Groundwater seepage and/ or waterlogging’, classifying as 3_B,
  - intermediate condition for the category 5 parameter ‘Periodic flooding’, classifying as 2_L, or
  - least favourable condition for the category 5 parameter ‘Periodic flooding’, classifying as 3_L.

- Unstable rocky slopes or steep slopes with loose soil:

  Areas exhibiting unstable rocky slopes will be flagged on the hand of any of the following:

  - intermediate condition for the category 1 parameter ‘Boulders at surface’, or
  - least favourable condition for the category 1 parameter ‘Boulders at surface’,

  as well as any of the following flagged issues:

  - intermediate condition for the category 5 parameter ‘Steep slopes’, classifying as 2_J, or
  - least favourable condition for the category 5 parameter ‘Steep slopes’, classifying as 3_J.

  Areas expected to exhibit steep slopes covered by loose soil are identified by way of:

  - the presence of relatively sandy or unconsolidated soils based on the pedological data upon which the preliminary geotechnical classification and the identification of flag issues are based, (mainly represented by soils of SEG-I, SEG-II, SEG-III, SEG-V, SEG-VII and SEG-VIII),

  as well as any of the following flagged issues:

  - intermediate condition for the category 5 parameter ‘Steep slopes’, classifying as 2_J, or
  - least favourable condition for the category 5 parameter ‘Steep slopes’, classifying as 3_J.

- Dispersive soils (soils that dissolve in water):

  The presence of potentially dispersive soil is identified on the hand of the following:

  - intermediate condition for the category 3 parameter 'Erodibility / dispersion', classifying as 2_E, or
  - least favourable condition for the category 3 parameter 'Erodibility / dispersion', classifying as 3_E,

  but only if the disseminated pedological information shows that:

  - soil forms containing a prismacutanic horizon (SEG-VI) occur,

  and where any of the following flag issues have also been raised:

  - intermediate condition for the category 5 parameter 'Steep slopes', classifying as 2_J, or
  - least favourable condition for the category 5 parameter 'Steep slopes', classifying as 3_J.
  - intermediate condition for the category 5 parameter 'Periodic flooding', classifying as 2_L, or
  - least favourable condition for the category 5 parameter 'Periodic flooding', classifying as 3_L.

- Soils with a high clay content (clay fraction more than 40%):

  The presence of soils with a clay content in excess of 40% are revealed by the pedological information as entered per soil form or soil/ rock complex during the dissemination of the pedological information (could be present within any of the SEGs). This information is not specifically included in the list of flagged issues, but must be obtained from the data upon which the preliminary geotechnical classification and the identification of flagged issues are based.

- Any other unstable soil or geological feature:

  The flagging of any of the following category 3, 4 and 5 factors considered to represent unstable soil or geological features that have not yet been addressed by any of the other questions, namely:

  - although considered a relatively favourable condition, flagging of a class 1_A condition for the category 3 parameter 'Collapse settlement' could be problematic,
  - intermediate condition for the category 3 parameter 'Collapse settlement', classifying as 2_A,
  - although considered a relatively favourable condition, flagging of a class 1_D condition for

the category 3 parameter 'Compressibility / 'soft clays' could be problematic,

- intermediate condition for the category 3 parameter 'Compressibility / 'soft clays'', classifying as 2_D,
- least favourable condition for the category 3 parameter 'Compressibility / 'soft clays'', classifying as 3_D,
- intermediate condition for the category 4 parameter 'Excavatability problems', classifying as 2_F,
- least favourable condition for the category 4 parameter 'Excavatability problems', classifying as 3_F,
- although considered a relatively favourable condition, flagging of a class 1_G condition for the category 5 parameter 'Undermining' could be problematic,
- intermediate condition for the category 5 parameter 'Undermining', classifying as 2_G,
- least favourable condition for the category 5 parameter 'Undermining', classifying as 3_G,
- intermediate condition for the category 5 parameter 'Seismicity', classifying as 2_K,
- least favourable condition for the category 5 parameter 'Seismicity', classifying as 3_K,
- intermediate condition for the category 5 parameter 'Other adverse characteristics', and/ or
- least favourable condition for the category 5 parameter 'Other adverse characteristics'.

- An area sensitive to erosion:

  Potentially erodible soil is expected to be present where any of the following flagged issues have been raised:

  - intermediate condition for the category 3 parameter 'Erodibility / dispersion', classifying as 2_E, or
  - least favourable condition for the category 3 parameter 'Erodibility / dispersion', classifying as 3_E,

  but only in the presence of any of the following:

  - intermediate condition for the category 5 parameter 'Steep slopes', classifying as 2_J, or
  - least favourable condition for the category 5 parameter 'Steep slopes', classifying as 3_J.
  - intermediate condition for the category 5 parameter 'Periodic flooding', classifying as 2_L, or

- least favourable condition for the category 5 parameter 'Periodic flooding', classifying as 3_L,

and only if the disseminated pedological information does not indicate the presence of potentially dispersive soil (addressed by means of a previous question).

- An area adjacent to or above an aquifer (Western Cape Province only):

  The conducting of an PSGI cannot furnish a suitable response to this issue, as specialist inputs by a suitably qualified geohydrologist or hydrogeologist are required.

- An area within 100 m of the source of surface water (Western Cape Province only):

  The conducting of an PSGI cannot furnish a suitable response to this issue, as specialist inputs by a suitably qualified geohydrologist or hydrogeologist are required.

The BAR template in terms of the Environmental Impact Assessment Regulations, promulgated in terms of the *National Environmental Management Act* (Act No. 107 of 1988, as amended), makes provision for characterising the site and alternatives based on the groundwater, soil, and geological stability by marking the appropriate boxes for the questions in Table 5.13. Table 5.13 provides an example of a list of responses of a geotechnical nature for BAR purposes resulting from the conducting of an PSGI utilising the SEG system, representing a site wholly comprising a valley floor within Land Type Af28 located near Kathu in the Northern Cape Province (based on flag issues as defined in Table 5.11 and pedological information provided in Figure 2.3-G).

In lieu of detailed site-specific geotechnical surveys or tests, it is evident that PSGIs conducted at the hand of pedological and other data timeously provide collated and scientifically sound information, backed up by the experience of the geopractitioner, on which environmental practitioners can base decisions with confidence.

Table 5.13: Example of a list of responses (marked with a black background) to questions of a geotechnical nature as required for the compilation of BARs.

QUESTIONS OF A GEOTECHNICAL NATURE AS SPECIALIST INPUT FOR BAR PURPOSES	RESPONSE		RELEVANT FLAG ISSUES from Table 5.12, and RELEVANT PEDOLOGICAL TYPE INFORMATION from Figure 2.3-G
Preliminary geotechnical zone wholly comprising a valley floor within Land Type Af28 located in the Northern Cape Province.			
Shallow water table (less than 1.5 m deep):	**YES**	NO	Class 3_B: Groundwater seepage and/ or waterlogging.
Dolomite, sinkhole or doline areas:	YES	**NO**	Area not indicated to be underlaid by dolomitic strata.
Seasonally wet soils (often close to water bodies):	**YES**	NO	Class 3_B: Groundwater seepage and/ or waterlogging, and Class 3_L: Periodic flooding.
Unstable rocky slopes or steep slopes with loose soil:	YES	**NO**	Class 2_I: Very gentle slopes to nearly flat-lying areas.
Dispersive soils (soils that dissolve in water):	**YES**	NO	Class 2_E: Erodibility / dispersion.
Soils with a high clay content (clay fraction more than 40%):	**YES**	NO	Clay content of up to 50% indicated for occurrences of the Katspruit soil form.
Any other unstable soil or geological feature:	**YES**	NO	Class 1_A: Collapse settlement, Class 3_D: Compressibility / 'soft clays', and Class 3_F: Excavatability problems.
An area sensitive to erosion:	**YES**	NO	Class 2_E: Erodibility / dispersion, and Class 3_L: Periodic flooding.

CHAPTER 6 CASE STUDIES (PHASE 5)

This chapter comprises a critical appraisal of the ease of application and efficacy of the refined SEG System by way of practical examples using an empirical approach, representing Phase 5 of the study (Figure 3.3), namely:

- comparison of the results obtained by means of an PSGI with that resulting from a detailed geotechnical investigation conducted at the same site, and
- application thereof to aid site selection with regard to development and/ or land use that could adversely affect the natural environment.

6.1 Selection of suitable case studies

In order to allow a critical appraisal of the refined SEG System under real-world conditions, the following suitable case studies, each representing a specific scenario and end-use, were chosen, namely:

- Assessment of regional geotechnical character of a site earmarked for residential development:

  Proposed residential development on a site in the eastern suburbs of the City of Tshwane was chosen as an ideal case study as it is located in an area covered by one of the published 1:50 000 scale regional geotechnical maps, with results of a detailed geotechnical investigation conducted at the stand also available. An PSGI utilising the refined SEG system was conducted to ascertain the regional geotechnical character of the area, with the resultant preliminary geotechnical classification correlated with the published regional geotechnical map to verify the accuracy of the available pedological information. The results of the detailed geotechnical investigation according to the NHBRC site classes (2015) were converted into the corresponding geotechnical parameters as defined by Partridge *et al*. (1993) to allow direct comparison thereof with those anticipated by the use of the refined SEG system.

- Comparison between two candidate sites comprising different terrain units:

  The results of PSGIs conducted by application of the refined SEG system were utilised to aid comparison between two candidate sites located in different terrain units and in different land types (i.e., exhibiting differing geospatial characteristics), in support of the hypothetical establishment of a new cemetery for the purpose of this research. Although the results of the PSGIs were not correlated with those of detailed geotechnical investigations, and the candidate sites are not located in areas covered by the published geotechnical maps, assessment of the inferred AGE impact realisation values and flag issues was heavily reliant on the experience of the geopractitioner familiar with the regional geotechnical character of the areas in question.

6.2 Case study 1: SEG-based PSGI in support of residential development

6.2.1 Background

Proposed residential development on a parcel of land approximately 25 Ha in size located in the eastern suburbs of the City of Tshwane was chosen as a suitable case study to assess the efficacy of an PSGI utilising the refined SEG system. The site is located in an area covered by the published 1:50 000 scale 2528CD Rietvlei Dam geotechnical series map (CGS, 2001), supplementing the 1:250 000 scale 2528 Pretoria (1987) land type map and memoir, with the results of a detailed geotechnical investigation of the study area also available (Meintjes, 2015a).

According to the published 1:250 000 scale 2528 Pretoria (1978) geological map, the site is expected to be underlaid by andesite of the Hekpoort Formation that forms part of the Pretoria Group, Transvaal Supergroup (Figure 6.1). The City of Tshwane is located in a semi-humid environment, as evidenced by a climatic N-value of approximately 2.4 (Weinert, 1980; Figure 6.2). Brink (1979) states that andesite typically decomposes into a highly expansive residual soil with occasional spheroidal boulders in a relatively humid climatic setting, rather than disintegrating into an abundance of coarse clasts occurring within a soil-like matrix prevalent in more arid areas.

6.2.2 Characterisation and refined SEG system results

6.2.2.1 Information obtained from the published 1:50 000 geotechnical series map (CGS)

The regional geotechnical character of the area, as described by the published 1:50 000 2528CD Rietvlei Dam (CGS, 2001) geotechnical map (Figure 6.3), classifies as 42^2, with:

42 defining areas where Act4 and Exc3 conditions (critical), as well as Per2 conditions (subcritical), can be expected (Figure 6.3), and

^{2} indicating the occurrence of a dominant geotechnical factor (in this case, Act) plus one critical and one or more subcritical factors (Figure 2.4).

The above-mentioned classification implies the following (a full list of descriptions of the various factors are provided in Table 2.2):

CRITICAL FACTORS:

Act4 Inferred occurrence of moderately expansive material with an expected heave in the order of between 5 and 30 mm; and

Exc3 Slight excavatability problems (can be hand-dug).

Figure 6.1: Case study 1: Regional geological setting according to the published 1:250 000 scale 2528 Pretoria (1978) geological map.

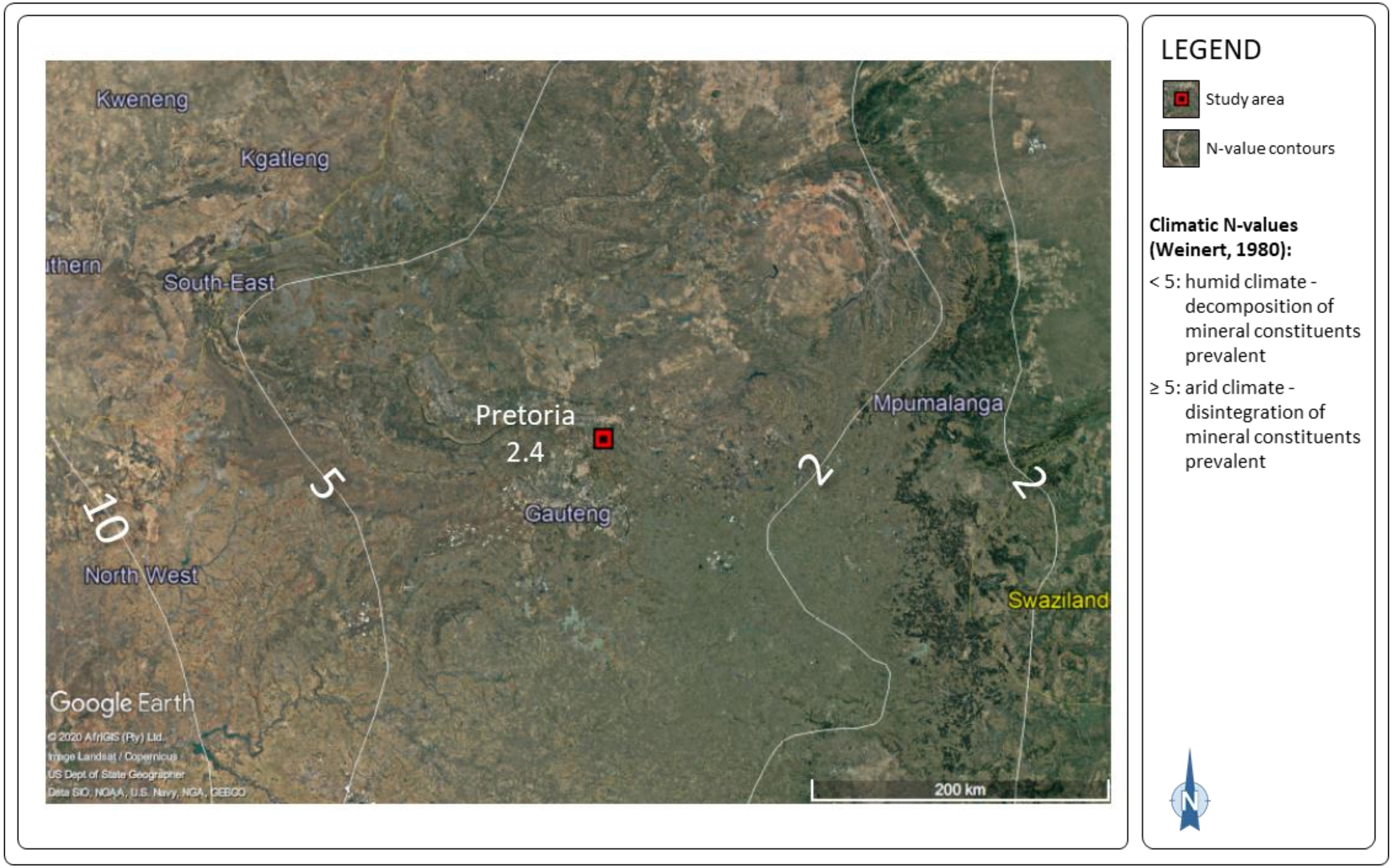


Figure 6.2: Case study 1: Contour map of climatic N-values (Weinert, 1980) overlaid onto a satellite image.

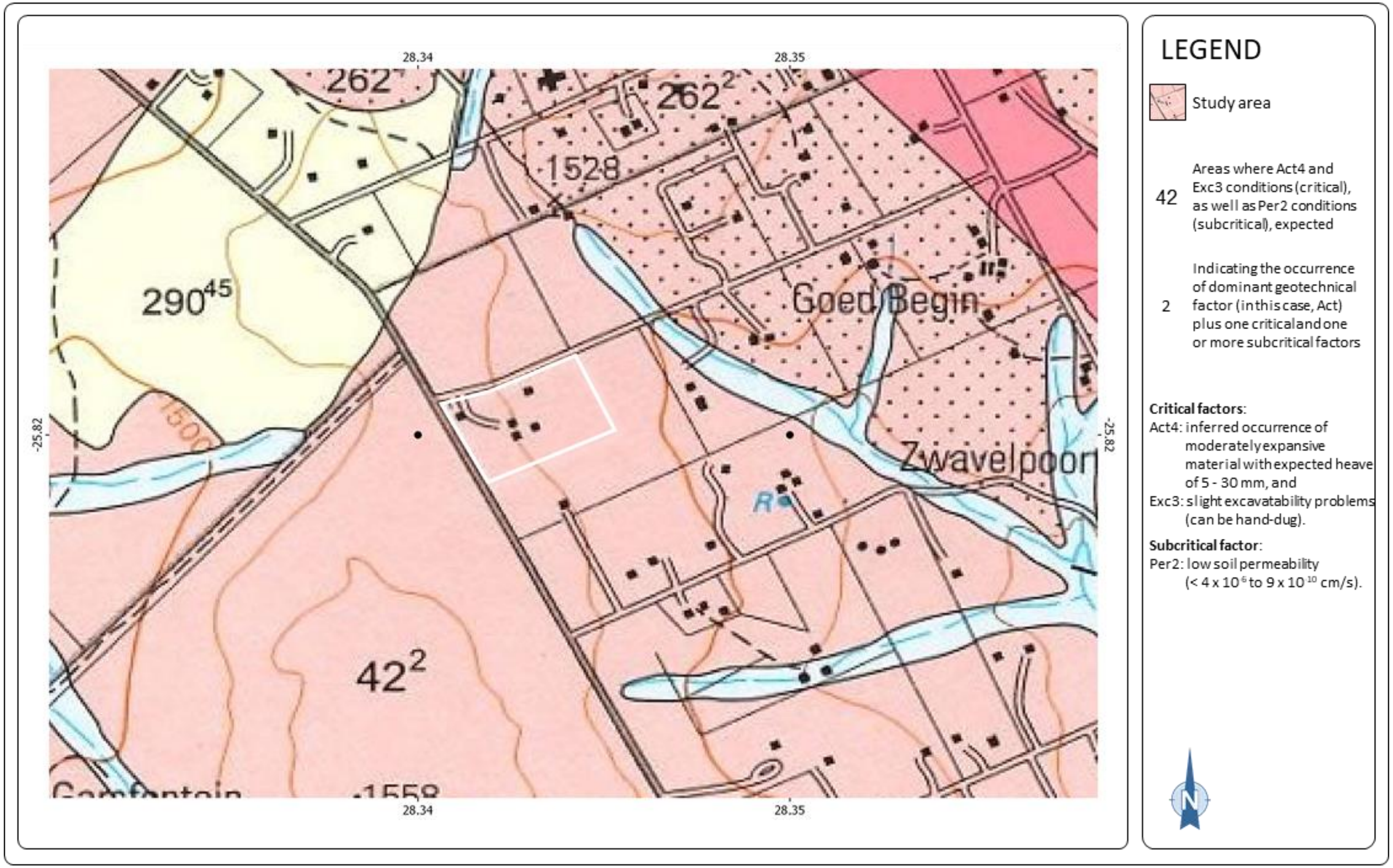


Figure 6.3: Case study 1: Excerpt from the 1:50 000 scale 2528 Rietvlei Dam (CGS, 2001) geotechnical series map.

SUBCRITICAL FACTOR:

Per2 Low soil permeability (< 4×10^{-6} to 9×10^{-10} cm/s).

6.2.2.2 Information obtained from a preliminary stage geotechnical investigation

As part of this research, an PSGI utilising the refined SEG system was conducted to obtain an estimate of the regional geotechnical character of the area in which the study area is located, and to identify flag issues in this regard.

The study area itself mainly comprises two terrain units, namely: a northeastwardly facing mid slope, with the extreme northeastern portion inferred to represent a foot slope, as defined by means of surface elevation contours, each representing a vertical elevation change of 1 m, obtained from JAXA (2020) (Figure 6.4). Natural slopes of less than 2° are expected. A non-perennial stream with a poorly defined floodplain occurs directly downslope of the study area, but is not inferred to encroach onto the site itself.

According to the published 1:250 000 scale 2528 Pretoria (ISCW, 1987) land type map and memoir, mid slopes in the area are indicated to be covered by soils of Land Type Ib7 (Figure 6.5) where exposed rock and shallow rocky soils (Glenrosa and Mispah soil forms) are expected to comprise approximately 55 and 30% of the area respectively (as shown in Figure 6.6). These conditions are inferred associated with the prominent Bronberg Mountain that occurs to the northeast of the study area where the rocky nature of the ridge crest and side slopes can be clearly seen on satellite images (Figure 6.7).

However, the results of a detailed geotechnical investigation conducted at the site revealed an abundance of thick moderately to strongly structured clayey soil (Meintjes, 2015a) with only highly scattered bedrock outcrops, as would be expected for a site underlaid by residual andesite. This finding corresponds to the regional classification on the 1:50 000 scale 2528CD Rietvlei Dam (CGS, 2001) geotechnical series map that indicates only slight excavatability problems, but the presence of potentially expansive overburden. In reality, the study area is characterised by the absence of the expected extensive bedrock outcrops as shown by both the satellite and field views presented in Figure 6.8a and Figure 6.8b respectively. The sub-surface conditions at the site therefore suggest that the land type designation for this region is not accurate and requires re-assessment by the geopractitioner.

It was therefore decided to extrapolate the regional soils information defining Land Type Ba9, indicated to primarily define weakly ferruginized soils occurring along the undulating landscape to the southwest and northeast of the Bronberg Mountain and covering the same mid slope and foot slope on which the study area is located (Figure 6.4), across the study area itself.

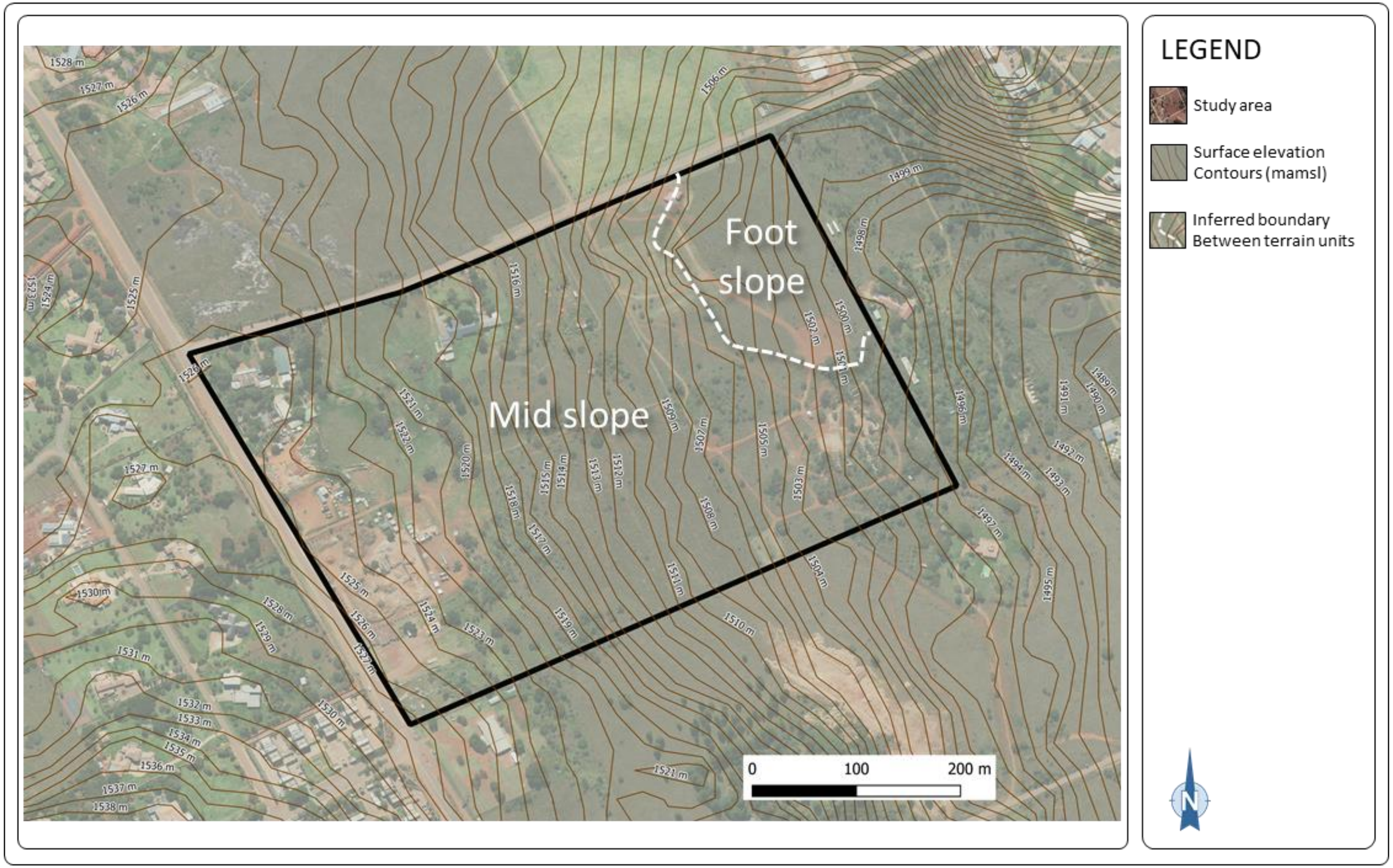


Figure 6.4: Case study 1: Delineation of terrain units based on surface elevation contours obtained from JAXA (2020), overlaid onto a satellite image.

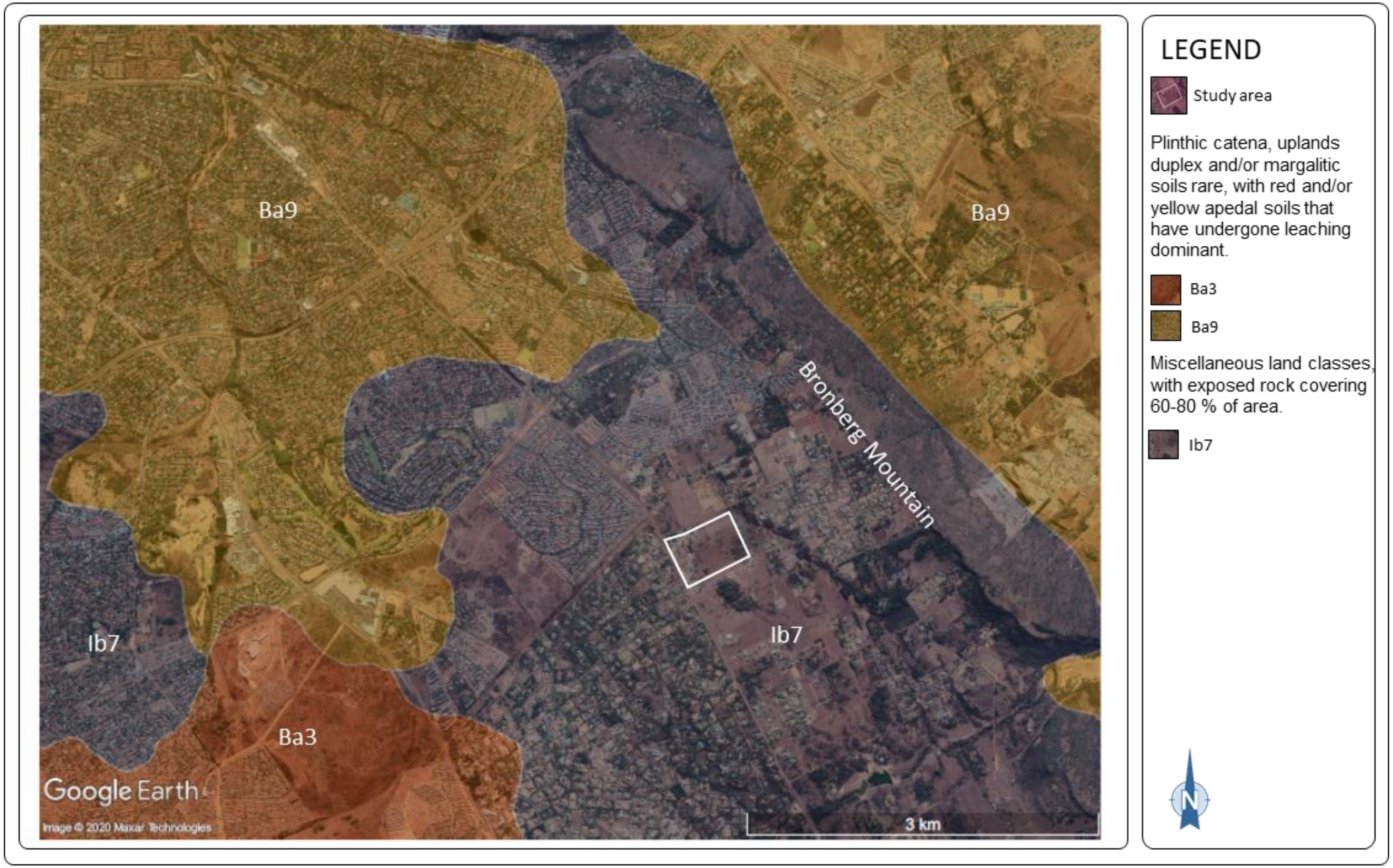
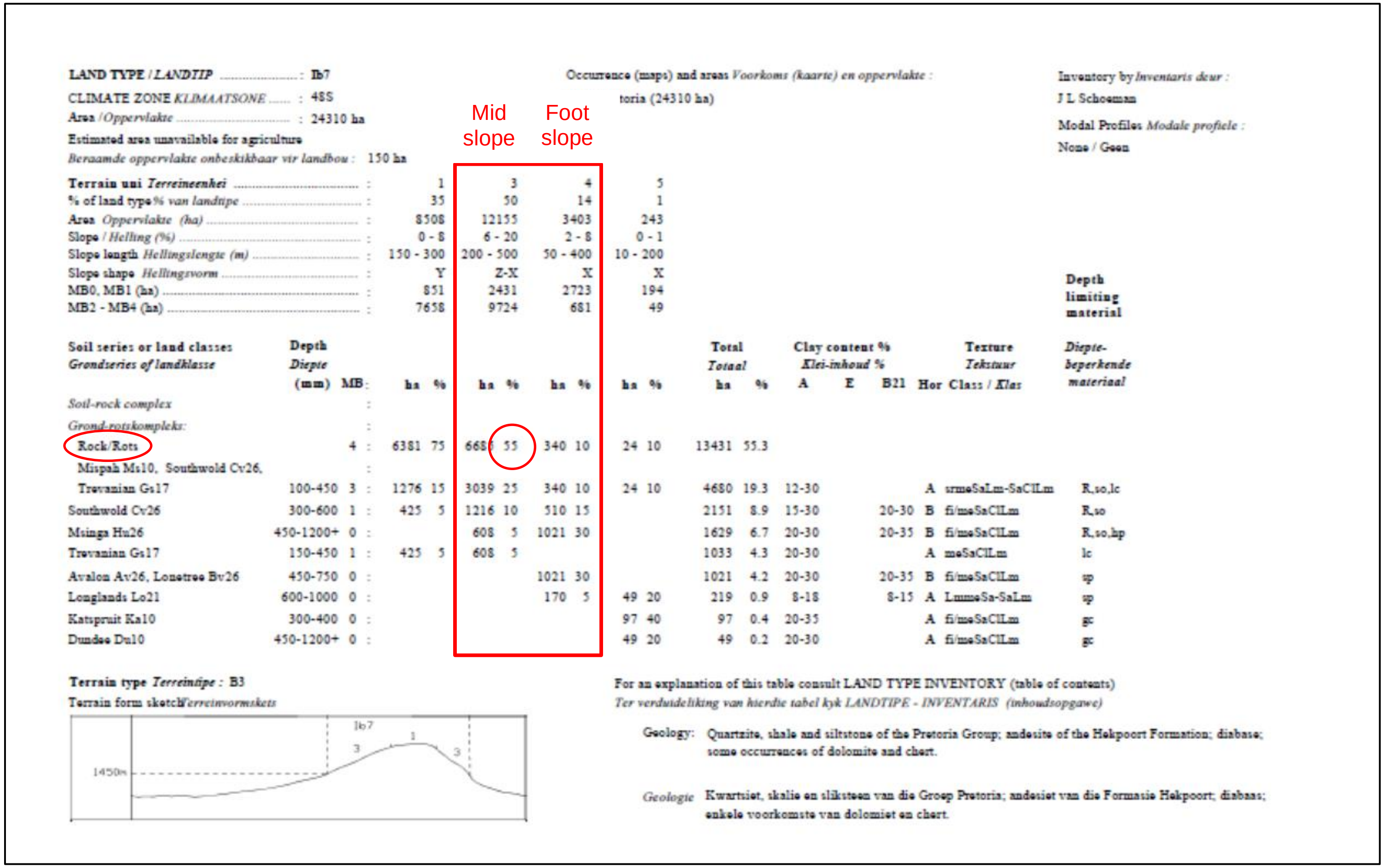


Figure 6.5: Case study 1: Spatial distribution of land types according to the 1:250 000 scale 2528 Pretoria (ISCW, 1987) land type map, overlaid onto a satellite image.



LAND TYPE / *LANDTIP* ....: Ib7

CLIMATE ZONE *KLIMAATSONE* ...... : 48S

Area /*Oppervlakte* .... : 24310 ha

Estimated area unavailable for agriculture

Beraamde oppervlakte onbeskikbaar vir landbou : 150 ha

Occurrence (maps) and areas *Voorkoms (kaarte) en oppervlakte* :

toria (24310 ha)

Inventory by *Inventaris deur* :

J L Schoeman

Modal Profiles *Modale profiele* :

None / Geen

	1	3	4	5
Terrain uni *Terreineenhei*	1	3	4	5
% of land type % *van landtipe*	35	50	14	1
Area *Oppervlakte (ha)*	8508	12155	3403	243
Slope / *Helling (%)*	0 - 8	6 - 20	2 - 8	0 - 1
Slope length *Hellingslengte (m)*	150 - 300	200 - 500	50 - 400	10 - 200
Slope shape *Hellingsvorm*	Y	Z-X	X	X
MB0, MB1 (ha)	851	2431	2723	194
MB2 - MB4 (ha)	7658	9724	681	49

Soil series or land classes *Grondseries of landklasse*	Depth *Diepte* (mm)	MB	ha	%	ha	%	ha	%	ha	%	Total *Totaal* ha	%	Clay content % *Klei-inhoud %* A	E	B21	Hor	Texture *Tekstuur* Class / *Klas*	Depth limiting material *Diepte-beperkende materiaal*
Soil-rock complex																		
Grond-rotskompleks:																		
Rock/Rots		4	6381	75	6686	55	340	10	24	10	13431	55.3						
Mispah Ms10, Southwold Cv26, Trevanian Gs17	100-450	3	1276	15	3039	25	340	10	24	10	4680	19.3	12-30			A	srmeSaLm-SaClLm	R,so,lc
Southwold Cv26	300-600	1	425	5	1216	10	510	15			2151	8.9	15-30		20-30	B	fi/meSaClLm	R,so
Msinga Hu26	450-1200+	0			608	5	1021	30			1629	6.7	20-30		20-35	B	fi/meSaClLm	R,so,hp
Trevanian Gs17	150-450	1	425	5	608	5					1033	4.3	20-30			A	meSaClLm	lc
Avalon Av26, Lonetree Bv26	450-750	0					1021	30			1021	4.2	20-30		20-35	B	fi/meSaClLm	sp
Longlands Lo21	600-1000	0					170	5	49	20	219	0.9	8-18		8-15	A	LmmeSa-SaLm	sp
Katspruit Ka10	300-400	0							97	40	97	0.4	20-35			A	fi/meSaClLm	gc
Dundee Du10	450-1200+	0							49	20	49	0.2	20-30			A	fi/meSaClLm	gc

Terrain type *Terreintipe* : B3

Terrain form sketch *Terreinvormskets*

For an explanation of this table consult LAND TYPE INVENTORY (table of contents)

Ter verduideliking van hierdie tabel kyk LANDTIPE - INVENTARIS (inhoudsopgawe)

Geology: Quartzite, shale and siltstone of the Pretoria Group; andesite of the Hekpoort Formation; diabase; some occurrences of dolomite and chert.

Geologie Kwartsiet, skalie en sliksteen van die Groep Pretoria; andesiet van die Formasie Hekpoort; diabaas; enkele voorkomste van dolomiet en chert.

Figure 6.6: Case study 1: Land type memoir for Land Type Ib7 that, according to the published 1:250 000 scale 2526 Pretoria (ISCW, 1987) land type map, defines the regional soils distribution for the area associated with the Bronberg Mountain. Information for mid slopes and foot slopes as pertaining to the study area is highlighted, as well as the inferred occurrence of extensive bedrock outcrops along the mid slopes.

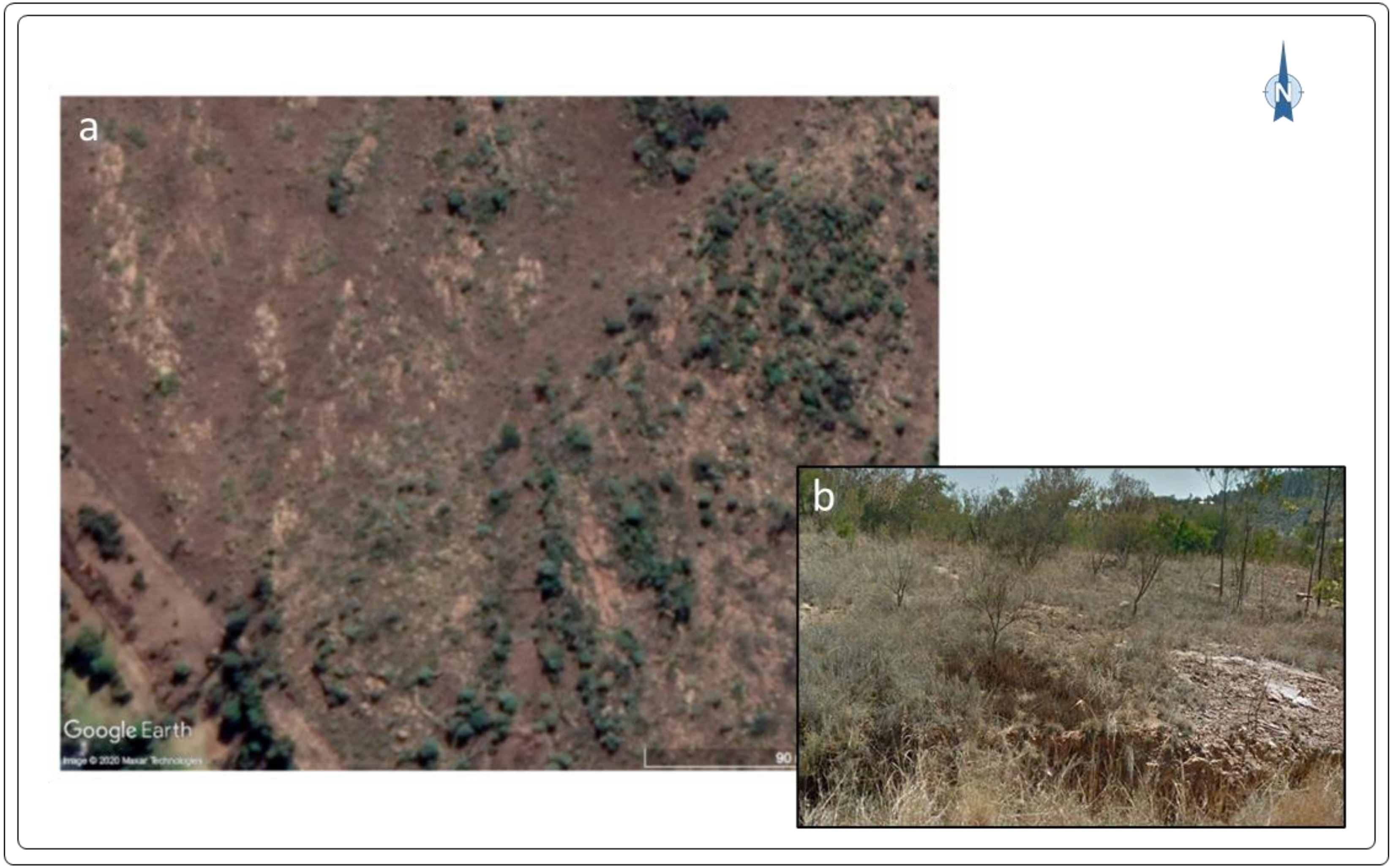


Figure 6.7: Case study 1: Satellite image (a) showing extensive bedrock outcrops (lighter patches) along the Bronberg Mountain directly to the northeast of the study area (Google Earth, 2020). Inset photograph (b) provides a panoramic view of a typical rock-strewn mid slope in this area.

Figure 6.8: Case study 1: Satellite image (a) showing a lack of bedrock outcrops in the vicinity of the study area (Google Earth, 2020). Inset photograph (b) provides a panoramic view of a typical soil-covered mid slope in this area.

Dissemination of information provided by the memoir for Land Type Ba9 by means of the refined SEG system yielded the following regarding soil conditions along the mid slope (left column of highlighted area in Figure 6.9 with the relevant data entries as annotated on the left):

- Mainly:
  - SEG-I Apedal soils (42%), comprising:
    Clovelly (d), Glencoe (l) and Hutton (e) soil forms with topsoil containing between 15 and 45% clay, in places containing coarse clasts, and sub-surface layers with between 15 and 60% clay, between 0.3 and more than 1.2 m thick, underlaid mainly by saprolite, and occasionally by hardpan ferricrete, weathered bedrock, and soft pedrocrete.
- Localised pockets:
  - SEG-VII Outcrops/ sub-outcrops of rock and/ or pedocrete (33.5%), comprising:
    scattered bedrock outcrops (a), and Mispah (b) soil form exhibiting topsoil with a clay content of up to 30%, up to 0.4 m thick, overlying weathered bedrock and hardpan ferricrete.
- Highly localised pockets:
  - SEG-VIII Shallow lithic soils (14.5%), comprising:
    Glenrosa (c) soil form where the topsoil contains between 15 and 30% clay, between 0.1 and 0.4 m thick, overlying saprolite.
- Very highly localised pockets:
  - SEG-VI Moderately to strongly structured clayey soils (5%), comprising:
    Swartland (o) soil form with between 20 and 35% clay in the topsoil that could contain coarse clasts and between 35 and 50% clay at depth, between 0.75 and more than 1.2 m thick overlying saprolite.
  - SEG-IV Weakly structured clayey soils (not gleyed) (2.5%), comprising:
    Shortlands (f) soil form with topsoil exhibiting 30 to 45% clay with occasional coarse clasts and between 35 and 60% clay at depth, between 0.45 and more than 1.2 m thick, underlaid by saprolite.
  - SEG-IX Soils that undergo periodic saturation (2.5%), comprising:
    Avalon (k) soil form with between 20 and 30% clay in topsoil and between 20 and 30% at depth, between 0.45 and 0.9 m thick, underlaid by soft pedocrete.

The land type memoir provides the following information regarding soil conditions along the foot slope in the extreme northeast of the study area (right column of highlighted area in Figure 6.9 with the relevant data entries as annotated on the left):

LAND TYPE / *LANDTIP* ....: Ba9
CLIMATE ZONE *KLIMAATSONE* ......: 26S
Area / *Oppervlakte* ....: 45310 ha
Estimated area unavailable for agriculture
Beraamde oppervlakte onbeskikbaar vir landbou : 500 ha

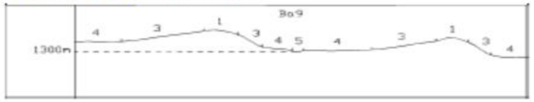
...ce (maps) and areas *Voorkoms (kaarte) en oppervlakte* :
...toria (45310 ha)

Inventory by *Inventaris deur* :
J L Schoeman
Modal Profiles *Modale profiele* :
P94

		Mid slope	Foot slope	
Terrain uni *Terreineenhei* ......:	1	3	4	5
% of land type *% van landtipe* ......:	15	50	30	5
Area *Oppervlakte (ha)* ......:	6796	22655	13593	2266
Slope / *Helling (%)* ......:	3 - 8	4 - 15	2 - 6	0 - 1
Slope length *Hellingslengte (m)* ......:	100 - 300	200 - 500	100 - 400	50 - 150
Slope shape *Hellingsvorm* ......:	Y	Y-X	X	X
MB0, MB1 (ha) ......:	0	10195	12234	2266
MB2 - MB4 (ha) ......:	6797	12460	1359	0

	Soil series or land classes / *Grondseries of landklasse*	Depth / *Diepte* (mm)	MB	1 ha	1 %	3 ha (Mid slope)	3 % (Mid slope)	4 ha (Foot slope)	4 % (Foot slope)	5 ha	5 %	Total / *Totaal* ha	Total / *Totaal* %	Clay content % / *Klei-inhoud %* A	E	B21	Hor	Texture / *Tekstuur* Class / *Klas*	Depth limiting material / *Diepte-beperkende materiaal*
	Soil-rock complex																		
	Grond-rotskompleks:																		
a	Rock/Rots		4	3398	50	4531	20					7929	17.5						
b,c,d	Mispah Ms10, Trevanian Gs17, Southwold Cv26	100-400	3	2718	40	4531	20					7250	16.0	15-25			A	meSaLm-SaClLm	R,so,lc
e	Msinga Hu26, Hutton Hu16	500-1200+	0			4531	20	1359	10			5890	13.0	20-30		20-35	B	fi/meSaClLm	so,hp
b,c	Mispah Ms10, Klipfontein Ms11, Trevanian Gs17, Williamson Gs16	150-400	3	680	10	3398	15	1359	10			5437	12.0	15-30			A	meSaLm-SaClLm	R,lc,hp
e,f	Doveton Hu27, Vimy Hu28, Argent Sd11, Richmond Sd12	450-1200+	1			1133	5	3398	25			4531	10.0	30-45		35-60	B	fiSaCl-ClLm-Cl	so
g,h	Longlands Lo21, Albany Lo22, Wasbank Wa21, Warrick Wa22	600-1200+	0					2719	20	227	10	2945	6.5	10-20	10-20		A	LmmeSa-SaLm	sp,hp
d	Southwold Cv26	300-750	0			2266	10	680	5			2945	6.5	20-30		20-35	B	fi/meSaClLm	so,R
I,j	Katspruit Ka10, Emfuleni Wo10, Willowbrook Wo11	350-750	0					1359	10	1360	60	2719	6.0	30-50			A	fi/meSaClLm-Cl	gc
k,l	Avalon Av26, Glencoe Gc26	450-900	0			1133	5	1359	10			2492	5.5	20-30		20-30	B	fi/meSaClLm	sp
m,n	Jozini Oa36, Dundee Du10	>900	0					1359	10	680	30	2039	4.5	20-30		20-35	A	fi/meSaClLm	gs
o	Swartland Sw31	750-1200+	1			1133	5					1133	2.5	20-35		35-50	A	fi/meSaClLm	so

LAND TYPE / *LANDTIP* ....: Ba9   Continued *Vervolg*
Terrain type *Terreintipe* : B3
Terrain form sketch *Terreinvormskets*



For an explanation of this table consult LAND TYPE INVENTORY (table of contents)
Ter verduideliking van hierdie tabel kyk LANDTIPE - INVENTARIS (inhoudsopgawe)

Geology: Shale, quartzite, hornfels and chert of the Pretoria Group; diabase; andesite of the Hekpoort Formation (Transvaal Sequence).

Geologie Skalie, kwartsiet, horingfels en chert van die Groep Pretoria; diabaas; andesiet van die Formasie Hekpoort (Opeenvolging Transvaal).

Figure 6.9: Case study 1: Land type memoir for Land Type Ba9 used for the conducting of an PSGI using the refined SEG system for proposed residential development within the study area. The left and right highlighted columns represent mid slope and foot slope conditions, respectively.

- Localised pockets:
  - SEG-I Apedal soils (32.5%), comprising:
    Clovelly (d), Glencoe (l) and Hutton (e) soil forms with topsoil containing between 20 and 45% clay with occasional coarse clasts and sub-surface layers with between 20 and 60% clay, between 0.3 and more than 1.2 m thick, underlaid mainly by saprolite, and occasionally by hardpan ferricrete, weathered bedrock, and soft pedrocrete.
- Highly localised pockets:
  - SEG-IV Weakly structured clayey soils (not gleyed) (17.5%), comprising:
    Oakleaf (m) and Shortlands (f) soil forms with topsoil exhibiting 20 to 45% clay with frequent coarse clasts and between 20 and 60% clay at depth, between 0.45 and more than 1.2 m thick, underlaid by saprolite or occasionally gleyed material.
  - SEG-VII Outcrops/ sub-outcrops of rock and/ or pedocrete (15%), comprising:
    scattered bedrock outcrops (a), and Mispah (b) and Wasbank (h) soil forms exhibiting topsoil with a clay content of up to 30%, generally up to 0.4 m thick, but very occasionally more than 1.2 m thick, overlying hardpan ferricrete and weathered bedrock.
  - SEG-IX Soils that undergo periodic saturation (15%), comprising:
    Avalon (k) and Longlands (g) soil forms with between 10 and 30% clay in topsoil and at depth, between 0.45 and more than 1.2 m thick, underlaid by soft pedocrete.
  - SEG-X Soils that undergo prolonged saturation (10%), comprising:
    Katspruit (i) and Willowbrook (j) soil forms with between 30 and 50% clay in topsoil and at depth, between 0.35 and 0.75 m thick, underlaid by gleyed material.
- Very highly localised pockets:
  - SEG-II Relatively unconsolidated soils (5%), comprising:
    Dundee (n) soil form with between 20 and 30% clay in the topsoil, increasing to between 20 and 35% at depth, between 0.9 and more than 1.2 m thick, underlaid by gleyed material.
  - SEG-VIII Shallow lithic soils (5%), comprising:
    Glenrosa (c) soil form where the topsoil contains between 15 and 30% clay, up to 0.4 m thick, overlying saprolite.

In this light, it is evident that there are significant differences between the soils occurring along the mid slopes and those along the foot slope, with the latter generally being thicker and overall exhibiting a higher clay content with the localised presence of unconsolidated material and gleyed sub-soil deemed indicative of the seasonal accumulation of soil moisture.

Results of the disseminated regional soils information are detailed in assessment sheets, with Figure 6.10 and Figure 6.11 representing mid slopes and foot slopes, respectively. These sheets list the SEG prominence values, inferred depth extent, types of underlying materials, stoniness of the topsoil, and the clay content of the topsoil and sub-surface materials for each relevant SEG, as derived from the land type memoir (based on the principles detailed in Figure 2.3). Note that these figures were generated by a customised spreadsheet based on the principles as detailed previously for the refined SEG system.

Based on the available information, AGE prominences, expressed as its inferred contribution to the overall geotechnical character of the SEG (Table 5.2), were allocated by a geopractitioner for each relevant SEG within each terrain unit (note that the absence of sandy topsoil overlying clayey material or denser material precludes the possible occurrence of 'quicksand' conditions). It must be noted that the highly expansive nature of the soil-like saprolite representing completely weathered andesite (Brink, 1979) underlying diagnostic soil horizons was considered during this assessment. The following results were obtained:

- Allocated AGE prominences for SEGs occurring along the mid slope:
  - SEG-I Apedal soils

    Category 1: Poor trafficability

    'Sticky'/ Slippery conditions when wet: 5 - strong contribution.

    Loss of cohesion when wet: 3 - slight contribution.

    Category 2: Materials re-use potential

    Soil-like natural materials: 4 - unsuitable.

    Category 3: Adverse soil behaviour

    Heave / shrinkage: 6 - significant contribution.

    Consolidation / 'soft clays': 5 - strong contribution.

    Category 4: Excavatability problems

    Engineering service trenches: 2 - very slight contribution.

    Road and foundation trenches: 2 - very slight contribution.
  - SEG-IV Weakly structured clayey soils (not gleyed)

    Category 1: Poor trafficability

    'Sticky'/ Slippery conditions when wet: 5 - strong contribution.

    Loss of cohesion when wet: 3 - slight contribution.

    Category 2: Materials re-use potential

    Soil-like natural materials: 4 - unsuitable.

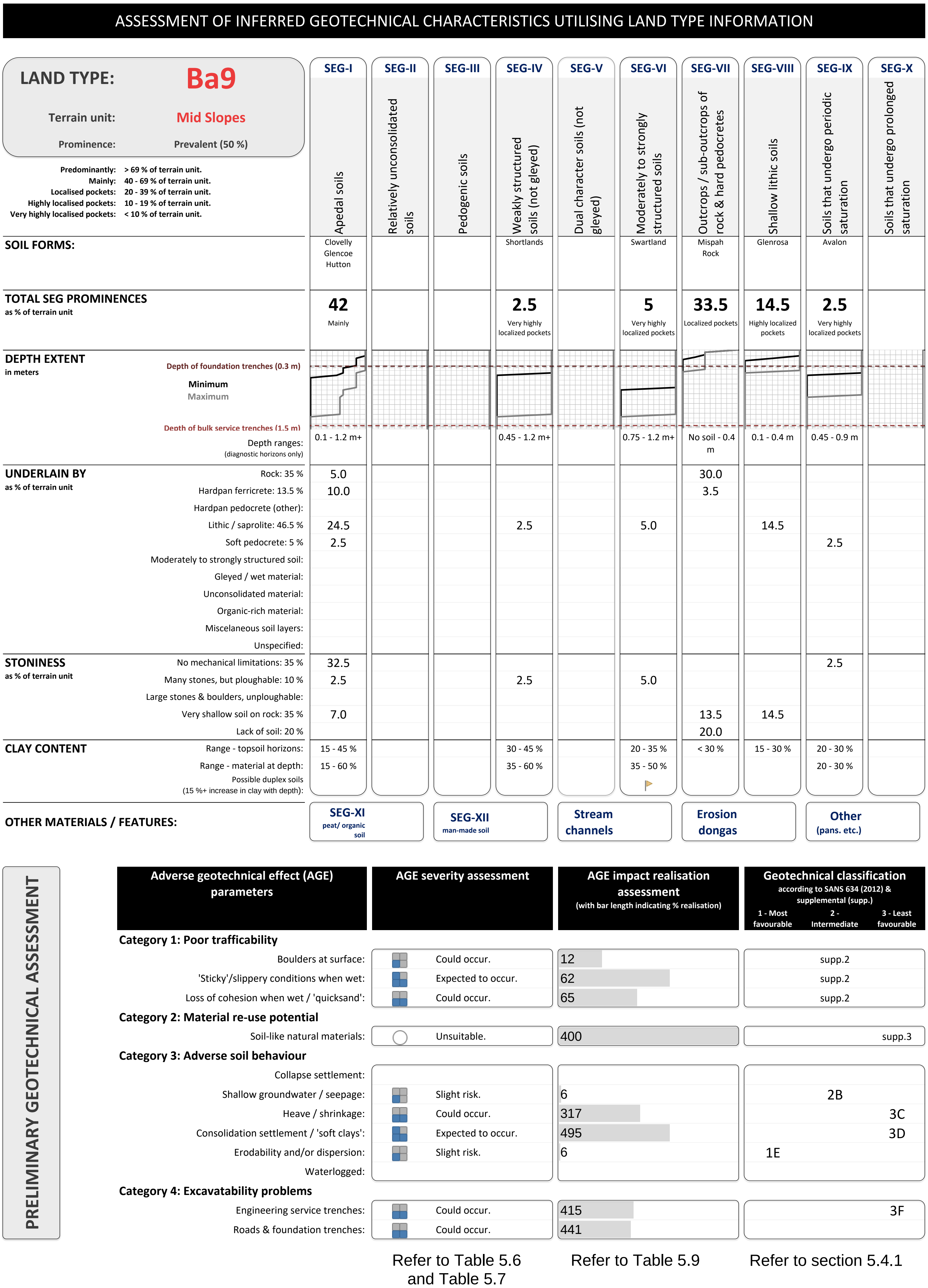


Figure 6.10: Case study 1: Results of a SEG assessment conducted for mid slopes located within Land Type Ba9 (based on data from Figure 6.9).

ASSESSMENT OF INFERRED GEOTECHNICAL CHARACTERISTICS UTILISING LAND TYPE INFORMATION

LAND TYPE: Ba9

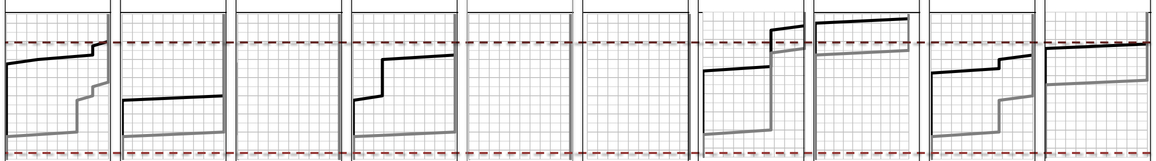
Terrain unit: **Foot Slopes**

Prominence: Frequent (30 %)

Predominantly: > 69 % of terrain unit.
Mainly: 40 - 69 % of terrain unit.
Localised pockets: 20 - 39 % of terrain unit.
Highly localised pockets: 10 - 19 % of terrain unit.
Very highly localised pockets: < 10 % of terrain unit.

	SEG-I	SEG-II	SEG-III	SEG-IV	SEG-V	SEG-VI	SEG-VII	SEG-VIII	SEG-IX	SEG-X
	Apedal soils	Relatively unconsolidated soils	Pedogenic soils	Weakly structured soils (not gleyed)	Dual character soils (not gleyed)	Moderately to strongly structured soils	Outcrops / sub-outcrops of rock & hard pedocretes	Shallow lithic soils	Soils that undergo periodic saturation	Soils that undergo prolonged saturation
SOIL FORMS:	Clovelly Glencoe Hutton	Dundee		Oakleaf Shortlands			Mispah Wasbank	Glenrosa	Avalon Longlands	Katspruit Willowbrook
TOTAL SEG PROMINENCES as % of terrain unit	32.5 Localized pockets	5 Very highly localized pockets		17.5 Highly localized pockets			15 Highly localized pockets	5 Very highly localized pockets	15 Highly localized pockets	10 Highly localized pockets
DEPTH EXTENT in meters — Depth ranges: (diagnostic horizons only)	0.3 - 1.2 m+	0.9 - 1.2 m+		0.45 - 1.2 m+			0.15 - 1.2 m+	0.05 - 0.4 m	0.45 - 1.2 m+	0.35 - 0.75 m
UNDERLAIN BY as % of terrain unit — Rock: 5 %	2.5						2.5			
Hardpan ferricrete: 17.5 %	5.0						12.5			
Hardpan pedocrete (other):										
Lithic / saprolite: 37.5 %	20.0			12.5				5.0		
Soft pedocrete: 20 %	5.0								15.0	
Moderately to strongly structured soil:										
Gleyed / wet material: 20 %		5.0		5.0						10.0
Unconsolidated material:										
Organic-rich material:										
Miscellaneous soil layers:										
Unspecified:										
STONINESS as % of terrain unit — No mechanical limitations: 65 %	20.0	5.0		5.0			10.0		15.0	10.0
Many stones, but ploughable: 25 %	12.5			12.5						
Large stones & boulders, unploughable:										
Very shallow soil on rock: 10 %							5.0	5.0		
Lack of soil:										
CLAY CONTENT — Range - topsoil horizons:	20 - 45 %	20 - 30 %		20 - 45 %			< 30 %	15 - 30 %	10 - 30 %	30 - 50 %
Range - material at depth:	20 - 60 %	20 - 35 %		20 - 60 %					10 - 30 %	
Possible duplex soils (15 %+ increase in clay with depth):										

Depth of foundation trenches (0.3 m)
Minimum
Maximum
Depth of bulk service trenches (1.5 m)



OTHER MATERIALS / FEATURES: SEG-XI peat/ organic soil | SEG-XII man-made soil | Stream channels | Erosion dongas | Other (pans, etc.)

PRELIMINARY GEOTECHNICAL ASSESSMENT

Adverse geotechnical effect (AGE) parameters	AGE severity assessment	AGE impact realisation assessment (with bar length indicating % realisation)	Geotechnical classification according to SANS 634 (2012) & supplemental (supp.) 1 - Most favourable; 2 - Intermediate; 3 - Least favourable
Category 1: Poor trafficability			
Boulders at surface:			
'Sticky'/slippery conditions when wet:	Expected to occur.	71	supp.2
Loss of cohesion when wet / 'quicksand':	Expected to occur.	77	supp.2
Category 2: Material re-use potential			
Soil-like natural materials:	Unsuitable.	400	supp.3
Category 3: Adverse soil behaviour			
Collapse settlement:			
Shallow groundwater / seepage:	Could occur.	139	2B
Heave / shrinkage:	Expected to occur.	375	3C
Consolidation settlement / 'soft clays':	Expected to occur.	537	3D
Erodability and/or dispersion:	Slight risk.	77	1E
Waterlogged:			
Category 4: Excavatability problems			
Engineering service trenches:	Could occur.	282	2F
Roads & foundation trenches:	Slight risk.	185	
	Refer to Table 5.6 and Table 5.7	Refer to Table 5.9	Refer to section 5.4.1

Figure 6.11: Case study 1: Results of a SEG assessment conducted for foot slopes located within Land Type Ba9 (based on data from Figure 6.9).

Category 3: Adverse soil behaviour

Heave / shrinkage: 6 - significant contribution.

Consolidation / 'soft clays': 5 - strong contribution.

Category 4: Excavatability problems

Engineering service trenches: 1 - nearly neglectable contribution.

- SEG-VI Moderately to strongly structured clayey soils

  Category 1: Poor trafficability

  'Sticky'/ Slippery conditions when wet: 5 - strong contribution.

  Loss of cohesion when wet: 3 - slight contribution.

  Category 2: Materials re-use potential

  Soil-like natural materials: 4 - unsuitable.

  Category 3: Adverse soil behaviour

  Heave / shrinkage: 7 - very significant contribution.

  Consolidation / 'soft clays': 5 - strong contribution.

  Category 4: Excavatability problems

  Engineering service trenches: 1 - nearly neglectable contribution.

- SEG-VII Outcrops / sub-outcrops of rock and hard pedocretes

  Category 1: Poor trafficability

  Boulders at surface: 5 - strong contribution.

  'Sticky'/ Slippery conditions when wet: 3 - slight contribution.

  Loss of cohesion when wet: 3 - slight contribution.

  Category 2: Materials re-use potential

  Soil-like natural materials: 4 - unsuitable.

  Category 3: Adverse soil behaviour

  Consolidation / 'soft clays': 3 - slight contribution.

  Category 4: Excavatability problems

  Engineering service trenches: 5 - strong contribution.

  Road and foundation trenches: 5 - strong contribution.

- SEG-VIII Shallow lithic soils

  Category 1: Poor trafficability

  'Sticky'/ Slippery conditions when wet: 5 - strong contribution.

  Loss of cohesion when wet: 3 - slight contribution.

  Category 2: Materials re-use potential

  Soil-like natural materials: 4 - unsuitable.

Category 3: Adverse soil behaviour

Heave / shrinkage: 1 - nearly neglectable contribution.

Consolidation / 'soft clays': 5 - strong contribution.

Category 4: Excavatability problems

Engineering service trenches: 2 - very slight contribution.

Road and foundation trenches: 2 - very slight contribution.

- SEG-IX Soils that undergo periodic saturation

  Category 1: Poor trafficability

  'Sticky'/ Slippery conditions when wet: 5 - strong contribution.

  Loss of cohesion when wet: 5 - strong contribution.

  Category 2: Materials re-use potential

  Soil-like natural materials: 4 - unsuitable.

  Category 3: Adverse soil behaviour

  Shallow groundwater / seepage: 3 - slight contribution.

  Consolidation / 'soft clays': 5 - strong contribution.

  Erodibility and/ or dispersion: 2 - very slight contribution.

  Category 4: Excavatability problems

  Engineering service trenches: 1 - nearly neglectable contribution.

- Allocated AGE prominences for SEGs occurring along the foot slope:

  - SEG-I Apedal soils

    Category 1: Poor trafficability

    'Sticky'/ Slippery conditions when wet: 5 - strong contribution.

    Loss of cohesion when wet: 3 - slight contribution.

    Category 2: Materials re-use potential

    Soil-like natural materials: 4 - unsuitable.

    Category 3: Adverse soil behaviour

    Heave / shrinkage: 6 - significant contribution.

    Consolidation / 'soft clays': 5 - strong contribution.

    Category 4: Excavatability problems

    Engineering service trenches: 2 - very slight contribution.

    Road and foundation trenches: 1 - nearly neglectable contribution.

  - SEG-II Relatively unconsolidated soils

    Category 1: Poor trafficability

    Loss of cohesion when wet: 5 - strong contribution.

Category 2: Materials re-use potential

Soil-like natural materials: 4 - unsuitable.

Category 3: Adverse soil behaviour

Shallow groundwater / seepage: 3 - slight contribution.

Consolidation / 'soft clays': 5 - strong contribution.

Erodibility and/ or dispersion: 2 - very slight contribution.

Category 4: Excavatability problems

Engineering service trenches: 1 - nearly neglectable contribution.

- SEG-IV Weakly structured clayey soils (not gleyed)

  Category 1: Poor trafficability

  'Sticky'/ Slippery conditions when wet: 5 - strong contribution.

  Loss of cohesion when wet: 3 - slight contribution.

  Category 2: Materials re-use potential

  Soil-like natural materials: 4 - unsuitable.

  Category 3: Adverse soil behaviour

  Shallow groundwater / seepage: 3 - slight contribution.

  Heave / shrinkage: 6 - significant contribution.

  Consolidation / 'soft clays': 5 - strong contribution.

  Category 4: Excavatability problems

  Engineering service trenches: 1 - nearly neglectable contribution.

- SEG-VII Outcrops / sub-outcrops of rock and hard pedocretes

  Category 1: Poor trafficability

  'Sticky'/ Slippery conditions when wet: 5 - strong contribution.

  Loss of cohesion when wet: 3 - slight contribution.

  Category 2: Materials re-use potential

  Soil-like natural materials: 4 - unsuitable.

  Category 3: Adverse soil behaviour

  Consolidation / 'soft clays': 3 - slight contribution.

  Category 4: Excavatability problems

  Engineering service trenches: 5 - strong contribution.

  Road and foundation trenches: 5 - strong contribution.

- SEG-VIII Shallow lithic soils

  Category 1: Poor trafficability

  'Sticky'/ Slippery conditions when wet: 5 - strong contribution.

  Loss of cohesion when wet: 3 - slight contribution.

Category 2: Materials re-use potential

Soil-like natural materials: 4 - unsuitable.

Category 3: Adverse soil behaviour

Heave / shrinkage: 1 - nearly neglectable contribution.

Consolidation / ‘soft clays’: 5 - strong contribution.

Category 4: Excavatability problems

Engineering service trenches: 2 - very slight contribution.

Road and foundation trenches: 2 - very slight contribution.

- SEG-IX Soils that undergo periodic saturation

Category 1: Poor trafficability

‘Sticky’/ Slippery conditions when wet: 5 - strong contribution.

Loss of cohesion when wet: 5 - strong contribution.

Category 2: Materials re-use potential

Soil-like natural materials: 4 - unsuitable.

Category 3: Adverse soil behaviour

Shallow groundwater / seepage: 3 - slight contribution.

Consolidation / ‘soft clays’: 5 - strong contribution.

Erodibility and/ or dispersion: 2 - very slight contribution.

Category 4: Excavatability problems

Engineering service trenches: 1 - nearly neglectable contribution.

- SEG-X Soils that undergo prolonged saturation

Category 1: Poor trafficability

‘Sticky’/ Slippery conditions when wet: 7 - very significant contribution.

Loss of cohesion when wet: 5 - strong contribution.

Category 2: Materials re-use potential

Soil-like natural materials: 4 - unsuitable.

Category 3: Adverse soil behaviour

Shallow groundwater / seepage: 5 - strong contribution.

Heave / shrinkage: 7 - very significant contribution.

Consolidation / ‘soft clays’: 5 - strong contribution.

Erodibility and/ or dispersion: 2 - very slight contribution.

Category 4: Excavatability problems

Engineering service trenches: 1 - nearly neglectable contribution.

Based on the allocated AGE prominence value within each SEG, AGE severity values and AGE impact realisation values were subsequently calculated to express the inferred geotechnical characteristics for each of the terrain units as a whole based on previously discussed principles.

The resultant values are provided in the lower portion of both Figure 6.10 (mid slope) and Figure 6.11 (foot slope). These results were further used to identify the following flag issues of a geological, geotechnical, and geomorphological nature according to the Partridge *et al*. (1993) and supplemental parameters, as highlighted by Table 6.1 and Table 6.2 for Zones A* and B* respectively, namely:

- Mid slope within Land Type Ba9:
  - It is expected that localised boulders occur at the surface that could hamper the movement of some vehicles in these areas, as evidenced by:
    AGE severity value: 24% (indicating one coloured segment), and
    AGE impact realisation value: 12 out of a maximum of 50.
    Classification: 2_{supp} - intermediate.
  - The topsoil covering the area is expected to become slippery during and after precipitation events, and as such would hamper the movement of mainly wheeled vehicles during construction, as evidenced by:
    AGE severity value: 62% (indicating three coloured segments), and
    AGE impact realisation value: 62 out of a maximum of 100.
    Classification: 2_{supp} - intermediate.
  - The soil-like overburden covering the area could undergo loss of cohesion under loading or during and after precipitation events, and as such would hamper the movement of most vehicles during construction to a degree, as evidenced by:
    AGE severity value: 44% (indicating two coloured segments), and
    AGE impact realisation value: 65 out of a maximum of 150.
    Classification: 2_{supp} - intermediate.
  - The soil-like natural materials in this area are considered to be unsuitable for re-use, predominantly due to the relatively high clay content, as evidenced by:
    AGE severity value: 100% (indicating no coloured segments), and
    AGE impact realisation value: 400 out of a maximum of 400.
    Classification: 3_{supp} - least favourable.
  - There is a slight risk of an accumulation of groundwater at a depth of less than 1.5 m within the soil-like overburden in highly localised areas after heavy precipitation events, as evidenced by:
    AGE severity value: 1% (indicating one coloured segment), and
    AGE impact realisation value: 6 out of a maximum of 600.
    Classification: 2_B - intermediate.

Table 6.1: List of flag issues, obtained from the use of pedological information through application of the refined SEG system and from other sources resultant from the conducting of an PSGI, for Zone A* representing mid slopes within Land Type Ba9.

FLAG ISSUES		INFERRED IMPACTS ON DEVELOPMENT According to Partridge *et al.* (1993), supplemented where indicated, based on AGE severity values.		
		1 - Most favourable	2 - Intermediate	3 - Least favourable
CATEGORY 1 - POOR TRAFFICABILITY	**Occurrence of boulders at the surface,** hampers movement of all types of vehicle.		2_{supp}: Boulders expected at the surface / scattered bedrock outcrops expected to occur.	
	'Sticky' / slippery conditions when wet, hampers movement of mainly wheeled vehicles.		2_{supp}: 'Sticky' / slippery conditions expected after rain.	
	Topsoil expected to lose cohesion when saturated / 'quicksand' conditions, e.g., liquefaction or 'quicksand' conditions will hamper movement of all types of vehicle.		2_{supp}: Topsoil expected to lose cohesion when saturated.	
CATEGORY 2 - MATERIALS RE-USE POTENTIAL	Natural soil-like overburden.			3_{supp}: Most to all natural materials expected to be unsuitable for re-use.
CATEGORY 3 - ADVERSE SOIL BEHAVIOUR	**Collapse settlement,** under loading or when saturated.			
	Groundwater seepage and/ or waterlogging.		Class 2_B: Seepage associated with permanent or perched water tables expected at a depth of < 1.5 m.	
	Heave / shrinkage, with changes in moisture content.			Class 3_C: High soil-heave expected, with an AGE impact realisation value of > 280.
	Compressibility / 'soft clays', under loading or when saturated.			Class 3_D: High soil compressibility expected, with an AGE impact realisation value of > 300.
	Erodibility / dispersion, dispersive soils / non-cohesive material along steep slopes or within areas where concentrated surface flow occurs.	Class 1_E: Low, with an AGE impact realisation value of ≤ 135.		
CATEGORY 4 - EXCAVATABILITY PROBLEMS	To a depth of 1.5 m.			Class 3_F: Bedrock / hardpan pedocrete expected to comprise > 40% of total profile up to 1.5 m, with an AGE impact realisation value of > 400.
CATEGORY 5 - MISCELLANEOUS GEOLOGICAL, GEOTECHNICAL & GEOMORPHOLOGICAL FACTORS	**Undermining,** risk of surface instability / differential settlement.			
	Dolomite land, risk of sinkholes and/or subsidences, with details regarding Inherent Hazard Classes (IHC) provided in Part 2 of SANS 1936 (2012).			
	Very gentle slopes to nearly flat-lying areas, periodic ponding of surface water possible, wet engineering services prone to blockage.		Class 2_I: Slopes of < 2˚.	
	Steep slopes, more complex construction work indicated.			
	Unstable natural slopes, based on the results of a slope analysis, risk of possible slope failure.			
	Seismicity, details regarding seismic hazard provided in Part 4 of SANS 10160 (2009).	Class 1_K: Areas exhibiting a 10% probability of a seismic event with a peak ground acceleration of < 100 cm/s^2 within 50 years.		
	Periodic flooding, mainly based on geospatial setting of the area.			
	Other adverse characteristics (soil and/ or strata), e.g., self-mulching, slaking, 'Southern Cape Condensation Problem Area', etc.			

Table 6.2: List of flag issues, obtained from the use of pedological information through application of the refined SEG system and from other sources resultant from the conducting of an PSGI, for Zone B* representing foot slopes within Land Type Ba9.

FLAG ISSUES		INFERRED IMPACTS ON DEVELOPMENT **According to** Partridge *et al.* (1993), **supplemented where indicated, based on AGE severity values.**		
		1 - Most favourable	2 - Intermediate	3 - Least favourable
CATEGORY 1 - POOR TRAFFICABILITY	**Occurrence of boulders at the surface,** hampers movement of all types of vehicle.			
	'Sticky' / slippery conditions when wet, hampers movement of mainly wheeled vehicles.		2_{supp}: 'Sticky' / slippery conditions expected after rain.	
	Topsoil expected to lose cohesion when saturated / 'quicksand' conditions, e.g., liquefaction or 'quicksand' conditions will hamper movement of all types of vehicle.		2_{supp}: Topsoil expected to lose cohesion when saturated.	
CATEGORY 2 - MATERIALS RE-USE POTENTIAL Natural soil-like overburden.				3_{supp}: Most to all natural materials expected to be unsuitable for re-use
CATEGORY 3 - ADVERSE SOIL BEHAVIOUR	**Collapse settlement,** under loading or when saturated.			
	Groundwater seepage and/ or waterlogging.		Class 2_B: Seepage associated with permanent or perched water tables expected at a depth of < 1.5 m.	
	Heave / shrinkage, with changes in moisture content.			Class 3_C: High soil-heave expected, with an AGE impact realisation value of > 280.
	Compressibility / 'soft clays', under loading or when saturated.			Class 3_D: High soil compressibility expected, with an AGE impact realisation value of > 300.
	Erodibility / dispersion, dispersive soils / non-cohesive material along steep slopes or within areas where concentrated surface flow occurs.	Class 1_E: Low, with an AGE impact realisation value of ≤ 135.		
CATEGORY 4 - EXCAVATABILITY PROBLEMS To a depth of 1.5 m.			Class 2_F: Pockets of bedrock / hardpan pedocrete expected to comprise between 10 and 40% of total profile up to 1.5 m, with an AGE impact realisation value of ≥ 100 and ≤ 400	
CATEGORY 5 - MISCELLANEOUS GEOLOGICAL, GEOTECHNICAL & GEOMORPHOLOGICAL FACTORS	**Undermining,** risk of surface instability / differential settlement.			
	Dolomite land, risk of sinkholes and/or subsidences, with details regarding Inherent Hazard Classes (IHC) provided in Part 2 of SANS 1936 (2012).			
	Very gentle slopes to nearly flat-lying areas, periodic ponding of surface water possible, wet engineering services prone to blockage.		Class 2_I: Slopes of < 2˚.	
	Steep slopes, more complex construction work indicated.			
	Unstable natural slopes, based on the results of a slope analysis, risk of possible slope failure.			
	Seismicity, details regarding seismic hazard provided in Part 4 of SANS 10160 (2009).	Class 1_K: Areas exhibiting a 10% probability of a seismic event with a peak ground acceleration of < 100 cm/s^2 within 50 years.		
	Periodic flooding, mainly based on geospatial setting of the area.			
	Other adverse characteristics (soil and/ or strata), e.g., self-mulching, slaking, 'Southern Cape Condensation Problem Area', etc.			

- The soil-like overburden could exhibit a highly expansive character (heave or shrink), as evidenced by:

  AGE severity value: 45% (indicating two coloured segments), and
  AGE impact realisation value: 317 out of a maximum of 700.
  Classification: 3_C - least favourable.

- The soil-like overburden is expected to undergo significant consolidation under loading or when saturated, as evidenced by:

  AGE severity value: 62% (indicating three coloured segments), and
  AGE impact realisation value: 495 out of a maximum of 800.
  Classification: 3_D - least favourable.

- The soil-like overburden could be only slightly prone to erosion, as evidenced by:

  AGE severity value: 1% (indicating one coloured segment), and
  AGE impact realisation value: 6 out of a maximum of 900.
  Classification: 1_E - most favourable.

- It is possible that problems could be encountered during the excavation of engineering service trenches in localised areas with rock or hardpan ferricrete comprising more than 40% of the volume of material to 1.5 m, as evidenced by:

  AGE severity value: 42% (indicating two coloured segments), and
  AGE impact realisation value: 415 out of a maximum of 1 000.
  Classification: 3_F - least favourable.

- It is possible that problems could be encountered during the excavation of roads and foundation trenches in localised areas, as evidenced by:

  AGE severity value: 40% (indicating one coloured segment), and
  AGE impact realisation value: 441 out of a maximum of 1 100.
  Classification: Not applicable.

- The available topographical information indicated that natural slopes of less than 2° can be expected, indicating:

  Classification: 2_I - intermediate.

- The regional seismic risk was considered to be low, indicating:

  Classification: 1_K - most favourable.

• Foot slope within Land Type Ba9:

- The topsoil covering the area is expected to become slippery during and after precipitation events, and as such would hamper the movement of mainly wheeled vehicles during construction, as evidenced by:

AGE severity value: 71% (indicating three coloured segments), and
AGE impact realisation value: 71 out of a maximum of 100.
Classification: 2_{supp} - intermediate.

- The soil-like overburden covering the area is expected to undergo loss of cohesion under loading or during and after precipitation events, and as such would hamper the movement of most vehicles during construction, as evidenced by:

  AGE severity value: 51% (indicating three coloured segments), and
  AGE impact realisation value: 77 out of a maximum of 150.
  Classification: 2_{supp} - intermediate.

- The soil-like natural materials in this area are considered to be unsuitable for re-use, predominantly due to the relatively high clay content, as evidenced by:

  AGE severity value: 100% (indicating no coloured segments), and
  AGE impact realisation value: 400 out of a maximum of 400.
  Classification: 3_{supp} - least favourable.

- There is a risk of an accumulation of groundwater at a depth of less than 1.5 m within the soil-like overburden in highly localised areas after heavy precipitation events, as evidenced by:

  AGE severity value: 23% (indicating one coloured segment), and
  AGE impact realisation value: 139 out of a maximum of 600.
  Classification: 2_B - intermediate.

- The soil-like overburden is expected to exhibit an expansive character (heave or shrink), as evidenced by:

  AGE severity value: 54% (indicating three coloured segments), and
  AGE impact realisation value: 375 out of a maximum of 700.
  Classification: 3_C - least favourable.

- The soil-like overburden is expected to undergo consolidation under loading or when saturated, as evidenced by:

  AGE severity value: 67% (indicating three coloured segments), and
  AGE impact realisation value: 537 out of a maximum of 800.
  Classification: 3_D - least favourable.

- The soil-like overburden could be only slightly prone to erosion, as evidenced by:

  AGE severity value: 3% (indicating one coloured segment), and
  AGE impact realisation value: 77 out of a maximum of 900.
  Classification: 1_E - most favourable.

- It is possible that problems could be encountered during the excavation of engineering service trenches in localised areas, as evidenced by:

  AGE severity value: 28% (indicating one coloured segment), and
  AGE impact realisation value: 282 out of a maximum of 1 000.
  Classification: 2_F - intermediate.

- It is possible that problems could be encountered during the excavation of roads and foundation trenches in highly localised areas, as evidenced by:

  AGE severity value: 17% (indicating one coloured segment), and
  AGE impact realisation value: 185 out of a maximum of 1 100.
  Classification: Not applicable.

- The available topographical information indicated that natural slopes of less than 2° can be expected, indicating:

  Classification: 2_I - intermediate.

- The regional seismic risk was considered to be low, indicating:

  Classification: 1_K - most favourable.

- The location of this terrain unit adjacent to a floodplain of a known stream channel, but with slopes in excess of 1% (approximately 0.5°), indicates that there is only a very slight risk of localised flooding after heavy precipitation events.

It is evident that the area defined as a foot slope exhibits a different geotechnical character than that of the mid slope, mainly as a result of thicker topsoil and the localised presence of gleyed material at depth. As such, the study area can be divided into the following two preliminary geotechnical zones (Figure 6.12), with the zonal designations based on the information detailed in the previous section, namely:

- Zone A*, defined as the mid slope, with a preliminary geotechnical classification of:

  $1_{E,K}$ $2_{B,I}$ $3_{C,D,F}$

  and comprising approximately 94% of the study area.

- Zone B*, defined by the foot slope, with a preliminary geotechnical classification of:

  $1_{E,K}$ $2_{B,F,I}$ $3_{C,D}$

  and comprising the remaining 6% of the study area.

Note that an * was added to the preliminary geotechnical zonal designation to prevent confusion with that allocated to the zones that resulted from the detailed geotechnical investigation.

Figure 6.12: Case study 1: Preliminary geotechnical zonation map resulting from an PSGI utilising the refined SEG system, overlaid onto a satellite image. The zonal designations are according to SANS 634 (2012).

These results were used to provide responses of a geotechnical nature for the BAR process identifying relevant flag issues of a geological, geotechnical, and geomorphological nature for each preliminary geotechnical zone according to previously discussed principles. The responses, and the relevant information on which these were based, are provided in Table 6.3. In particular, the PSGI flagged the following issues:

- Shallow water table (less than 1.5 m deep),
- Soils with a high clay content (clay fraction more than 40%), and
- Any other unstable soil or geological feature.

6.2.2.3 Information obtained from the results of a detailed geotechnical investigation

A detailed geotechnical site investigation (DGSI) comprising the excavation and profiling of test pits and the determination of basic geotechnical properties by a materials laboratory was conducted on the land parcel by an experienced engineering geologist (Meintjes, 2015a). The primary aim of the investigation was to aid township establishment, as well as to provide geotechnical information for design and construction purposes. The following site-specific geotechnical characteristics were subsequently identified:

- It was found that the majority of the site is covered by soils exhibiting moderately to very highly expansive character with the soils exhibiting a clay content of up to 58%, classifying as NHBRC site class H3 (Table 2.3).
- The soil-like overburden was considered to be slightly compressible for most of the total volume of material that will be affected by bearing pressures to be exerted by single-storey residential structures, classifying as NHBRC Site Class S2 with pockets of S/ S1 (Table 2.3).
- The presence of weakly ferruginized material was inferred to indicate the weak seasonal formation of perched water tables at a depth of less than 1.5 m throughout the mid slope area, indicated by the designation ($P^{perched}$), with more significant groundwater seepage indicated to occur along the foot slope, designated as $P^{perched}$.
- Excavatability by means of a light mechanical excavator was generally in excess of 2.5 m with rock and/ or hardpan ferricrete comprising less than 10% of the volume to 1.5 m. It must be noted that the completely weathered andesite occurring at depth (defining saprolite underlying the diagnostic soil horizons) occasionally contained weathered andesite corestones that hampered excavation at depth. Scattered outcrops and sub-outcrops with relatively small volumes of highly expansive and compressible saprolite were encountered in one area in the southwest of the study area where rock comprises more than 40% of the volume to 1.5 m, classifying as NHBRC Site Class (R).

Table 6.3: List of responses (black background) to questions of a geotechnical nature for preliminary geotechnical zone A* and zone B* as required for the compilation of a BAR based on the results of the PSGI. Class designations are according to Partridge *et al*. (1993).

QUESTIONS OF A GEOTECHNICAL NATURE AS SPECIALIST INPUT FOR BAR PURPOSES	ZONE A*			ZONE B*		
	RESPONSES		RELEVANT FLAG ISSUES from Table 6.1, and RELEVANT PEDOLOGICAL INFORMATION from Figure 6.9	RESPONSES		RELEVANT FLAG ISSUES from Table 6.3, and RELEVANT PEDOLOGICAL INFORMATION from Figure 6.9
Shallow water table (less than 1.5 m deep):	**YES**	NO	Class 2_B: Groundwater seepage.	**YES**	NO	Class 2_B: Groundwater seepage.
Dolomite, sinkhole or doline areas:	YES	**NO**	Area not indicated to be underlaid by dolomitic strata.	YES	**NO**	Area not indicated to be underlaid by dolomitic strata.
Seasonally wet soils (often close to water bodies):	YES	**NO**	Area not located within floodplain or surface drainage feature.	YES	**NO**	Area not located within floodplain or surface drainage feature.
Unstable rocky slopes or steep slopes with loose soil:	YES	**NO**	Class 2_I: Very gentle slopes.	YES	**NO**	Class 2_I: Very gentle slopes.
Dispersive soils (soils that dissolve in water):	YES	**NO**	Class 1_E: Low risk of dispersion.	YES	**NO**	Class 1_E: Low risk of dispersion.
Soils with a high clay content (clay fraction more than 40%):	**YES**	NO	Clay content of more than 40% indicated for some of the soil forms within the area.	**YES**	NO	Clay content of more than 40% indicated for various soil forms within the area.
Any other unstable soil or geological feature:	**YES**	NO	Class 3_C: Highly active soils, Class 3_D: High compressibility, and Class 3_F: Excavatability problems.	**YES**	NO	Class 3_C: Highly active soils, Class 3_D: High compressibility, and Class 2_F: Excavatability problems.
An area sensitive to erosion:	YES	**NO**	Class 1_E: Low erodibility indicated.	YES	**NO**	Class 1_E: Low erodibility indicated.

- The laboratory test results indicated that the residual material is potentially highly dispersive.
- It must be noted that construction rubble and domestic waste have been haphazardly dumped on top of the natural soil material, inferred to represent similar conditions to that of Zone A, in a localised portion of the study area, with the designation $P^{\text{uncontrolled fill}}$ assigned.

Based on the results of the detailed geotechnical investigation, Meintjes (2015a) subsequently divided the study area into four geotechnical zones, designated zone A to zone D (Figure 6.13). Zone A roughly encompasses those portions of the study area defined as a mid-slope (representing approximately 56% of the study area), while zone B includes the foot slope and a portion of the mid slope (16% of the study area). Zone C delineates a highly localised area in the southwest where scattered andesite outcrops were encountered (2% of the study area). The area where haphazard dumping has occurred defines zone D (6% of the study area) where significant cost and effort will be required to rehabilitate, rendering this area unsuitable for residential development. Note that an existing road servitude and the land parcel surrounding an existing homestead (20% of the study area) were excluded from the zonation.

Meintjes (2015a) expressed the geotechnical character of each zone according to the requirement of the NHBRC (2015) as follows:

Zone A: H3 S2 (S/ S1) (P^{perched}).
Zone B: H3 S2 P^{perched}.
Zone C: H3 S2 (R) (P^{perched}).
Zone D: $P^{\text{uncontrolled fill}}$ upon inferred H3 S2 (P^{perched}).

In order to allow comparison between the PSGI and DGSI results, the distinctive geotechnical characteristics exhibited by each of the geotechnical zones based on the NHBRC (2015) site classification, as well as other factors of a geological, geotechnical, and geomorphological nature noted during that investigation, were translated to its corresponding Partridge *et al*. (1993) parameters based on the definition of flag issues listed in Table 5.11 and the principles discussed in section 5.4.1. This process yielded the following (excluding the unsuitable zone D and the servitudes):

Zone A:	Rock less than 10% of the volume to 1.5 m:	1_F - most favourable
	Low seismicity:	1_K - most favourable
	Groundwater seepage at less than 1.5 m:	2_B - intermediate
	Slopes of less than 2°:	2_I - intermediate
	NHBRC site class high H3:	3_C - least favourable
	NHBRC site class S2 (mainly):	3_D - least favourable
	High risk of dispersion:	3_E - least favourable

Figure 6.13: Case study 1: Geotechnical zonation map resulting from a DGSI by Meintjes (2015a), overlaid onto a satellite image. The zonal designations are according to SANS 634 (2012).

Zone B:	Rock less than 10% of the volume to 1.5 m:	1_F - most favourable
	Low seismicity:	1_K - most favourable
	Groundwater seepage at less than 1.5 m:	2_B - intermediate
	Slopes of less than 2°:	2_I - intermediate
	NHBRC site class high H3:	3_C - least favourable
	NHBRC site class S2 (mainly):	3_D - least favourable
	High risk of dispersion:	3_E - least favourable
Zone C:	Low risk of dispersion:	1_E - most favourable
	Low seismicity:	1_K - most favourable
	Groundwater seepage at less than 1.5 m:	2_B - intermediate
	Slopes of less than 2°:	2_I - intermediate
	NHBRC site class high H3:	3_C - least favourable
	NHBRC site class S2 (mainly):	3_D - least favourable
	Rock more than 40% of the volume to 1.5 m:	3_F - least favourable

As the detailed geotechnical investigation was not conducted as a specialist study for BAR or EIA purposes, the report by Meintjes (2015a) did not include any recommendations in this regard. However, the results from that investigation were subsequently applied to provide responses for BAR purposes as part of this research, as shown in Table 6.4, with the following issues flagged:

- Shallow water table (less than 1.5 m deep),
- Dispersive soil (soils that dissolve in water) - applicable to saprolite occurring at depth in zone A and zone B only,
- Soils with a high clay content (clay fraction more than 40%), and
- Any other unstable soil or geological feature.

6.2.3 Discussion of results

A comparison between the results of the PSGI, conducted by utilisation of the refined SEG system, and that of the DGSI conducted by Meintjes (2015a) is provided in Table 6.5. This table provides a comparison between the various distinctive geotechnical characteristics translated into its corresponding parameter class according to Partridge *et al*. (1993). This comparison between the PSGI and DGSI results is illustrated diagrammatically by the accuracy columns for the mid slope and foot slope in Table 6.5 respectively.

The results revealed the following regarding the accuracy of the PSGI for this specific case:

Table 6.4: List of responses (black background) to questions of a geotechnical nature for geotechnical zones A, B and C as required for the compilation of a BAR based on the results of the DGSI. Class designations are according to Partridge *et al*. (1993).

QUESTIONS OF A GEOTECHNICAL NATURE AS SPECIALIST INPUT FOR BAR PURPOSES	ZONE A			ZONE B			ZONE C		
	RESPONSES		RELEVANT FLAG ISSUES refer to Table 5.11	RESPONSES		RELEVANT FLAG ISSUES refer to Table 5.11	RESPONSES		RELEVANT FLAG ISSUES refer to Table 5.11
Shallow water table (less than 1.5 m deep):	**YES**	NO	Class 2_B: Groundwater seepage.	**YES**	NO	Class 2_B: Groundwater seepage.	**YES**	NO	Class 2_B: Groundwater seepage.
Dolomite, sinkhole or doline areas:	YES	**NO**	Area not indicated to be underlaid by dolomitic strata.	YES	**NO**	Area not indicated to be underlaid by dolomitic strata.	YES	**NO**	Area not indicated to be underlaid by dolomitic strata.
Seasonally wet soils (often close to water bodies):	YES	**NO**	Area not located within floodplain or surface drainage feature.	YES	**NO**	Area not located within floodplain or surface drainage feature.	YES	**NO**	Area not located within floodplain or surface drainage feature.
Unstable rocky slopes or steep slopes with loose soil:	YES	**NO**	Class 2_I: Slopes < 2°.	YES	**NO**	Class 2_I: Slopes < 2°.	YES	**NO**	Class 2_I: Slopes < 2°.
Dispersive soils (soils that dissolve in water):	**YES**	NO	Class 3_E: High risk of dispersion, but relevant to materials occurring at depth only.	**YES**	NO	Class 3_E: High risk of dispersion, but relevant to materials occurring at depth only.	YES	**NO**	Class 1_E: Low risk of dispersion.
Soils with a high clay content (clay fraction more than 40%):	**YES**	NO	Clay content of more than 40% measured for some soil layers in the area.	**YES**	NO	Clay content of more than 40% measured for some soil layers in the area.	**YES**	NO	Clay content of more than 40% measured for some soil layers in the area.
Any other unstable soil or geological feature:	**YES**	NO	Class 3_C: Highly active soils, Class 3_D: High compressibility, and Class 1_F: Occasional excavatability problems.	**YES**	NO	Class 3_C: Highly active soils, Class 3_D: High compressibility, and Class 1_F: Occasional excavatability problems.	**YES**	NO	Class 3_C: Highly active soils, Class 3_D: High compressibility, and Class 3_F: Excavatability problems.
An area sensitive to erosion:	YES	**NO**	Although soils are potentially dispersive, very gentle slopes will limit risk of erosion.	YES	**NO**	Although soils are potentially dispersive, very gentle slopes will limit risk of erosion.	YES	**NO**	Although soils are potentially dispersive, very gentle slopes will limit risk of erosion.

Table 6.5: Case study 1: Graphical comparison between the results of the PSGI and DGSI according to Partridge *et al*. (1993) parameters.

Geotechnical parameters	**Mid slope**			**Foot slope**		
	PSGI **Zone A*** from Table 6.1	**DGSI** **Zone A and Zone C** from Figure 6.13	**Accuracy**	**PSGI** **Zone B*** from Table 6.2	**DGSI** **Zone B** from Figure 6.13	**Accuracy**
Collapsible soil:	-	-	⟳	-	-	⟳
Seepage:	2_B	2_B	⟳	2_B	2_B	⟳
Active soil:	3_C	3_C	⟳	3_C	3_C	⟳
Highly compressible soil:	3_D	3_D	⟳	3_D	3_D	⟳
Erodibility of soil:	1_E	3_E (Zone C: 1_E)	▼	1_E	3_E	▼
Difficulty of excavation to 1.5 m:	3_F	1_F (Zone C: 3_F)	▲	3_F	1_F	▲
Undermined ground:	-	-	⟳	-	-	⟳
Stability: dolomite/ limestone:	-	-	⟳	-	-	⟳
Very gentle slopes/ steep slopes:	2_I	2_I	⟳	2_I	2_I	⟳
Areas of unstable natural slopes:	-	-	⟳	-	-	⟳
Areas subject to seismic activity:	1_K	1_K	⟳	1_K	1_K	⟳
Areas subject to flooding:	-	-	⟳	-	-	⟳
Trafficability (mainly when wet):	Poor	-	+	Poor	-	+
Re-use of materials:	Unsuitable	Unsuitable	⟳	Unsuitable	Unsuitable	⟳
Man-made soil:	-	Localised pockets	-	-	-	⟳

LEGEND:

Underestimated: ▼

Similar: ⟳

Overestimated: ▲

Additional information: +

Unidentified: -

- **Accuracy**:

  It is evident that the PSGI correctly flagged most of the observed and measured adverse characteristics for both the mid-slope and foot-slope areas when compared to the results of the detailed geotechnical investigation.

- **Deviations**:

  - **Overestimation**:

    The PSGI erred on the side of caution (i.e., overestimated) with regard to the inferred impact of some parameters on residential development, namely:

    The expected problems with the excavation of engineering service trenches along the mid slopes (PSGI zone A*: class 3_F) were proven to be restricted to a localised portion of the study area only (DGSI zone C: class 3_F), with hard material generally comprising less than 10% of the remainder of the mid slope and foot slope (DGSI zones A and B: class 1_F). This implies that although the pedological information allows identification of possible shallow bedrock within a terrain unit, the generalised nature of this information requires analysis of remote sensing images followed by verification by means of a walk-over survey to delineate affected areas more accurately.

  - **Underestimation**:

    The results of the PSGI underestimated the effects of the following adverse characteristic on residential development to a degree, namely:

    The proven highly dispersive character (DGSI zone A and zone B: class 3_E) of the residual material was not anticipated based on the types and inferred characteristics of the diagnostic soil horizons that excluded assessment of the underlying saprolite (PSGI all zones: class 1_E). However, it must be noted that the relevant 1:50 000 scale geotechnical series map also did not indicate a high erosion potential for the area (as would be indicated by factor Dis2 to Dis5; Table 2.2). This implies that care must be taken when conducting an PSGI to take the known characteristics of residual material occurring beneath the diagnostic soil horizons into account when assessing erosion and/ or dispersion potential.

  - **Unidentified**:

    The PSGI did not identify the pockets of construction rubble and domestic waste haphazardly dumped on top of the natural soil material within portions of the study area, as encountered during the detailed investigation (DGSI zone D). This implies that the conducting of an PSGI should preferably include a limited walk-over site survey to verify on-site conditions that could be at variance with that revealed by the available information.

Comparison between the lists of flag issues in response to questions of a geotechnical nature for BAR purposes reveal that the PSGI (Table 6.3) correctly identified most of the issues flagged by the DGSI (Table 6.4), with the exception of the highly dispersive nature of the sub-surface materials not considered to have a significant impact on the proposed residential development as these will not typically be exposed during development.

6.2.4 Case study 1: Conclusions

The use of the refined SEG system when conducting an PSGI as part of this research can be considered a success, as it predicted the geotechnical character of the site to a sufficient level of accuracy. This information, if available prior to the detailed geotechnical investigation, would have made the geopractitioner aware of the possible occurrence of specific adverse geotechnical conditions. This could have influenced the planning and costing of the DGSI with regard to the number and placement of test pits (e.g., to investigate the inferred zonal boundary), and dictated the types of laboratory tests required (e.g., the need for undisturbed soil samples for the determination of the free swell potential and consolidation settlement).

Underestimation of the thickness of the soil-like overburden and the dispersion potential of the saprolite can be attributed to both imprecise information regarding the non-diagnostic materials occurring at depth, and the depth limit of 1.2 m inherent to the Binomial Soil Classification System.

The personal experience of the practitioner, supported by the published regional geotechnical map and remote sensing images, was required to overcome inaccuracies regarding the spatial distribution of land types in the area. It is evident that the results PSGI would have been enhanced by a walk-over site survey during which the scattered bedrock outcrops and the highly localised occurrence of man-made soils in the southeast of the site could have been documented.

6.3 Case study 2: Comparison between two candidate sites located in different land types and terrain units

6.3.1 Background

In case study 2, SEG-based PSGIs were applied in support of site selection for a hypothetical new cemetery for Potchefstroom in the JB Marks Local Municipality. Two vacant plots, approximately 2 hectares in extent each representing a specific geological, geotechnical, and geomorphological character based on differing terrain units and land types were selected, namely:

Site 1: located along a foot slope in the Van der Hoff Park suburb (Figure 6.14) within Land Type Bc25.

Site 2: located along a mid-slope to the west of the Dassierand suburb (Figure 6.15) within Land Type Fa14.

An PSGI utilising the refined SEG system was conducted at each of the two candidate sites to identify and assess the following perceived impacts of a geotechnical nature on the natural environment as defined by Dippenaar *et al*. (2018), with the PSGI results correlated with the standard rating scores proposed by Hall and Hanbury (1990) where indicated:

- Graves could act as preferential infiltration pathways along which ingress water from the surface or perched water tables accumulates, allowing introduction thereof into deeper horizons. Additionally, water entering graves that have been excavated into relatively impermeable bedrock could either flow deeper into the rock along joints or fissures or build up to the surface leading to anaerobic conditions within the grave.
- The hydrogeological character of a candidate site, especially regarding the depth of the **static groundwater level**, is primarily assessed on the hand of available geological maps and/ or reports, and is scored as follows:

  Deep water table (> 8 m) - based on available information: 25

  Intermediate water table (4 - 8 m) - based on available information: 5

  Possible perched water table - Partridge *et al*. (1993) class 2_B: 5

  Waterlogged soil - Partridge *et al*. (1993) class 3_B, 2_L or 3_L: FAIL

- The proper functioning of a cemetery is dependent on the geomechanical properties of the material into which graves are to be excavated, specifically with regard to the following:
  - **Excavatability**, with graves ideally to be excavated to a depth of at least 1.8 m by hand or light mechanical excavator, and the presence of rock, boulders and/or hardpan pedocrete being especially problematic, scored as follows:

    Easy spade - Partridge *et al*. (1993) class 1_F: 15

    Pick and spade - Partridge *et al*. (1993) class 1_F and/ or moderate stoniness (1: many stones and boulders, but ploughable; Figure 2.3-G): 10

    Machine - Partridge *et al*. (1993) class 2_F and/ or significant stoniness (2: large stones and boulders, unploughable; Figure 2.3-G) 5

    Blasting - Partridge *et al*. (1993) class 3_F: 0

Figure 6.14: Case study 2: Location of candidate site 1 (Van der Hoff Park suburb).

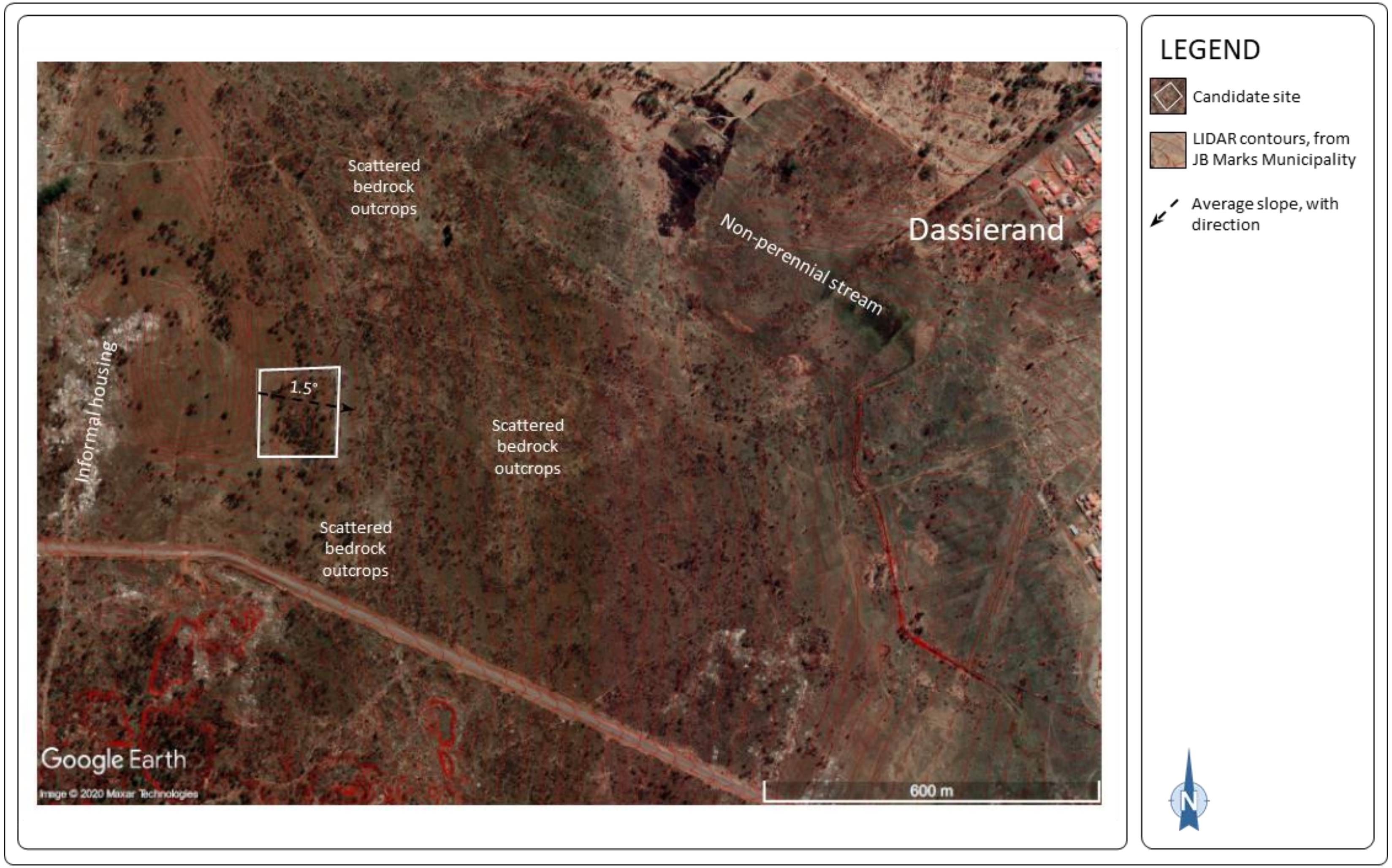


Figure 6.15: Case study 2: Location of candidate site 2 (west of Dassierand suburb).

- **Excavation stability**, influenced by the cohesiveness of the various layers to be exposed along the sidewalls, especially when saturated, scored as follows:

  Stable - Partridge *et al*. (1993) classes 1_A or 2_A not indicated: 20

  Overbreak - soils with high clay content and/ or saprolite: 15

  Slightly unstable - Partridge *et al*. (1993) class 1_A: 8

  Unstable - Partridge *et al*. (1993) class 2_A: 1

- **Material workability**, where materials should ideally not undergo significant consolidation or densification when disturbed or wet, and backfill compaction, with the presence of a large volume of materials unsuitable for re-use as backfill material considered a drawback, scored as follows:

  Excellent to good - Material re-use potential 1_{supp}: 10

  Fair - Partridge *et al*. (1993) class 1_D and/ or Material re-use potential no worse than 2_{supp}: 5

  Poor - Partridge *et al*. (1993) class 2_D: 2

  Very poor - Partridge *et al*. (1993) class 3_D, Material re-use potential 3_{supp}: 0

- **Subsoil permeability**, that influences groundwater ingress and movement through graves from the subsoil, scored as follows:

  Impermeable - soils inferred to exhibit a clay content of 10% and/ or classifying as Partridge *et al*. (1993) classes 2_C or 3_C: 15

  Relatively impermeable - soils inferred to exhibit a clay content of between 6 and 10% and/ or not classifying as Partridge *et al*. (1993) classes 2_C or 3_C: 20

  Relatively permeable - soils inferred to exhibit a clay content of between 3 and 6% and/ or not classifying as Partridge *et al*. (1993) classes 1_C or 2_C: 10

  Permeable - soils exhibiting a clay content of up to 3%, or containing a humic topsoil: 0

- **Backfill permeability**, that influences surface water ingress and movement through graves, scored as follows:

  Impermeable - soils inferred to exhibit a clay content of 10% and/ or classifying as Partridge *et al*. (1993) classes 2_C or 3_C: 5

  Relatively impermeable - soils inferred to exhibit a clay content of between 6 and 10% and/ or not classifying as Partridge *et al*. (1993) classes 2_C or 3_C: 10

Relatively permeable - soils inferred to exhibit a clay content of between 3 and 6% and/ or not classifying as Partridge *et al*. (1993) classes 1_C or 2_C: 7

Very permeable - soils exhibiting a clay content of up to 3%, or containing a humic topsoil: 0

- The presence of **water-soluble strata** (e.g., dolomite or limestone; not scored by Hall and Hanbury (1990), with areas classified as IHCs 6 to 8 posing too high a risk to allow placement of a cemetery, assessed as follows:

  Problematic - areas classifying as Partridge *et al*. (1993) class 3_H

  Intermediate - areas classifying as Partridge *et al*. (1993) class 1_H or 2_H.

- The stability of especially steep **slopes** is considered problematic with regard to slope instability and erosion, while nearly flat-lying areas could lead to the ponding of surface water and waterlogging, assessed as follows:

  Problematic - areas classifying as Partridge *et al*. (1993) class 2_I or 3_I.

Additional factors that need to be assessed during the conducting of an PSGI for the selection of a cemetery site include (Dippenaar *et al*., 2018):

- distance to drinking water source should be at least between 250 and 500m, and
- distance to a river, well or spring should be at least between 30 and 100 m, thus avoiding waterlogged land, wetlands, and flood plains.

Unfortunately, the Council for Geoscience has not yet published a regional geotechnical map for the area in which the candidate sites are located, and as such the accuracy of the information from the land type map and memoir is highly reliant on the personal experience of the geopractitioner conducting the PSGIs.

Potchefstroom exhibits a climatic N-value of approximately 4.7 (Weinert, 1980; Figure 6.16), and as such the various minerals comprising the strata underlying both candidate sites are expected to have undergone decomposition contributing to soil formation, rather than disintegration into an abundance of rocky clasts within a soil-like matrix.

6.3.2 Characterisation and refined SEG system results of candidate site 1

The candidate site is a vacant plot of land located along a foot slope exhibiting an average slope of approximately 0.25° (very gentle sloping) towards the southwest (Figure 6.14). A concrete-lined irrigation canal is located upslope of the site, with the nearly flat-lying flood plain of the perennial Mooi River directly to the southwest. The main channel of the river is currently located approximately 250 m from the southwestern boundary of the site with both the 1 in 50 and 1 in 100 year flood lines of that river, as rendered by Messrs. BKS for the JB Marks Municipality (Lubbe, 2001), indicated to encroach on at least 52% of the site itself, as shown in Figure 6.17.

Figure 6.16: Case study 2: Contour map of climatic N-values (Weinert, 1980) , overlaid onto a satellite image.

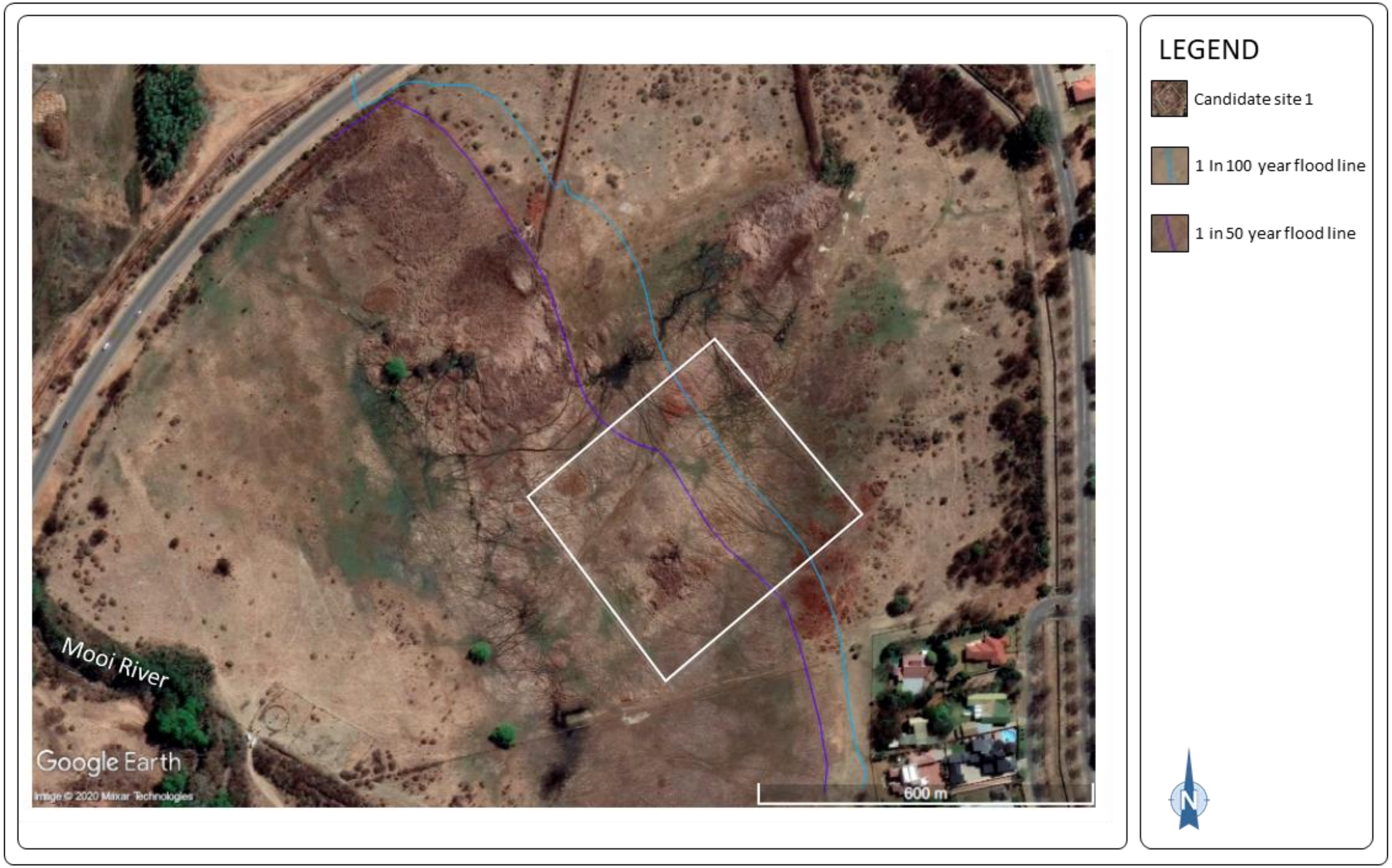


Figure 6.17: Case study 2: Available 1 in 50 and 1 in 100 year flood lines of the Mooi River in relation to candidate site 1, as rendered by Messrs. BKS for the JB Marks Municipality (Lubbe, 2001), overlaid onto a satellite image.

Available hydrogeological information indicates that the static groundwater level in the Van der Hoff Park suburb upslope of the candidate site can be expected at a depth of between 1.73 and 7.80 m below ground level (Van Zyl *et al*., 2012).

According to the published 1:250 000 scale 2626 West Rand (1980) geological map, the area is covered by a significant thickness of alluvial deposits of Quaternary Age, inferred to be underlaid by shale with interbedded quartzite of the Silverton Formation of the Pretoria Group, Transvaal Supergroup (Figure 6.18).

The published 1:250 000 scale 2626 West Rand (ISCW, 1985) land type map indicates that the site is covered by soils within Land Type Bc25 (Figure 6.19) typically exhibiting a ferruginized (i.e., plinthic) and leached character with the absence of moderately to strongly structured soils along ridge crests and mid-slopes (Table 2.1). Information regarding the regional soils and soil/ rock complexes is provided by the relevant memoir (Figure 6.20, with the relevant data entries as annotated on the left). Dissemination of the pedological information (Figure 6.20) by means of the refined SEG system based on previously discussed principles yielded the following (Figure 6.21):

- Localised pockets:
    - SEG-I Apedal soils (31%), comprising:
      Clovelly (l), Glencoe (m) and Hutton (d) soil forms with topsoil containing between 4 and 35% clay and sub-surface layers with between 6 and 45% clay, between 0.3 and more than 1.2 m thick, underlaid by saprolite and weathered bedrock, and very occasionally by hardpan ferricrete.
    - SEG-VI Moderately to strongly structured clayey soils (28%), comprising:
      Arcadia (i), Bonheim (o), Swartland (f) and Valsrivier (e) soil forms with topsoil exhibiting between 15 to 60% clay, between 0.2 and 0.9 m thick, underlaid mainly by similar material to the overlying diagnostic horizons, and occasionally saprolite or weathered bedrock.
    - SEG-IX Soils that undergo periodic saturation (23%), comprising:
      Avalon (k), Longlands (p) and Westleigh (j) soil forms with between 15 and 40% clay in topsoil and between 20 and 60% at depth, between 0.3 and 1.2 m thick, underlaid predominantly by gleyed material, and very occasionally by soft pedocrete.
- Very highly localised pockets:
    - SEG-VII Outcrops/ sub-outcrops of rock and/ or pedocrete (6.5%), comprising:
      scattered bedrock outcrops (a), and Mispah (b) soil form exhibiting topsoil with a clay content of up to 25%, up to 0.2 m thick, overlying weathered bedrock or hardpan ferricrete.

Figure 6.18: Case study 2: Regional geological map for candidate site 1, based on the published 1:250 000 scale 2626 West Rand (CGS, 1980) geological map.

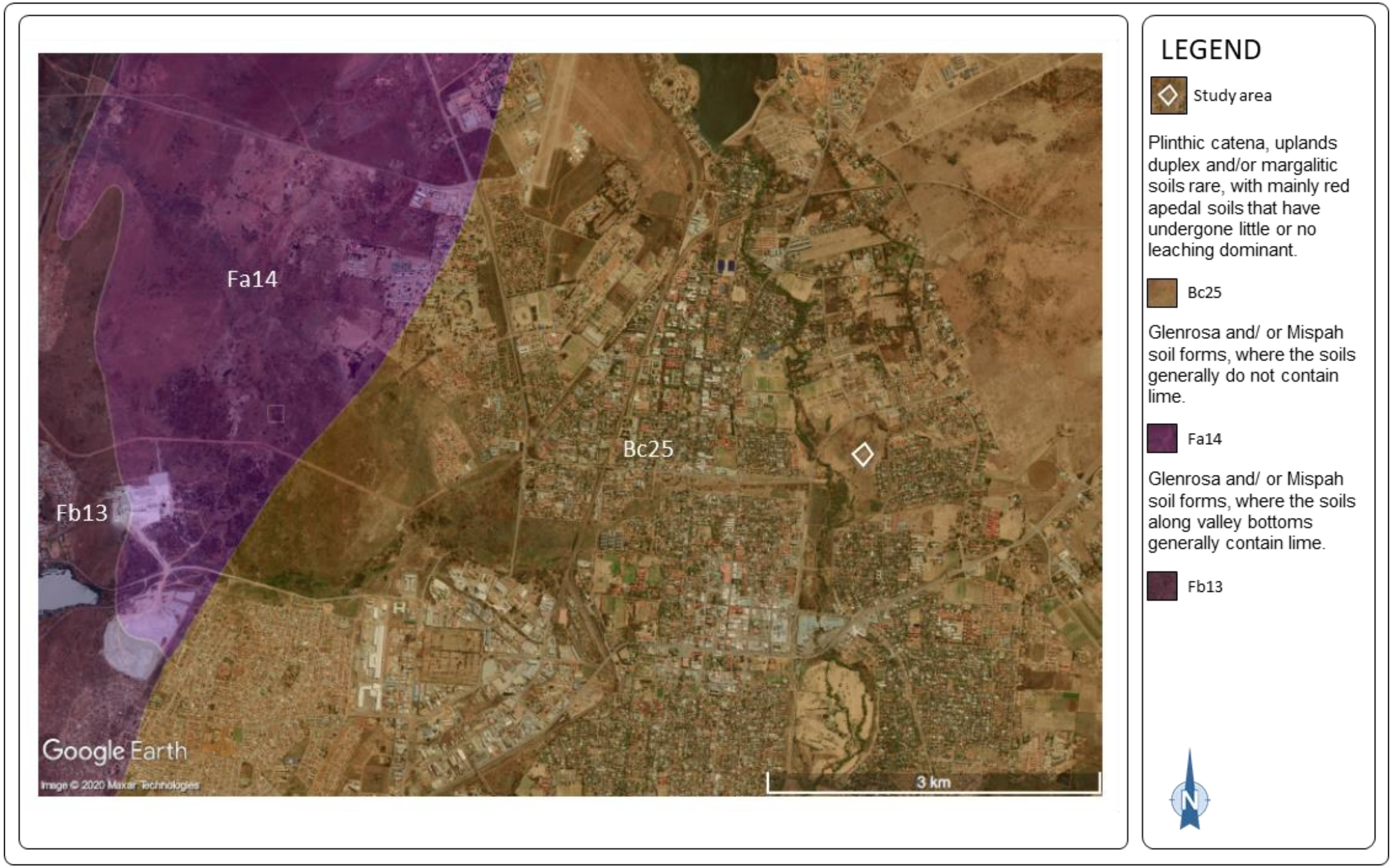
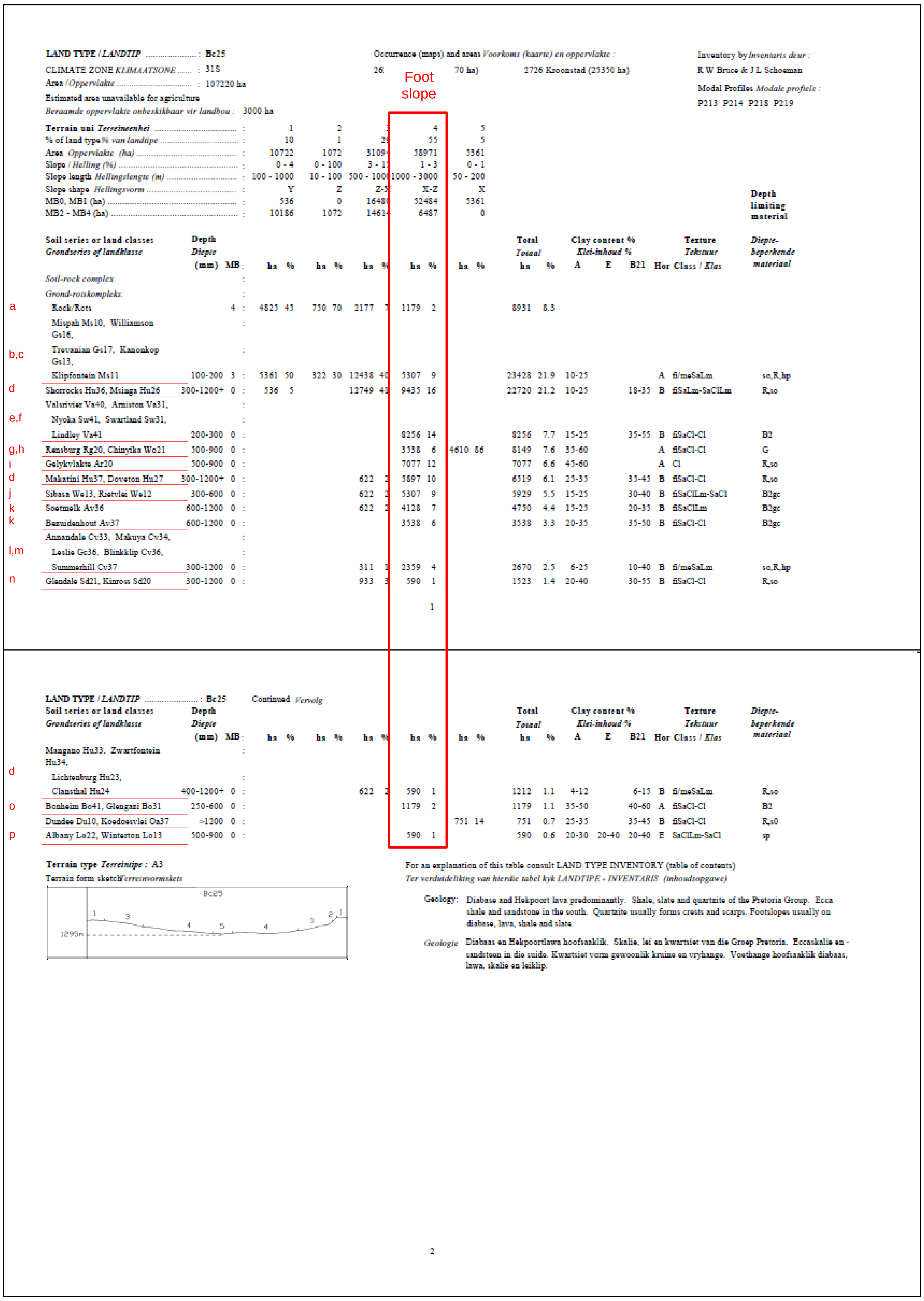


Figure 6.19: Case study 2: Spatial distribution of land types for candidate site 1 according to the 1:250 000 scale 2626 West Rand (ISCW, 1985) land type map, overlaid onto a satellite image.



LAND TYPE / *LANDTIP* ....: Bc25
CLIMATE ZONE *KLIMAATSONE* ...... : 31S
Area / *Oppervlakte* .... : 107220 ha
Estimated area unavailable for agriculture
Beraamde oppervlakte onbeskikbaar vir landbou : 3000 ha

Occurrence (maps) and areas *Voorkoms (kaarte) en oppervlakte* :
26 70 ha) 2726 Kroonstad (25350 ha)

Inventory by *Inventaris deur* :
R W Bruce & J L Schoeman

Modal Profiles *Modale profiele* :
P213 P214 P218 P219

Foot slope

Terrain unit *Terreineenheid*	1	2	3	4	5
% of land type *% van landtipe*	10	1	2	55	5
Area *Oppervlakte (ha)*	10722	1072	3109	58971	5361
Slope / *Helling (%)*	0 - 4	0 - 100	3 - 1	1 - 3	0 - 1
Slope length *Hellingslengte (m)*	100 - 1000	10 - 100	500 - 100	1000 - 3000	50 - 200
Slope shape *Hellingsvorm*	Y	Z	Z-X	X-Z	X
MB0, MB1 (ha)	536	0	1648	52484	5361
MB2 - MB4 (ha)	10186	1072	1461	6487	0

	Soil series or land classes *Grondseries of landklasse*	Depth *Diepte* (mm)	MB	1 ha	1 %	2 ha	2 %	3 ha	3 %	4 ha	4 %	5 ha	5 %	Total *Totaal* ha	Total %	Clay content % *Klei-inhoud %* A	E	B21	Hor	Texture *Tekstuur* Class / *Klas*	Depth limiting material *Diepte-beperkende materiaal*
	Soil-rock complex *Grond-rotskompleks:*																				
a	Rock/Rots		4	4825	45	750	70	2177	7	1179	2			8931	8.3						
b,c	Mispah Ms10, Williamson Gs16, Trevanian Gs17, Kanonkop Gs13, Klipfontein Ms11	100-200	3	5361	50	322	30	12438	40	5307	9			23428	21.9	10-25			A	fi/meSaLm	so,R,hp
d	Shorrocks Hu36, Msinga Hu26	300-1200+	0	536	5			12749	41	9435	16			22720	21.2	10-25		18-35	B	fiSaLm-SaClLm	R,so
e,f	Valsrivier Va40, Arniston Va31, Nyoka Sw41, Swartland Sw31, Lindley Va41	200-300	0							8256	14			8256	7.7	15-25		35-55	B	fiSaCl-Cl	B2
g,h	Rensburg Rg20, Chinyika Wo21	500-900	0							3538	6	4610	86	8149	7.6	35-60			A	fiSaCl-Cl	G
i	Gelykvlakte Ar20	500-900	0							7077	12			7077	6.6	45-60			A	Cl	R,so
d	Makatini Hu37, Doveton Hu27	300-1200+	0					622	2	5897	10			6519	6.1	25-35		35-45	B	fiSaCl-Cl	R,so
j	Sibasa We13, Rietvlei We12	300-600	0					622	2	5307	9			5929	5.5	15-25		30-40	B	fiSaClLm-SaCl	B2gc
k	Soetmelk Av36	600-1200	0					622	2	4128	7			4750	4.4	15-25		20-35	B	fiSaClLm	B2gc
k	Bezuidenhout Av37	600-1200	0							3538	6			3538	3.3	20-35		35-50	B	fiSaCl-Cl	B2gc
l,m	Annandale Cv33, Makuya Cv34, Leslie Gc36, Blinkklip Cv36, Summerhill Cv37	300-1200	0					311	1	2359	4			2670	2.5	6-25		10-40	B	fi/meSaLm	so,R,hp
n	Glendale Sd21, Kinross Sd20	300-1200	0					933	3	590	1			1523	1.4	20-40		30-55	B	fiSaCl-Cl	R,so

1

LAND TYPE / *LANDTIP* ....: Bc25 Continued *Vervolg*

	Soil series or land classes *Grondseries of landklasse*	Depth *Diepte* (mm)	MB	1 ha	1 %	2 ha	2 %	3 ha	3 %	4 ha	4 %	5 ha	5 %	Total *Totaal* ha	Total %	Clay content % *Klei-inhoud %* A	E	B21	Hor	Texture *Tekstuur* Class / *Klas*	*Diepte-beperkende materiaal*
d	Mangano Hu33, Zwartfontein Hu34, Lichtenburg Hu23, Clansthal Hu24	400-1200+	0					622	2	590	1			1212	1.1	4-12		6-15	B	fi/meSaLm	R,so
o	Bonheim Bo41, Glengazi Bo31	250-600	0							1179	2			1179	1.1	35-50		40-60	A	fiSaCl-Cl	B2
	Dundee Du10, Koedoesvlei Oa37	>1200	0									751	14	751	0.7	25-35		35-45	B	fiSaCl-Cl	R,s0
p	Albany Lo22, Winterton Lo13	500-900	0							590	1			590	0.6	20-30	20-40	20-40	E	SaClLm-SaCl	sp

Terrain type *Terreintipe* : A3
Terrain form sketch *Terreinvormskets*

For an explanation of this table consult LAND TYPE INVENTORY (table of contents)
Ter verduideliking van hierdie tabel kyk LANDTIPE - INVENTARIS (inhoudsopgawe)

Geology: Diabase and Hekpoort lava predominantly. Shale, slate and quartzite of the Pretoria Group. Ecca shale and sandstone in the south. Quartzite usually forms crests and scarps. Footslopes usually on diabase, lava, shale and slate.

Geologie Diabaas en Hekpoortlawa hoofsaaklik. Skalie, lei en kwartsiet van die Groep Pretoria. Eccaskalie en -sandsteen in die suide. Kwartsiet vorm gewoonlik kruine en vryhange. Voethange hoofsaaklik diabaas, lawa, skalie en leiklip.

2

Figure 6.20: Case study 2: Land type memoir for Land Type Bc25 that defines the regional soils distribution for candidate site 1. Information for foot slopes is highlighted and the relevant data entries annotated.

ASSESSMENT OF INFERRED GEOTECHNICAL CHARACTERISTICS UTILISING LAND TYPE INFORMATION

LAND TYPE: **Bc25**

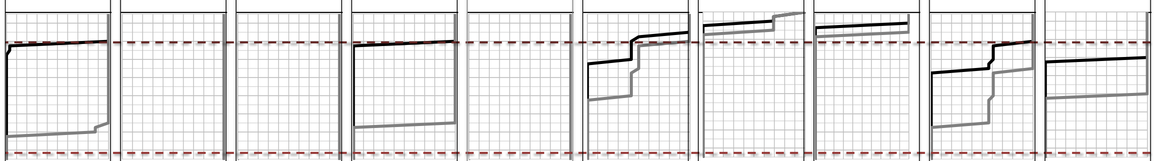
Terrain unit: **Foot Slopes**

Prominence: Prevalent (55 %)

Predominantly: > 69 % of terrain unit.
Mainly: 40 - 69 % of terrain unit.
Localised pockets: 20 - 39 % of terrain unit.
Highly localised pockets: 10 - 19 % of terrain unit.
Very highly localised pockets: < 10 % of terrain unit.

	SEG-I	SEG-II	SEG-III	SEG-IV	SEG-V	SEG-VI	SEG-VII	SEG-VIII	SEG-IX	SEG-X
	Apedal soils	Relatively unconsolidated soils	Pedogenic soils	Weakly structured soils (not gleyed)	Dual character soils (not gleyed)	Moderately to strongly structured soils	Outcrops / sub-outcrops of rock & hard pedocretes	Shallow lithic soils	Soils that undergo periodic saturation	Soils that undergo prolonged saturation
SOIL FORMS:	Clovelly Glencoe Hutton			Shortlands		Arcadia Bonheim Swartland Valsrivier	Mispah Rock	Glenrosa	Avalon Longlands Westleigh	Rensburg Willowbrook
TOTAL SEG PROMINENCES as % of terrain unit	**31** Localized pockets			**1** Very highly localized pockets		**28** Localized pockets	**6.5** Very highly localized pockets	**4.5** Very highly localized pockets	**23** Localized pockets	**6** Very highly localized pockets
DEPTH EXTENT in meters — Depth ranges: (diagnostic horizons only)	0.3 - 1.2 m+			0.3 - 1.2 m		0.2 - 0.9 m	No soil - 0.2 m	0.1 - 0.2 m	0.3 - 1.2 m	0.5 - 0.9 m
UNDERLAIN BY as % of terrain unit — Rock: 25.5 %	14.5			0.5		6.0	4.5			
Hardpan ferricrete: 4 %	2.0						2.0			
Hardpan pedocrete (other):										
Lithic / saprolite: 25.5 %	14.5			0.5		6.0		4.5		
Soft pedocrete: 1 %									1.0	
Moderately to strongly structured soil:										
Gleyed / wet material: 28 %									22.0	6.0
Unconsolidated material:										
Organic-rich material:										
Miscellaneous soil layers: 16 %						16.0				
Unspecified:										
STONINESS as % of terrain unit — No mechanical limitations: 89 %	31.0			1.0		28.0			23.0	6.0
Many stones, but ploughable:										
Large stones & boulders, unploughable:										
Very shallow soil on rock: 9 %							4.5	4.5		
Lack of soil: 2 %							2.0			
CLAY CONTENT — Range - topsoil horizons:	4 - 35 %			20 - 40 %		15 - 60 %	< 25 %	10 - 25 %	15 - 40 %	35 - 60 %
Range - material at depth:	6 - 45 %			30 - 55 %					20 - 60 %	
Possible duplex soils (15 %+ increase in clay with depth):										

DEPTH EXTENT (in meters): Depth of foundation trenches (0.3 m); Minimum; Maximum; Depth of bulk service trenches (1.5 m)



OTHER MATERIALS / FEATURES: SEG-XI (peat/ organic soil) | SEG-XII (man-made soil) | Stream channels | Erosion dongas | Other (pans. etc.)

PRELIMINARY GEOTECHNICAL ASSESSMENT

Adverse geotechnical effect (AGE) parameters	AGE severity assessment	AGE impact realisation assessment (with bar length indicating % realisation)	Geotechnical classification according to SANS 634 (2012) & supplemental (supp.) (1 - Most favourable; 2 - Intermediate; 3 - Least favourable)
Category 1: Poor trafficability			
Boulders at surface:	Slight risk.	1	supp.2
'Sticky'/slippery conditions when wet:	High risk.	81	supp.3
Loss of cohesion when wet / 'quicksand':	Expected to occur.	115	supp.3
Category 2: Material re-use potential			
Soil-like natural materials:	Unsuitable.	342	supp.3
Category 3: Adverse soil behaviour			
Collapse settlement:	Slight risk.	22	2A
Shallow groundwater / seepage:	Slight risk.	85	3B
Heave / shrinkage:	Could occur.	305	3C
Consolidation settlement / 'soft clays':	Expected to occur.	549	3D
Erodability and/or dispersion:	Could occur.	278	2E
Waterlogged:	Slight risk.	31	3L
Category 4: Excavatability problems			
Engineering service trenches:	Could occur.	367	2F
Roads & foundation trenches:	Slight risk.	75	
	Refer to Table 5.6 and Table 5.7	Refer to Table 5.9	Refer to section 5.4.1

Figure 6.21: Case study 2: Results of a SEG assessment conducted for foot slopes located within Land Type Bc25 (based on data from Figure 6.20) for candidate site 1.

- SEG-X Soils that undergo prolonged saturation (6%), comprising:

  Rensburg (g) and Willowbrook (h) soil forms where the soil horizons contain between 35 and 60% clay, between 0.5 and 0.9 m thick, overlying gleyed material.

- SEG-VIII Shallow lithic soils (4.5%), comprising:

  Glenrosa (c) soil form where the topsoil contains between 10 and 25% clay, up to 0.2 m thick, overlying saprolite.

- SEG-IV Weakly structured clayey soils (not gleyed) (1%), comprising:
  Shortlands (n) soil form with topsoil exhibiting 20 to 40% clay and between 30 and 55% clay at depth, between 0.3 and 1.2 m thick, underlaid by either saprolite, or weathered bedrock.

The available geological and geotechnical information was utilised to allocate AGE prominences, expressed as its inferred contribution to the overall geotechnical character of each relevant SEG based on previously discussed principles (Table 5.2), namely:

- Allocated AGE prominences for SEGs occurring along the foot slope:
  - SEG-I Apedal soils
    Category 1: Poor trafficability
    ‘Sticky’/ Slippery conditions when wet: 5 - strong contribution.
    Loss of cohesion when wet: 5 - strong contribution.
    Category 2: Materials re-use potential
    Soil-like natural materials: 3 - unlikely to be suitable.
    Category 3: Adverse soil behaviour
    Collapse settlement: 1 - nearly neglectable contribution.
    Heave / shrinkage: 2 - very slight contribution.
    Consolidation / ‘soft clays’: 5 - strong contribution.
    Erodibility: 2 - very slight contribution.
    Category 4: Excavatability problems
    Engineering service trenches: 1 - nearly neglectable contribution.
  - SEG-IV Weakly structured clayey soils (not gleyed)
    Category 1: Poor trafficability
    ‘Sticky’/ Slippery conditions when wet: 7 - very significant contribution.
    Loss of cohesion when wet: 5 - strong contribution.
    Category 2: Materials re-use potential
    Soil-like natural materials: 4 - unsuitable.

Category 3: Adverse soil behaviour

- Heave / shrinkage: 5 - strong contribution.
- Consolidation / 'soft clays': 7 - very significant contribution.
- Erodibility: 2 - very slight contribution.

Category 4: Excavatability problems

- Engineering service trenches: 1 - nearly negligible contribution.

- SEG-VI Moderately to strongly structured clayey soils

Category 1: Poor trafficability

- 'Sticky'/ Slippery conditions when wet: 7 - very significant contribution.
- Loss of cohesion when wet: 5 - strong contribution.

Category 2: Materials re-use potential

- Soil-like natural materials: 4 - unsuitable.

Category 3: Adverse soil behaviour

- Heave / shrinkage: 7 - very significant contribution.
- Consolidation / 'soft clays': 5 - strong contribution.
- Erodibility: 2 - very slight contribution.

Category 4: Excavatability problems

- Engineering service trenches: 3 - slight contribution.

- SEG-VII Outcrops / sub-outcrops of rock and hard pedocretes

Category 1: Poor trafficability

- Boulders at surface: 2 - very slight contribution.
- 'Sticky'/ Slippery conditions when wet: 5 - strong contribution.
- Loss of cohesion when wet: 3 - slight contribution.

Category 2: Materials re-use potential

- Soil-like natural materials: 4 - unsuitable.

Category 3: Adverse soil behaviour

- Consolidation / 'soft clays': 3 - slight contribution.

Category 4: Excavatability problems

- Engineering service trenches: 6 - significant contribution.
- Road and foundation trenches: 6 - significant contribution.

- SEG-VIII Shallow lithic soils

Category 1: Poor trafficability

- 'Sticky'/ Slippery conditions when wet: 5 - strong contribution.
- Loss of cohesion when wet: 3 - slight contribution.

Category 2: Materials re-use potential

- Soil-like natural materials: 3 - unlikely to be suitable.

Category 3: Adverse soil behaviour

Consolidation / 'soft clays': 5 - strong contribution.

Erodibility: 2 - very slight contribution.

Category 4: Excavatability problems

Engineering service trenches: 6 - significant contribution.

Road and foundation trenches: 2 - very slight contribution.

- SEG-IX Soils that undergo periodic saturation

Category 1: Poor trafficability

'Sticky'/ Slippery conditions when wet: 5 - strong contribution.

Loss of cohesion when wet: 7 - very significant contribution.

Category 2: Materials re-use potential

Soil-like natural materials: 3 - unlikely to be suitable.

Category 3: Adverse soil behaviour

Shallow groundwater / seepage: 3 - slight contribution.

Consolidation / 'soft clays': 5 - strong contribution.

Erodibility and/ or dispersion: 2 - very slight contribution.

Category 4: Excavatability problems

Engineering service trenches: 3 - slight contribution.

Road and foundation trenches: 2 - very slight contribution.

- SEG-X Soils that undergo prolonged saturation

Category 1: Poor trafficability

'Sticky'/ Slippery conditions when wet: 7 - very significant contribution.

Loss of cohesion when wet: 7 - very significant contribution.

Category 2: Materials re-use potential

Soil-like natural materials: 4 - unsuitable.

Category 3: Adverse soil behaviour

Shallow groundwater / seepage: 5 - strong contribution.

Heave / shrinkage: 7 - very significant contribution.

Consolidation / 'soft clays': 5 - strong contribution.

Erodibility and/ or dispersion: 3 - slight contribution.

Waterlogged: 3 - slight contribution.

Category 4: Excavatability problems

Engineering service trenches: 1 - nearly negligible contribution.

The allocated AGE prominence value within each SEG were used to calculate AGE severity values and AGE impact realisation values, as provided in the lower portion of Figure 6.21, to express the inferred geotechnical characteristics for the site based on previously discussed principles. Using these results, the following flag issues of a geological, geotechnical, and geomorphological nature according to Partridge *et al*. (1993) and supplemental parameters were subsequently identified, as highlighted in Table 6.6, namely:

- Flag issues for foot slope within Land Type Bc25:
  - Highly localised boulders could occur at the surface that could hamper the movement of some vehicles in this area, as evidenced by:

    AGE severity value: 2% (indicating one coloured segment), and
    AGE impact realisation value: 1 out of a maximum of 50.
    Classification (supplemental): 2_{supp} - intermediate.

  - There is a high risk that the topsoil covering the area will become slippery during and after precipitation events, and as such would hamper the movement of mainly wheeled vehicles, as evidenced by:

    AGE severity value: 81% (indicating four coloured segments), and
    AGE impact realisation value: 81 out of a maximum of 100.
    Classification (supplemental): 3_{supp} - least favourable.

  - The soil-like overburden covering the area is expected to undergo loss of cohesion under loading or during and after precipitation events, and as such would hamper the movement of most vehicles, as evidenced by:

    AGE severity value: 77% (indicating four coloured segments), and
    AGE impact realisation value: 115 out of a maximum of 150.
    Classification (supplemental): 3_{supp} - least favourable.

  - The clayey nature of the soil-like natural materials in this area severely limits its suitability for re-use, as evidenced by:

    AGE severity value: 85% (indicating one coloured segment), and
    AGE impact realisation value: 342 out of a maximum of 400.
    Classification (supplemental): 3_{supp} - least favourable.

  - Localised pockets of more sandy topsoil in excess of 0.75 m thick could undergo a degree of collapse, as evidenced by:

    AGE severity value: 4% (indicating one coloured segment), and
    AGE impact realisation value: 22 out of a maximum of 600.
    Classification: 2_A - intermediate.

Table 6.6: Case study 2: List of flag issues, obtained from disseminated pedological information by means of the refined SEG system and supplemental information, for candidate site 1 located along a foot slope within Land Type Bc25.

FLAG ISSUES		INFERRED IMPACTS ON DEVELOPMENT **According to** Partridge *et al.* (1993)**, supplemented where indicated, based on AGE severity values.**		
		1 - Most favourable	2 - Intermediate	3 - Least favourable
CATEGORY 1 - POOR TRAFFICABILITY	**Occurrence of boulders at the surface,** hampers movement of all types of vehicle.		2_{supp}: Boulders expected at the surface / scattered bedrock outcrops expected to occur.	
	'Sticky' / slippery conditions when wet, hampers movement of mainly wheeled vehicles.			3_{supp}: 'Sticky' / slippery conditions expected at all times.
	Topsoil expected to lose cohesion when saturated / 'quicksand' conditions, e.g., liquefaction or 'quicksand' conditions will hamper movement of all types of vehicle.			3_{supp}: Quicksand conditions expected after rain / in inundated areas.
CATEGORY 2 - MATERIALS RE-USE POTENTIAL Natural soil-like overburden.				3_{supp}: Most to all natural materials expected to be unsuitable for re-use.
CATEGORY 3 - ADVERSE SOIL BEHAVIOUR	**Collapse settlement,** under loading or when saturated.		Class 2_A: Potentially collapsible material > 0.75 m thick expected to occur.	
	Groundwater seepage and/ or waterlogging.		Class 2_B: Seepage associated with permanent or perched water tables expected at a depth of < 1.5 m.	
	Heave / shrinkage, with changes in moisture content.			Class 3_C: High soil-heave expected, with an AGE impact realisation value of > 280.
	Compressibility / 'soft clays', under loading or when saturated.			Class 3_D: High soil compressibility expected, with an AGE impact realisation value of > 300.
	Erodibility / dispersion, dispersive soils / non-cohesive material along steep slopes or within areas where concentrated surface flow occurs.		Class 2_E: Intermediate, with an AGE impact realisation value of > 135 and ≤ 355.	
CATEGORY 4 - EXCAVATABILITY PROBLEMS To a depth of 1.5 m.			Class 2_F: Pockets of bedrock / hardpan pedocrete expected to comprise between 10 and 40% of total profile up to 1.5 m, with an AGE impact realisation value of ≥ 100 and ≤ 400.	
CATEGORY 5 - MISCELLANEOUS GEOLOGICAL, GEOTECHNICAL & GEOMORPHOLOGICAL FACTORS	**Undermining,** risk of surface instability / differential settlement.			
	Dolomite land, risk of sinkholes and/or subsidences, with details regarding Inherent Hazard Classes (IHC) provided in Part 2 of SANS 1936 (2012).			
	Very gentle slopes to nearly flat-lying areas, periodic ponding of surface water possible, wet engineering services prone to blockage.		Class 2_I: Slopes of < 2˚.	
	Steep slopes, more complex construction work indicated.			
	Unstable natural slopes, based on the results of a slope analysis, risk of possible slope failure.			
	Seismicity, details regarding seismic hazard provided in Part 4 of SANS 10160 (2009).		Class 2_K: Area exhibiting a risk of mining-induced seismicity with a peak ground acceleration of > 100 cm/s^2.	
	Periodic flooding, mainly based on geospatial setting of the area.			Class 3_L: Periodic flooding expected due to location within surface water courses.
	Other adverse characteristics (soil and/ or strata), e.g., self-mulching, slaking, 'Southern Cape Condensation Problem Area', etc.			

- There is a slight risk of an accumulation of groundwater at a depth of less than 1.5 m within the soil-like overburden after heavy precipitation events, as evidenced by:

  AGE severity value: 14% (indicating one coloured segment), and
  AGE impact realisation value: 85 out of a maximum of 600.
  Classification: 2_B - intermediate.

- The predominantly clay-rich soil-like overburden is expected to undergo a degree of heave and shrinkage with changes in moisture content, as evidenced by:

  AGE severity value: 44% (indicating two coloured segments), and
  AGE impact realisation value: 305 out of a maximum of 700.
  Classification: 3_C - least favourable.

- The soil-like overburden is expected to undergo consolidation under loading or when saturated, as evidenced by:

  AGE severity value: 69% (indicating three coloured segments), and
  AGE impact realisation value: 549 out of a maximum of 800.
  Classification: 3_D - least favourable.

- The soil-like overburden could be prone to erosion, as evidenced by:

  AGE severity value: 31% (indicating two coloured segments), and
  AGE impact realisation value: 278 out of a maximum of 900.
  Classification: 2_E - intermediate.

- The portion located within the 1 in 50 year flood line could undergo occasional waterlogging after heavy precipitation events, as evidenced by:

  AGE severity value: 3% (indicating one coloured segment), and
  AGE impact realisation value: 31 out of a maximum of 1 200.
  Classification: 3_L - least favourable.

- It is possible that problems could be encountered during the excavation of engineering service trenches (or graves) in highly localised areas, as evidenced by:

  AGE severity value: 37% (indicating two coloured segments), and
  AGE impact realisation value: 367 out of a maximum of 1 000.
  Classification: 2_F - intermediate.

- It is possible that problems could be encountered during the excavation of roads and foundation trenches in very highly localised areas only, as evidenced by:

  AGE severity value: 7% (indicating one coloured segment), and
  AGE impact realisation value: 75 out of a maximum of 1 100.
  Classification: Not applicable.

- The available topographical information indicated that natural slopes of less than 2° can be expected, indicating:

  Classification: 2_I - intermediate.

- The regional seismic risk was considered to be intermediate with a risk of possible mining-induced seismicity, indicating:

  Classification: 2_K - intermediate.

- The location of this terrain unit within a floodplain of a known perennial river, and with slopes of less than 1% (approximately 0.5°), indicates a seasonal risk of localised flooding after heavy precipitation events.

  Classification: 3_L - least favourable.

6.3.2.1 Summarised geological, geotechnical, and geomorphological character of candidate site 1

The summarised geological, geotechnical, and geomorphological character of candidate site 1 can be expressed as follows according to the parameters defined by Partridge *et al*. (1993) (Table 2.5 with results from Table 6.6):

$2_{A,B,E,F,I,K}$ $3_{C,D,L}$.

Ranking of the resultant geological, geotechnical, geomorphological, and hydrological characteristics resulting from the PSGI according to the parameters proposed by Hall and Hanbury (1990) is provided in Table 6.7, with the following scores allocated:

- Excavatability - machine required: Partridge *et al*. (1993) class 2_F indicated: 5
- Excavation stability - unstable: Partridge *et al*. (1993) class 2_A indicated: 1
- Workability - very poor: Partridge *et al*. (1993) class 3_D and Material re-use 3_{supp} indicated: 0
- Water table - Partridge *et al*. (1993) classes 2_B and 3_L indicated: FAIL
- Subsoil permeability - impermeable: overall clay content more than 10% indicated: 15
- Backfill permeability - impermeable: overall clay content more than 10% indicated: 5

A resultant score total of only 26 was obtained, with the flagging of an inferred risk of occasional flooding considered to indicate unacceptable conditions.

Table 6.7: Case study 2: Suitability ranking of candidate site 1 according to Hall and Hanbury (1990) using results of an PSGI based on the parameters by Dippenaar *et al*., 2018).

PERCEIVED IMPACTS ON THE NATURAL ENVIRONMENT after Hall & Hanbury (1990), and Dippenaar *et al*. (2018).	**SUITABILITY ASSESSMENT** Based on flag issues and supplemental information provided Table 6.6 and Figure 6.21.	
EXCAVATABILITY	ASSESSMENT	SCORE
Easy spade:		
Pick and spade:		
Machine:	Partridge *et al*. (1993) class 2_F indicated.	5
Blasting:		
EXCAVATION STABILITY	ASSESSMENT	SCORE
Stable:		
Overbreak:		
Slightly unstable:		
Unstable:	Partridge *et al*. (1993) class 2_A indicated.	1
WORKABILITY	ASSESSMENT	SCORE
Excellent to good:		
Fair:		
Poor:		
Very poor:	Partridge *et al*. (1993) class 3_D and Material re-use 3_{supp} indicated.	0
WATER TABLE	ASSESSMENT	SCORE
Deep water table:		
Intermediate water table:		
Possible perched water table:	Perched water table, Partridge *et al*. (1993) class 2_B indicated.	
Waterlogged soil:	Partridge *et al*. (1993) class 2_B and 3_L indicated.	FAIL
SUBSOIL PERMEABILITY	ASSESSMENT	SCORE
Impermeable:	Overall: clay content in excess of 10% inferred.	15
Relatively impermeable:		
Relatively permeable:	Very highly localised pockets of soils containing ± 4% clay inferred.	
Permeable:		
BACKFILL PERMEABILITY	ASSESSMENT	SCORE
Impermeable:	Overall: clay content in excess of 10% inferred.	5
Relatively impermeable:		
Relatively permeable:	Very highly localised pockets of soils containing ± 4% clay inferred.	
Very permeable:		
	TOTAL SCORE:	FAIL

< 60: Unacceptable	60 - 75: Poor	70 - 90: Satisfactory	> 90: Very good

6.3.3 Characterisation and refined SEG system results of candidate site 2

A vacant plot of land located along a mid-slope exhibiting an average slope of approximately 1.5° (gently sloping) to the east directly to the east of an informal settlement occurring to the west of the Dassierand suburb of Potchefstroom was selected as the second candidate site (Figure 6.15). The weakly defined floodplain of a non-perennial stream occurs approximately 450 m to the northeast of the site (Figure 6.15) and is not considered to have any effect on the character of the site itself.

The published 1:250 000 scale 2626 West Rand (CGS, 1980) geological map indicates that the site is underlaid by ferruginous quartzite of the Timeball Hill Formation that forms part of the Pretoria Group, Transvaal Supergroup (Figure 6.22). Scattered bedrock outcrops are visible on the satellite image in the direct vicinity of the candidate site (Figure 6.22).

It must be noted that dolomitic strata indicated to occur to the west of the site are not considered to have any bearing on the character of the candidate site, with the results of drilling work conducted at the Potchefstroom waste disposal facility located in a similar geological regime to the southwest of the candidate site indicated the presence of non-dolomitic strata (Figure 6.22). This is corroborated by Meintjes (2015b) who states that vertical displacement of strata of up to 200 m have been encountered along faults that define the eastern extent of the dolomitic strata.

The static groundwater level is expected to occur at a depth of between 28.3 and 29.5 m beneath ground surface in the area, as encountered during a previous geohydrological investigation at the Potchefstroom waste disposal facility located downslope of the site (Godfrey & Meyer, 2001).

According to the published 1:250 000 scale 2626 West Rand (ISCW, 1985) land map, the site is covered by soils within Land Type Fa14 (Figure 6.23), generally typified by the presence of shallow, lime-poor, rocky soils (i.e., mainly Glenrosa and Mispah soil forms). Figure 6.24 provides information regarding the regional soils and soil/ rock complexes for mid slopes within Land Type Fa14.

Utilising the refined SEG system to disseminate the pedological information (Figure 6.24) based on previously discussed principles, yielded the following, as detailed in Figure 6.25 with the relevant data entries as annotated on the left, namely:

- Mainly:
  - SEG-I Apedal soils (47%), comprising:

    Hutton (d) soil form containing between 10 and 25% clay in the topsoil, and between 13 and 30% in the sub-surface layers, between 0.25 and more than 1.2 m thick, underlaid by saprolite and/ or weathered bedrock.

Figure 6.22: Case study 2: Regional geological map for candidate site 2, based on the published 1:250 000 scale 2626 West Rand (CGS, 1980) geological map.

Figure 6.23: Case study 2: Spatial distribution of land types for candidate site 2 according to the 1:250 000 scale 2626 West Rand (ISCW, 1985) land type map, overlaid onto a satellite image.

LAND TYPE / *LANDTIP* ....: Fa14
CLIMATE ZONE *KLIMAATSONE* ...... : 19S
Area / *Oppervlakte* .... : 79950 ha
Estimated area unavailable for agriculture
Beraamde oppervlakte onbeskikbaar vir landbou : 2200 ha

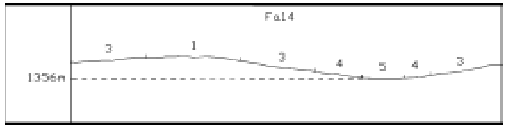
Occurrence (maps) and areas *Voorkoms (kaarte) en oppervlakte* :
2626 Wes-Rand (79950 ha)

Inventory by *Inventaris deur* :
R W Bruce
Modal Profiles *Modale profiele* :
P215 P217

		Mid slope		
Terrain uni *Terreineenhei*	1	3	4	5
% of land type *% van landtipe*	25	60	10	5
Area *Oppervlakte (ha)*	19988	47970	7995	3998
Slope / *Helling (%)*	0 - 2	2 - 5	1 - 2	0 - 1
Slope length *Hellingslengte (m)*	400 - 600	800 - 1200	400 - 600	40 - 60
Slope shape *Hellingsvorm*	Y	Z-Y	Z-X	X
MB0, MB1 (ha)	2398	22546	3998	3198
MB2 - MB4 (ha)	17589	25424	3998	800

	Soil series or land classes *Grondseries of landklasse*	Depth *Diepte* (mm)	MB	ha	%	ha	%	ha	%	ha	%	Total *Totaal* ha	%	Clay content % *Klei-inhoud %* A	E	B21	Texture *Tekstuur* Hor	Class / *Klas*	Depth limiting material *Diepte-beperkende materiaal*
	Soil-rock complex																		
	Grond-rotskompleks:																		
a	Rock/Rots		4	3198	16	3358	7	1359	17	240	6	8155	10.2						
b,c	Mispah Ms10, Klipfontein Ms11, Platt Gs14, Glenrosa Gs15, Trevanian Gs17	100-150	3	14391	72	22066	46	2638	33	560	14	39655	49.6	10-20			A	me/coSaLm	so,R,hp
d	Msinga Hu26, Hutton Hu16, Clansthal Hu24, Lichtenburg Hu23	250-1200+	0	2399	12	22546	47	3998	50	1599	40	30541	38.2	10-25		13-30	B	meSaLm-SaClLm	R,so
	Devon We22, Newport Cv27, Southwold Cv26, Avalon Av26, Chinyika Wo21	250-1200+	0							1599	40	1599	2.0	20-40					

Terrain type *Terreintipe* : A2
Terrain form sketch *Terreinvormskets*



For an explanation of this table consult LAND TYPE INVENTORY (table of contents)
Ter verduideliking van hierdie tabel kyk LANDTIPE - INVENTARIS (inhoudsopgawe)

Geology: Dolomite and chert of the Chuniespoort Group; chert gravels are abundant on middle and footslopes including valley bottoms.

Geologie Dolomiet en chert van die Groep Chuniespoort; chertgruise is volop op middelhange en voethange asook valleivloere.

1

Figure 6.24: Case study 2: Land type memoir for Land Type Fa14 that defines the regional soils distribution for candidate site 2. Information for mid slopes is highlighted and the relevant data entries annotated.

ASSESSMENT OF INFERRED GEOTECHNICAL CHARACTERISTICS UTILISING LAND TYPE INFORMATION

LAND TYPE: Fa14

Terrain unit: Mid Slopes

Prominence: Prevalent (60 %)

Predominantly: > 69 % of terrain unit.
Mainly: 40 - 69 % of terrain unit.
Localised pockets: 20 - 39 % of terrain unit.
Highly localised pockets: 10 - 19 % of terrain unit.
Very highly localised pockets: < 10 % of terrain unit.

	SEG-I Apedal soils	SEG-II Relatively unconsolidated soils	SEG-III Pedogenic soils	SEG-IV Weakly structured soils (not gleyed)	SEG-V Dual character soils (not gleyed)	SEG-VI Moderately to strongly structured soils	SEG-VII Outcrops / sub-outcrops of rock & hard pedocretes	SEG-VIII Shallow lithic soils	SEG-IX Soils that undergo periodic saturation	SEG-X Soils that undergo prolonged saturation
SOIL FORMS:	Hutton						Mispah Rock	Glenrosa		
TOTAL SEG PROMINENCES as % of terrain unit	47 Mainly						30 Localized pockets	23 Localized pockets		
DEPTH EXTENT in meters (Depth of foundation trenches (0.3 m); Minimum; Maximum; Depth of bulk service trenches (1.5 m))										
Depth ranges: (diagnostic horizons only)	0.25 - 1.2 m+						No soil - 0.15 m	0.1 - 0.15 m		
UNDERLAIN BY as % of terrain unit — Rock: 42 %	23.5						18.5			
Hardpan ferricrete: 11.5 %							11.5			
Hardpan pedocrete (other):										
Lithic / saprolite: 46.5 %	23.5							23.0		
Soft pedocrete:										
Moderately to strongly structured soil:										
Gleyed / wet material:										
Unconsolidated material:										
Organic-rich material:										
Miscelaneous soil layers:										
Unspecified:										
STONINESS as % of terrain unit — No mechanical limitations: 47 %	47.0									
Many stones, but ploughable:										
Large stones & boulders, unploughable:										
Very shallow soil on rock: 46 %							23.0	23.0		
Lack of soil: 7 %							7.0			
CLAY CONTENT — Range - topsoil horizons:	10 - 25 %						< 20 %	10 - 20 %		
Range - material at depth:	13 - 30 %									
Possible duplex soils (15 %+ increase in clay with depth):										

OTHER MATERIALS / FEATURES: SEG-XI peat/ organic soil | SEG-XII man-made soil | Stream channels | Erosion dongas | Other (pans. etc.)

PRELIMINARY GEOTECHNICAL ASSESSMENT

Adverse geotechnical effect (AGE) parameters	AGE severity assessment	AGE impact realisation assessment (with bar length indicating % realisation)	Geotechnical classification according to SANS 634 (2012) & supplemental (supp.) (1 - Most favourable; 2 - Intermediate; 3 - Least favourable)
Category 1: Poor trafficability			
Boulders at surface:	Slight risk.	6	supp.2
'Sticky'/slippery conditions when wet:	Could occur.	43	supp.2
Loss of cohesion when wet / 'quicksand':	Expected to occur.	94	supp.2
Category 2: Material re-use potential			
Soil-like natural materials:	Unsuitable.	377	supp.3
Category 3: Adverse soil behaviour			
Collapse settlement:			
Shallow groundwater / seepage:			
Heave / shrinkage:			
Consolidation settlement / 'soft clays':	Could occur.	274	2D
Erodability and/or dispersion:	Could occur.	189	2E
Waterlogged:			
Category 4: Excavatability problems			
Engineering service trenches:	Expected to occur.	657	3F
Roads & foundation trenches:	Could occur.	346	
	Refer to Table 5.6 and Table 5.7	Refer to Table 5.9	Refer to section 5.4.1

Figure 6.25: Case study 2: Results of a SEG assessment conducted for mid slopes located within Land Type Fa14 (based on data from Figure 6.24) for candidate site 2.

- Localised pockets:
  - SEG-VII Outcrops/ sub-outcrops of rock and/ or pedocrete (30%), comprising:
    scattered bedrock outcrops (a), and Mispah (b) soil form exhibiting topsoil with a clay content of up to 20%, up to 0.15 m thick, overlying weathered bedrock or hardpan ferricrete.
  - SEG-VIII Shallow lithic soils (23%), comprising:
    Glenrosa (c) soil form where the topsoil contains between 10 and 20% clay, up to 0.15 m thick, overlying saprolite.

AGE prominences, expressed as its inferred contribution to the overall geotechnical character of each relevant SEG (Table 5.2), were subsequently assigned as shown in the lower portion of Figure 6.25, based on the available geological and geotechnical information, namely:

- Allocated AGE prominences for SEGs occurring along the foot slope:
  - SEG-I Apedal soils

    Category 1: Poor trafficability

'Sticky'/ Slippery conditions when wet:	3 - slight contribution.
Loss of cohesion when wet:	5 - strong contribution.

    Category 2: Materials re-use potential

Soil-like natural materials:	4 - unsuitable.

    Category 3: Adverse soil behaviour

Consolidation / 'soft clays':	3 - slight contribution.
Erodibility:	2 - very slight contribution.

    Category 4: Excavatability problems

Engineering service trenches:	4 - moderate contribution.
Road and foundation trenches:	1 - nearly neglectable contribution.

  - SEG-VII Outcrops / sub-outcrops of rock and hard pedocretes

    Category 1: Poor trafficability

Boulders at surface:	3 - slight contribution.
'Sticky'/ Slippery conditions when wet:	3 - slight contribution.
Loss of cohesion when wet:	3 - slight contribution.

    Category 2: Materials re-use potential

Soil-like natural materials:	4 - unsuitable.

    Category 3: Adverse soil behaviour

Consolidation / 'soft clays':	1 - nearly neglectable contribution.
Erodibility:	1 - nearly neglectable contribution.

Category 4: Excavatability problems

Engineering service trenches: 6 - significant contribution.

Road and foundation trenches: 6 - significant contribution.

- SEG-VIII Shallow lithic soils

  Category 1: Poor trafficability

  ‘Sticky’/ Slippery conditions when wet: 5 - strong contribution.

  Loss of cohesion when wet: 3 - slight contribution.

  Category 2: Materials re-use potential

  Soil-like natural materials: 3 - unlikely to be suitable.

  Category 3: Adverse soil behaviour

  Consolidation / ‘soft clays’: 5 - strong contribution.

  Erodibility: 2 - very slight contribution.

  Category 4: Excavatability problems

  Engineering service trenches: 6 - significant contribution.

  Road and foundation trenches: 2 - very slight contribution.

These results were then used to calculate AGE severity values and AGE impact realisation values to express the inferred geotechnical character of the site as a whole, as provided in the lower portion of Figure 6.25, based on previously discussed principles. The following flag issues of a geological, geotechnical, and geomorphological nature according to Partridge *et al*. (1993) and supplemental parameters could be identified for candidate site 2, as highlighted in Table 6.8, namely:

- Flag issues for mid slope within Land Type Fa14:
  - Highly localised boulders could occur at the surface that could hamper the movement of some vehicles in this area, as evidenced by:

    AGE severity value: 13% (indicating one coloured segment), and

    AGE impact realisation value: 6 out of a maximum of 50.

    Classification (supplemental): 2_{supp} - intermediate.
  - The topsoil covering the area could become slippery during and after precipitation events, and as such could hamper the movement of mainly wheeled vehicles, as evidenced by:

    AGE severity value: 43% (indicating two coloured segments), and

    AGE impact realisation value: 43 out of a maximum of 100.

    Classification (supplemental): 2_{supp} - intermediate.
  - The soil-like overburden covering the area is expected to undergo loss of cohesion under loading or during and after precipitation events, and as such would hamper the movement of most vehicles during construction, as evidenced by:

Table 6.8: Case study 2: List of flag issues, obtained from disseminated pedological information by means of the refined SEG system and supplemental information, for candidate site 2 located along a mid-slope within Land Type Fa14.

FLAG ISSUES		INFERRED IMPACTS ON DEVELOPMENT **According to** Partridge *et al.* (1993)**, supplemented where indicated, based on AGE severity values.**		
		1 - Most favourable	2 - Intermediate	3 - Least favourable
CATEGORY 1 - POOR TRAFFICABILITY	**Occurrence of boulders at the surface,** hampers movement of all types of vehicle.		2_{supp}: Boulders expected at the surface / scattered bedrock outcrops expected to occur.	
	'Sticky' / slippery conditions when wet, hampers movement of mainly wheeled vehicles.		2_{supp}: 'Sticky' / slippery conditions expected after rain.	
	Topsoil expected to lose cohesion when saturated / 'quicksand' conditions, e.g., liquefaction or 'quicksand' conditions will hamper movement of all types of vehicle.		2_{supp}: Topsoil expected to lose cohesion when saturated.	
CATEGORY 2 - MATERIALS RE-USE POTENTIAL Natural soil-like overburden.				3_{supp}: Most to all natural materials expected to be unsuitable for re-use.
CATEGORY 3 - ADVERSE SOIL BEHAVIOUR	**Collapse settlement,** under loading or when saturated.			
	Groundwater seepage and/ or waterlogging.			
	Heave / shrinkage, with changes in moisture content.			
	Compressibility / 'soft clays', under loading or when saturated.		Class 2_D: Moderate soil compressibility expected, with an AGE impact realisation value of > 100 and ≤ 300.	
	Erodibility / dispersion, dispersive soils / non-cohesive material along steep slopes or within areas where concentrated surface flow occurs.		Class 2_E: Intermediate, with an AGE impact realisation value of > 135 and ≤ 355.	
CATEGORY 4 - EXCAVATABILITY PROBLEMS To a depth of 1.5 m.				Class 3_F: Bedrock / hardpan pedocrete expected to comprise > 40% of total profile up to 1.5 m, with an AGE impact realisation value of > 400.
CATEGORY 5 - MISCELLANEOUS GEOLOGICAL, GEOTECHNICAL & GEOMORPHOLOGICAL FACTORS	**Undermining,** risk of surface instability / differential settlement.			
	Dolomite land, risk of sinkholes and/or subsidences, with details regarding Inherent Hazard Classes (IHC) provided in Part 2 of SANS 1936 (2012).			
	Very gentle slopes to nearly flat-lying areas, periodic ponding of surface water possible, wet engineering services prone to blockage.		Class 2_I: Slopes of < 2˚.	
	Steep slopes, more complex construction work indicated.			
	Unstable natural slopes, based on the results of a slope analysis, risk of possible slope failure.			
	Seismicity, details regarding seismic hazard provided in Part 4 of SANS 10160 (2009).		Class 2_K: Area exhibiting a risk of mining-induced seismicity with a peak ground acceleration of > 100 cm/s^2.	
	Periodic flooding, mainly based on geospatial setting of the area.			
	Other adverse characteristics (soil and/ or strata), e.g., self-mulching, slaking, 'Southern Cape Condensation Problem Area', etc.			

AGE severity value: 63% (indicating three coloured segments), and
AGE impact realisation value: 94 out of a maximum of 150.
Classification (supplemental): 2_{supp} - intermediate.

- The clayey nature of the soil-like natural materials in this area limits its' suitability for re-use, as evidenced by:
  AGE severity value: 94% (indicating one coloured segment), and
  AGE impact realisation value: 377 out of a maximum of 400.
  Classification (supplemental): 3_{supp} - least favourable.
- The soil-like overburden could undergo slight consolidation under loading or when saturated, as evidenced by:
  AGE severity value: 34% (indicating two coloured segments), and
  AGE impact realisation value: 274 out of a maximum of 800.
  Classification: 2_D - least favourable.
- The soil-like overburden could be prone to erosion, as evidenced by:
  AGE severity value: 21% (indicating one coloured segment), and
  AGE impact realisation value: 189 out of a maximum of 900.
  Classification: 2_E - intermediate.
- It is expected that problems could be encountered during the excavation of engineering service trenches (or graves) throughout the area, as evidenced by:
  AGE severity value: 66% (indicating three coloured segments), and
  AGE impact realisation value: 657 out of a maximum of 1 000.
  Classification: 3_F - least favourable.
- It is possible that problems could be encountered during the excavation of roads and foundation trenches in very highly localised areas only, as evidenced by:
  AGE severity value: 31% (indicating two coloured segments), and
  AGE impact realisation value: 346 out of a maximum of 1 100.
  Classification: Not applicable.
- The available topographical information indicated that natural slopes of less than 2° can be expected, indicating:
  Classification: 2_I - intermediate.
- The regional seismic risk was considered to be intermediate with a risk of possible mining-induced seismicity, indicating:
  Classification: 2_K - intermediate.

- The location of this site far from known surface drainage features (e.g., streams or floodplains) indicates a low risk of seasonal surface flooding.

  Classification: Not applicable.

6.3.3.1 Summarised geological, geotechnical, and geomorphological character of candidate site 2

The summarised geological, geotechnical, and geomorphological character of candidate site 2 can be expressed as follows according to the parameters proposed by Partridge *et al*. (1993) (Table 2.5 with results from Table 6.8):

$2_{D,E,I,K}$ 3_F.

The resultant geological, geotechnical, geomorphological, and hydrological characteristics resulting from the PSGI were subsequently ranked according to the parameters proposed by Hall and Hanbury (1990), as shown in Table 6.9, with the following scores allocated:

- Excavatability - blasting required: Partridge *et al*. (1993) class 3_F indicated: 0
- Excavation stability - overbreak: saprolite and weathered bedrock expected at depth: 15
- Workability - poor: Partridge *et al*. (1993) class 2_D indicated: 2
- Water table - static groundwater level in excess of 8 m indicated: 25
- Subsoil permeability - impermeable: clay content more than 10% indicated: 15
- Backfill permeability - impermeable: clay content more than 10% indicated: 5

The resultant score total of 62 indicate that this candidate site is considered poorly suited for the establishment of a cemetery.

6.3.4 Discussion of results with regard to site selection

In the light of the ranking of the various parameters proposed by Hall and Hanbury (1990) and Dippenaar *et al*. (2018), the following is evident regarding the geotechnical character exhibited by each of the candidate sites:

- Candidate site 1:

  The expected site characteristics (detailed in Table 6.6 and ranked in Table 6.7) indicate intermediately favourable excavatability as a result of the inferred presence of relatively thick soil-like overburden, with favourable subsoil and backfill permeability as a result of a high clay content.

Table 6.9: Case study 2: Suitability ranking of candidate site 2 according to Hall and Hanbury (1990) using results of an PSGI based on the parameters by Dippenaar *et al*., 2018).

PERCEIVED IMPACTS ON THE NATURAL ENVIRONMENT after Hall and Hanbury (1990), and Dippenaar *et al*. (2018).	**SUITABILITY ASSESSMENT** Based on flag issues and supplemental information provided in Table 6.8 and Figure 6.25.	
EXCAVATABILITY	ASSESSMENT	SCORE
Easy spade:		
Pick and spade:		
Machine:		
Blasting:	Partridge *et al*. (1993) class 3_F indicated.	0
EXCAVATION STABILITY	ASSESSMENT	SCORE
Stable:		
Overbreak:	Saprolite and/ or weathered bedrock expected at depth.	15
Slightly unstable:		
Unstable:		
WORKABILITY	ASSESSMENT	SCORE
Excellent to good:		
Fair:		
Poor:	Partridge *et al*. (1993) class 2_D indicated.	2
Very poor:		
WATER TABLE	ASSESSMENT	SCORE
Deep water table:	> 8 m indicated.	25
Intermediate water table:		
Possible perched water table:		
Waterlogged soil:		
SUBSOIL PERMEABILITY	ASSESSMENT	SCORE
Impermeable:	Overall: clay content in excess of 10% inferred.	15
Relatively impermeable:		
Relatively permeable:		
Permeable:		
BACKFILL PERMEABILITY	ASSESSMENT	SCORE
Impermeable:	Overall: clay content in excess of 10% inferred.	5
Relatively impermeable:		
Relatively permeable:		
Very permeable:		
	TOTAL SCORE:	62

< 60: Unacceptable	60 - 75: Poor	70 - 90: Satisfactory	> 90: Very good

Conversely, excavation stability is considered poor, due to the possible presence of pockets of potentially collapsible material, while the highly compressible and clayey nature of the soil-like overburden indicates very poor workability thereof during backfilling.

However, its location partially within the 1 in 50 year flood line of the Mooi River disqualifies this site from further consideration.

- Candidate site 2:

  The expected site characteristics (detailed in Table 6.8 and ranked in Table 6.9) revealed the presence of weathered bedrock inferred to comprise in excess of 40% of the volume of material to a depth of 1.5 m that is considered a significant impediment that will require advance preparation of rows of graves by means of a heavy mechanical excavator or even blasting.

  Additionally, densification of the potentially moderately compressible soil-like overburden could hamper workability during backfilling of graves. Conversely, the relatively clayey soil is considered to exhibit favourably low subsoil and backfill permeability, while the static groundwater level is expected to occur at a favourable depth.

Given the results of the above-mentioned assessments, it was possible to provide the necessary responses of a geotechnical nature (Table 6.10) required for the BAR process in support of site selection. It is evident that the affirmative responses to the questions regarding the inferred presence of seasonally wet soil and dispersive soil provide a clear distinction between the two candidate sites. When viewed in conjunction with the rankings for each candidate site resulting from the conducting of PSGIs, these responses provide unambiguous guidance to the environmental practitioner and other decision-makers with regard to site selection.

6.3.5 Conclusions: Case study 2

The results of PSGIs conducted by means of the refined SEG system based on disseminated pedological information yielded the necessary information to allow assessment of potentially adverse geotechnical conditions at each candidate site, including excavatability, excavation stability, material workability, the possible presence of perched water tables, and subsoil and backfill permeability. It must be noted that it was possible to conduct both PSGIs in a period of less than a week, thereby allowing the rendering of cost-effective information beneficial to site selection undoubtedly allowing the timeous focussing of resources on the more suitable of the candidate sites for the conducting of specialist studies required for the EIA process.

Table 6.10: List of responses (black background) to questions of a geotechnical nature based on the results of an PSGI conducted for each of the two candidate sites as required for the compilation of a BAR in support of site selection.

QUESTIONS OF A GEOTECHNICAL NATURE AS SPECIALIST INPUT FOR BAR PURPOSES	CANDIDATE SITE 1			CANDIDATE SITE 2		
	RESPONSES		RELEVANT FLAG ISSUES from Table 6.6, and RELEVANT PEDOLOGICAL INFORMATION from Figure 6.21	RESPONSES		RELEVANT FLAG ISSUES from Table 6.8, and RELEVANT PEDOLOGICAL INFORMATION from Figure 6.25
Shallow water table (less than 1.5 m deep):	YES	NO	Class 2_B: Groundwater seepage.	YES	NO	Class 2_B: Groundwater seepage.
Dolomite, sinkhole or doline areas:	YES	NO	Area not indicated to be underlaid by dolomitic strata.	YES	NO	Area not indicated to be underlaid by dolomitic strata.
Seasonally wet soils (often close to water bodies):	YES	NO	Area partially located within a floodplain.	YES	NO	Area not located within floodplain or surface drainage feature.
Unstable rocky slopes or steep slopes with loose soil:	YES	NO	Class 2_I: Nearly flat-lying.	YES	NO	Class 2_I: Very gentle slopes.
Dispersive soils (soils that dissolve in water):	YES	NO	Class 2_E: Moderate risk of dispersion.	YES	NO	Although class 2_E, low risk of dispersion expected.
Soils with a high clay content (clay fraction more than 40%):	YES	NO	Clay content of more than 40% indicated for some of the soil forms within the area.	YES	NO	Clay content of more than 40% indicated for various soil forms within the area.
Any other unstable soil or geological feature:	YES	NO	Class 3_C: Highly active soils, Class 3_D: High compressibility, and Class 2_F: Localised excavatability problems.	YES	NO	Class 2_D: High compressibility, and Class 3_F: Excavatability problems.
An area sensitive to erosion:	YES	NO	Class 2_E: only moderate erodibility indicated along very gentle slope.	YES	NO	Class 2_E: only moderate erodibility indicated along very gentle slope.

Dippenaar *et al*. (2018) state that the influence of other cross-disciplinary factors, such as socio-economic, climatic, ecological, or spatial planning considerations, must also be taken into consideration during site selection. In the author's experience, however, these factors are occasionally given preference over inferred adverse geotechnical characteristics that would otherwise disqualify a specific site, requiring the implementation of specific remediation and precautionary measures to facilitate the proper functioning of such a facility. The proposed establishment of a new cemetery at a village near Lichtenburg where the surrounding countryside is characterised by the occurrence of extensive hardpan calcrete layers overlying dolomite bedrock, without the option of an alternative site exhibiting more suitable conditions, serves as an example (Calitz, 2020b).

CHAPTER 7 CONCLUSIONS AND RECOMMENDATIONS

Based on the stated aims of this study as stated in chapter 1, and in the light of the results of case studies detailed in the previous chapter, the following conclusions can be made:

- This study resulted in the development of a geographical system by which readily available pedological information could be disseminated and combined with geological, geotechnical, hydropedological, and geomorphological information obtained from other sources to render generalised geotechnical characteristics for a study area according to industry-standard parameters. Output obtained from the use of proposed refined Soils Effects Grouping (SEG) system was shown to be successful in describing the regional geotechnical character of areas earmarked for development in a standardised manner in accordance with the relevant industry standards and guidelines. The system also rendered results in a format suitable for use by environmental practitioners. Establishment of the refined SEG system, broadly corresponding to the principles for the interpretation of pedological information for engineering purposes stated by various South African and international pedologists and geopractitioners, as well as the successful implementation of its first edition in practice over more than a decade after publication thereof, is considered proof that the first primary aim of the study has been achieved.
- The principles established during this study allow dissemination of regional soils information classified according to the various soil classification systems of South Africa, mainly provided by the land type maps and memoirs available for most of the spatial extent of the Republic of South Africa, but also that resulting from regional soil mapping surveys according to the Taxonomical and Natural and Anthropogenic Soil Classification System for South Africa from other sources, where available. Standardised procedures were developed to facilitate dissemination of pedological information by geopractitioners who do not necessarily specialise in soil science by providing precise guidelines for ascribing geotechnical characteristics to the various soil forms within the relevant SEGs. It is anticipated that this approach should be sufficient to overcome resistance to the use of regional soils information by geopractitioners, thereby fulfilling the second primary aim of the study.

Achieving the above-mentioned aims of the study relied on the addressing of a number of successive objectives. The various aspects revealed by the reaching of each of these objectives can be summarised as follows:

- The results of a literature study established the regulatory framework that requires the conducting of preliminary stage geotechnical investigations (PSGIs). This framework was used to guide establishment of the proposed geographical system for the dissemination of regional soils information. In this, the following became apparent:

- The industry-standard protocols state that any geotechnical investigation in support of development should commence with a reconnaissance-level assessment, typically conducted to establish the suitability of a specific land parcel with regard to the type of development.
- This type of assessment has to comply with a list of industry-standard geotechnical parameters to be determined by a suitably qualified and experienced geopractitioner.
- The literature study also established the requirements for the provision of geotechnical information for environmental impact assessment processes, in particular the compilation of Basic Assessment Reports (BARs), comprising a list of questions of a geotechnical nature that requires responses by a geopractitioner.
- Sources of regional geotechnical information that include published reports, articles, maps, and memoirs obtainable online or from corporate libraries and the ENGEODE database of the Council for Geoscience, were identified during the study. Additionally, it was established that the currently still spatially limited series of regional geotechnical maps published by the Council for Geoscience provide more detailed regional information. Additionally, the collection of land type maps and associated memoirs based on the Binomial Soil Classification System published by the Institute for Soil, Climate and Water was found to provide pertinent details on soil forms, soil thicknesses, underlying materials, stoniness of the soil-like overburden and the clay content thereof for most of the surface area of South Africa. However, it was quickly established that the nature of the pedological information does not readily allow correlation with the regional geotechnical assessment parameters, and that regional soils mapping information is perceived by geopractitioners to be of importance only for agricultural applications.

- The results of the literature study and that of a critical appraisal of the first version of a system tailor-made for the use of pedological information for the conducting of preliminary stage geotechnical investigations, facilitated development of the refined SEG system. The development process incorporated the following aspects:
  - It was established that terrain units used as primary mapping units during the compilation of the land type maps and memoirs define an ideal basic mapping unit for use when conducting PSGIs.
  - A list of 12 adverse geotechnical effects (AGEs), each considered to have a specific effect on the cost and/ or ease of development, was established and refined. These are based on industry-standard parameters as required by the relevant national guidelines, supplemented by the addition of a number of additional geotechnical parameters regarding trafficability and material re-use potential, with the results of work conducted by

others on the allocation of geotechnical properties to specific soil forms or horizons also considered.

    - Inferred adverse geotechnical characteristics were allocated to the different soil forms comprising the primary South African soil classifications systems, with emphasis on those of the new Natural and Anthropogenic Soil Classification System.
    - The various soil forms were subsequently grouped into soil type categories (STCs) where each STC reflects a specific inferred primary geotechnical character.
    - Weighting of the AGEs and STCs by means of a ranking matrix led to the establishment of 12 Soils Effects Groupings (SEGs) that define the foundation of the proposed geographical system.

- Dissemination of the regional soils information by means of the refined SEG system, and the subsequent output of results relied on the following:
    - An effective data input format was developed to facilitate dissemination of the pedological information in a systematic and practical manner requiring only rudimentary knowledge of the South African soil forms and soil classification systems.
    - Rendering of the disseminated results was achieved by the development of a standardised tabular and diagrammatical format that, with the incorporation of supplemental geological, geotechnical, and geomorphological information, allows grouping of terrain units exhibiting similar geotechnical characteristics into preliminary geotechnical zones. Maps based on these zones create one of the primary products of an PSGI.
    - The inferred geotechnical characteristics exhibited by the natural materials occurring within each preliminary geotechnical zone further define a series of flag issues, considered to be the second primary product of an PSGI, that allows geopractitioners to make informed decisions regarding the suitability of a site for development, especially in cases where other geotechnical information is not available.
    - The results of PSGIs based on the refined SEG system were found to render rapid, cost-effective, and scientifically verifiable responses to the list of generalised questions typically posed by environmental practitioners during the compilation of BARs that form part of the EIA process. These lists define the third primary product of an PSGI.
- A critical appraisal of the efficacy of the proposed refined SEG system in the assessment of the generalised geotechnical character of sites when conducting PSGIs was conducted by means of a number of case studies. These studies focussed on the following real-world scenarios:

- Comparison of the results of an PSGI with that resulting from a detailed geotechnical investigation confirmed that the refined SEG system allowed prediction of the geotechnical characteristics exhibited by the natural materials occurring within the site to a sufficient degree of accuracy. This case study did highlight some shortcomings and limitations inherent to the nature of regional soils information based on the BSCS and desktop-level assessments that should be considered when conducting PSGIs.
- PSGIs utilising the refined SEG system conducted to facilitate comparison between two candidate sites in support of the site selection process for a proposed cemetery were successful in the identification of flag issues and subsequent ranking of the sites. The PSGIs also effectively yielded responses to questions of a geotechnical nature in support of the BAR process.

As previously noted, the proposed refined SEG system was not found to be infallible, and some limitations have been encountered, including:

- It is evident that the depth limit of 1.2 m used during regional soils mapping utilising the BSCS on which the land type inventories are based, hampers accurate interpolation of geotechnical information at depth. Again, area-specific experience of the geopractitioner conducting PSGIs was found to be invaluable in overcoming this limitation.
- The accuracy of the land type boundaries based on regional soils mapping using the BSCS must be assessed prior to use of the pedological information, as some discrepancies have been encountered during the conducting of PSGIs using the SEG system. This can be achieved by utilisation of the 1:50 000 scale geotechnical series maps published by the Council for Geoscience, where available, that allow verification of the spatial accuracy of the pedological information, supported by the study of available remote sensing imagery and the area-specific experience of the geopractitioner. In this, it must be noted that the refined SEG system is not intended to replace the regional geotechnical series maps of the Council for Geoscience.

The following conclusions of a more generalised nature can be made:

- Reliance on the personal experience of the practitioner is built into the refined SEG system, thereby preventing use thereof as a ‘recipe’ by practitioners outside the engineering geological fraternity to conduct regional geotechnical assessments. This approach is considered beneficial to the geotechnical profession as a whole, as well as ensuring the trust of engineers, developers and other decision-makers depending on the accuracy of this information.
- The emphasis on personal experience and the assessment of a wide range of inferred geotechnical properties, rather than just a select few parameters, has the unexpected benefit of reducing reliance on an as-yet unavailable databank of the geotechnical properties of the

different soil horizons as stated by several other researchers. Conversely, establishment of such a databank will undoubtedly provide geopractitioners with additional geotechnical information for the various soil forms to further enhance accuracy of PSGIs conducted by means of the refined SEG system.

- Collation of the results of the literature review has led to the establishment of a repository of the pertinent information relevant to the conducting of PSGIs, including introductory discussions on the different South African soil classification systems. This thesis therefore represents a handy reference work for geopractitioners, further enhancing its efficacy.
- As more detailed soil maps according to the new Natural and Anthropogenic Soil Classification System primarily for agricultural purposes become available to the geotechnical fraternity in the future, it is anticipated that more detailed soil information will feed into the refined SEG system. The increased profiling depth (i.e., 1.5 m), and the classification of non-diagnostic horizons underlying the various soil forms, are specifically important for the purposes of regional geotechnical assessments. In this light, even more accurate results from preliminary stage geotechnical investigations can be expected, as the soils effects groupings on which the refined SEG system is based already incorporates the new soil forms.
- Utilisation of the refined SEG system is particularly useful in guiding the delineation of less suitable land parcels within large study areas or along linear routings. This aids cost-effective development by allowing developers to focus on the most suitable land portions. Additionally, the results of PSGIs based on the refined SEG system are of great benefit to geopractitioners during the definition and costing of detailed geotechnical investigations. The preliminary geotechnical zonation aids in determining the number of test pits required, and the precise placement thereof within the study area. The anticipated adverse soil behaviour helps to guide planning of the number and type of expensive field and laboratory tests required during the detailed investigations.
- Although predominantly applicable to the assessment of the geotechnical character of large sites, the conducting of PSGIs utilising the refined SEG system has been found to facilitate comparison between various candidate sites (e.g., for the establishment of a cemetery) or different routes for linear development (e.g., roads or pipelines) based on the resultant lists of fatal flaws. The refined SEG system also provides adequate geotechnical information for small sites (e.g., an individual land parcel for the placement of a cellular mast) as specialist input during the BAR process.

Repeated utilisation of the refined SEG system revealed the following interesting avenues for further research, namely:

- Although considered a considerable task, it is recommended that the geotechnical fraternity, in close cooperation with pedologists, embark on a concerted effort to establish the proposed databank of geotechnical properties for each of the various soil horizons.
- It is recommended that further research be conducted to quantify the financial impact that the relevant AGEs could have on the ease and cost of development. This would allow the inclusion of a cost impact calculation in the preliminary geotechnical zoning, thus providing highly practical information for use by decision-makers, and further enhancing the efficacy of the conducting of PSGIs based on the refined SEG system.
- Additionally, it is recommended that further work be undertaken to classify the various soil forms falling within each SEG according to both the World Reference Base (WRB) and the Pedological Referential (RP) system to allow application of the refined SEG system outside of the boundaries of South Africa.

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ANNEXURE A: FACT SHEETS DEFINING THE SOILS EFFECTS GROUPING (SEG), WITH GENERALISED GEOTECHNICAL CHARACTERISTICS AND SOIL FORMS

Last Updated: 02 March 2022

SEG-I

APEDAL SOILS

SOIL GROUPINGS **according to Fey, 2010**	**HUMIC SOILS** soils with a humic horizon.		**PODZOLIC SOILS** soils with a podzol horizon.		**OXIDIC SOILS** relatively thick apedal soils.					
SOIL FORMS according to the Natural & Anthropogenic Soil Classification System (NASCS). Corresponding soil forms of the Binomial Soil Classification System (BSCS) underlined in red.	Dm - Dartmoor	humic yellow-brown apedal gleyic	Cc - Concordia	orthic albic podzol	Bd - Bloemdal	orthic red apedal gleyic	Nk - Nkonkoni	orthic red apedal lithic		
	Ga - Gangala	humic red apedal lithic	Gk - Groenkop	orthic podzol lithic	Ca - Carolina	orthic yellow-brown apedal hard rock	Pn - Pinedene	orthic yellow-brown apedal gleyic		
	Hm - Highmoor	humic red apedal gleyic	Hh - Houwhoek	orthic albic podzol lithic	Ct - Constantia	orthic albic yellow-brown apedal	Sp - Shepstone	orthic albic red apedal		
	Ia - Inanda	humic red apedal (thick)	Jb - Jonkersberg	orthic podzol with plagic pan	Cv - Clovelly	orthic yellow-brown apedal lithic	Vb - Vaalbos	orthic red apedal hard rock		
	Kp - Kranskop	humic yellow-brown apedal red apedal	Pg - Pinegrove	orthic podzol	Er - Ermelo	orthic yellow-brown apedal				
	Lg - Longtom	humic yellow-brown apedal lithic	Ts - Tsitsikamma	orthic albic podzol with plagic pan	Gf - Griffen	orthic yellow-brown apedal red apedal				
	Ma - Magwa	humic yellow-brown apedal (thick)			Hu - Hutton	orthic red apedal (thick)				
					Kf - Kransfontein	orthic yellow-brown apedal albic				

SOIL CHARACTERISTICS (based on Fey, 2010):

CLIMATIC REGIME:	Cool, humid (sub-tropical) climate (Weinert N-value: <5) with high rainfall.	Predominantly in high rainfall areas with mainly winter rainfall (Weinert N-value: <5); very occasionally in humid areas with summer rainfall.	Highly variable, with red soils more prevalent in warmer, drier climatic conditions (Weinert N-value: >5), and yellowish soils in cooler, moister areas (Weinert N-value: < 5).		
PARENT MATERIAL:	Mainly hillwash, invariably enriched by an accumulation of organic material.	Mainly arenaceous sedimentary rocks (e.g., sandstone), and extensive sandy colluvial, alluvial, and aeolian deposits.	Highly variable, generally associated with weathered basic igneous rocks (e.g., basalt, diabase, dolerite, gabbro, etc.), granite, quartzite, sandstone, phyllite, and schist, and associated colluvium, as well as alluvial and aeolian deposits.		
MORPHOLOGY:	Highly variable, but mainly along gentle slopes.	Variable, but mainly along mid and foot slopes.	Predominantly along gentle slopes, with red soil along ridge crests, and yellow soils along mid slopes.		
HYDROPEDOLOGY:	RECHARGE - Deep (Ga, Ia, Kp, Lo, Ma) INTERFLOW - Soil / Bedrock (Dm, Hm)	RECHARGE - Deep (Cc, Gk, Hh, Pg, Ts) RECHARGE - Shallow (Jb)	RECHARGE - Deep (Ca, Ct, Cv, Er, Gf, Hu, Kf, Nk, Sp, Vb) INTERFLOW - Soil / Bedrock (Bd, Pn)		
WRB CLASSES:	Ferralsols: Ia, Kp, Ma Unclassified: Dm, Ga, Hm, Lg	Podzols	Ferralsols: Bd, Ct, Cv, Gf, Hu, Pn Unclassified: Ca, Er, Kf, Nk, Sh, Vb		

INFERRED GEOTECHNICAL CHARACTERISTICS:

CATEGORY 1: POOR TRAFFICABILITY	Soil forms where the topsoil horizon contains > 15% clay could become 'sticky'/ slippery when wet (including soils falling in USCS classes SC, CL, & CH). All of these soil forms could undergo loss of cohesion under loading when wet, while soil forms with an albic sub-surface horizon (Cc, Ct, Hh, Kf, Sp, & Ts) or podzol horizon (Cc, Gk, Hh, Jb, Pn, & Ts) could form 'quicksand' conditions when seepage is present.
CATEGORY 2: MATERIAL RE-USE POTENTIAL	Soil forms indicated to contain < 6% clay could be suitable for use as pipe-bedding and/or backfill material (excluding soils falling in USCS classes SC, ML, MH, CL, & CH). Soil forms indicated to contain > 6% clay or those with a humic topsoil horizon are expected to be unsuitable for use in engineered fills without treatment (including soils falling in USCS classes SC, ML, MH, CL, & CH). Soil forms with a lithic horizon (Cv, Ga, Gk, Hh, Lg, & Nk) could yield soil-rock mixtures suitable for use as backfill material with removal of potentially plastic fines and large rock fragments.
CATEGORY 3: ADVERSE BEHAVIOUR	Soil forms comprising mainly sand with < 20% clay could undergo collapse settlement under loading or when wet. Formation of a weak perched water table is possible within those soil forms exhibiting interflow hydropedological characteristics (Bd, Dm, Hm, & Pn). Soils with > 12% clay could undergo a degree of heave/ shrinkage with changes in moisture content. Soil forms with > 20% clay, or > 15% when a humic topsoil horizon is present, could undergo moderate to significant consolidation settlement under loading , especially when wet, in particular those soil forms with a humic topsoil or podzol sub-surface horizon (Cc, Dm, Ga, Gk, Hh, Hm, Ia, Jb, Kp, Lg, Ma, Pg, & Ts). These soil forms are not considered significantly prone to erosion.
CATEGORY 4: EXCAVATABILITY PROBLEMS	Hard rock occurring at depth could hamper the excavation of some engineering service trenches, and very occasionally road and foundation trenches where close to the surface. Some lithic horizons (Cv, Ga, Gk, Hh, Lg, & Nk) could grade into hard rock at relatively shallow depth hampering the excavation of engineering service trenches, and very occasionally road and foundation trenches, while others could be several metres thick, albeit containing occasional large corestones of relatively fresh rock that could be challenging to remove during the excavation of service trenches.

SEG-II

RELATIVELY UNCONSOLIDATED SOILS

SOIL GROUPINGS **according to Fey, 2010**	**MELANIC SOILS** soils with a melanic horizon.	**INCEPTIC SOILS - CUMULIC** relatively young soils.				
SOIL FORMS according to the Natural & Anthropogenic Soil Classification System (NASCS). Corresponding soil forms of the Binomial Soil Classification System (BSCS) underlined in red.	<u>Ik - Inhoek</u> melanic alluvial (thick)	<u>Du - Dundee</u> orthic alluvial (thick) <u>Fw - Fernwood</u> orthic albic (thick) Kk - Kinkelbos orthic albic neocarbonate Nb - Namib orthic regic sand (thick) Tu - Tukulu orthic neocutanic gleyic				

SOIL CHARACTERISTICS (based on Fey, 2010):

CLIMATIC REGIME:	Generally sub-arid (Weinert N-value: 5-7.5) to sub-humid (Weinert N-value: 2-5), but occasionally on young landscapes in humid areas (Weinert N-value: <2).	Highly variable, but with soils containing a neocarbonate horizon limited to arid areas (Weinert N-value: >7.5).				
PARENT MATERIAL:	Originating from saprolite of basic or intermediate rocks (e.g., andesite, basalt, dacite, diabase, diorite, dolerite, granodiorite, etc.) or its derived alluvial or colluvial deposits.	Typically, alluvial, colluvial, or aeolian deposits, but also associated with weathered granite, sandstone, and quartzite.				
MORPHOLOGY:	Variable, but mainly near or along gentle valley floors.	Youthful landscapes: mainly concave foot slopes and valley floors, with fluvic deposits occurring along flood plains, and arenic soils present as littoral and desert dunes and leeward fluvial deposits.				
HYDROPEDOLOGY:	RECHARGE - Deep	RECHARGE - Deep (Du, Nb) INTERFLOW - A / B Horizon (Kk) INTERFLOW - Soil / Bedrock (Fw, Tu)				
WRB CLASSES:	Fluvisols	Cambisols: Tu Fluvisols: Du Arenosols: Fw, Nb Acrisols / Lixisols / Arenosols / Cambisols: Kk				

INFERRED GEOTECHNICAL CHARACTERISTICS:

CATEGORY 1: POOR TRAFFICABILITY	Soil forms where the topsoil horizon contains > 15% clay, especially those with a melanic topsoil horizon (Ik), could become 'sticky'/ slippery when wet (including soils falling in USCS classes SC, CL, & CH). Most of the soil forms are expected to undergo loss of cohesion under loading when wet, while those with an albic sub-surface horizon (Fw & Kk) could form 'quicksand' conditions when seepage present.
CATEGORY 2: MATERIAL RE-USE POTENTIAL	Soil forms indicated to contain < 6% clay could be suitable for use as pipe-bedding and/or backfill material (excluding soils falling in USCS classes SC, ML, MH, CL, & CH). Soil forms indicated to contain > 6% clay, especially those with a melanic topsoil horizon (Ik), are expected to be unsuitable for use in engineered fills without treatment (including soils falling in USCS classes SC, ML, MH, CL, & CH).
CATEGORY 3: ADVERSE BEHAVIOUR	Those soil forms containing < 6% clay could undergo collapse settlement under loading or when wet. Formation of a weak perched water table is possible within those soil forms exhibiting interflow hydropedological characteristics (Fw, Kk, & Tu). Some clay-rich soils, especially those with a melanic topsoil horizon (Ik), could undergo a slight degree of heave/ shrinkage with changes in moisture content. All of the soil forms could undergo moderate to significant consolidation settlement under loading, especially when wet. The soil form with a neocarbonate horizon (Kk) could be potentially dispersive, especially when exposed along relatively steep slopes or in areas where sheetwash occurs. Could become waterlogged / undergo flooding for a short period of time.
CATEGORY 4: EXCAVATABILITY PROBLEMS	Non-diagnostic hard rock, hard carbonate and dorbank horizons occurring at depth could occasionally hamper the excavation of engineering service trenches, and very occasionally foundation trenches where close to the surface.

SEG-III

PEDOGENIC SOILS

SOIL GROUPINGS **according to Fey, 2010**	**HUMIC SOILS** soils with a humic horizon.	**PLINTHIC SOILS** soils with an orthic horizon underlaid by a soft or hard plinthic horizon.				
SOIL FORMS according to the Natural & Anthropogenic Soil Classification System (NASCS). Corresponding soil forms of the Binomial Soil Classification System (BSCS) underlined in red.	El - Eland: humic, yellow-brown apedal, soft plinthic Ne - Netherley: humic, red apedal, soft plinthic	Av - Avalon: orthic, yellow-brown apedal, soft plinthic Bv - Bainsvlei: orthic, red apedal, soft plinthic Lc - Lichtenburg: orthic, red apedal, hard plinthic Lo - Longlands: orthic, albic, soft plinthic We - Westleigh: orthic, soft plinthic, gleyic				
SOIL CHARACTERISTICS (based on Fey, 2010):						
CLIMATIC REGIME:	Cool, humid (sub-tropical) climate with high rainfall (Weinert N-value: <5).	Mainly sub-humid (Weinert N-value: 2-5) to humid (Weinert N-value: <2) areas, with distinct dry season, and absent in with very low or very high rainfall.				
PARENT MATERIAL:	Mainly hillwash, invariably enriched by an accumulation of organic material.	Variable, but more prominently associated with weathered granite, sandstone, quartzite, shale, phyllite, and schist, and occasionally aeolian sand. Generally, red plinthic soils absent on basic igneous rocks (e.g., andesite, basalt, diabase, diorite, dolerite, gabbro, norite, pyroxenite, etc.).				
MORPHOLOGY:	Highly variable, but mainly along gentle slopes.	Generally gentle, concave lower slopes where seasonal lateral groundwater movement can be expected.				
HYDROPEDOLOGY:	INTERFLOW - Soil / Bedrock	INTERFLOW - A / B Horizon (Lo) INTERFLOW - Soil / Bedrock (Av, Bv, Lc, We)				
WRB CLASSES:	Plinthosols	Plinthosols				

INFERRED GEOTECHNICAL CHARACTERISTICS:

CATEGORY 1: POOR TRAFFICABILITY	Soil forms where the topsoil horizon contains > 15% clay could become 'sticky'/ slippery when wet (including soils falling in USCS classes SC, CL, & CH). Most of the soil forms expected to undergo loss of cohesion under loading when wet.
CATEGORY 2: MATERIAL RE-USE POTENTIAL	Soil forms indicated to contain < 6% clay could be suitable for use as pipe-bedding and/or backfill material (excluding soils falling in USCS classes SC, ML, MH, CL, & CH). Soil forms indicated to contain > 6% clay or those with a humic topsoil horizon (El & Ne) are expected to be unsuitable for use in engineered fills without treatment (including soils falling in USCS classes SC, ML, MH, CL, & CH). Mixtures of topsoil with < 6% clay and a soft plinthic horizon (Av, Bv, El, Lo, Ne, & We) could be suitable for use in compacted engineered fills, especially beneath floor slabs and in low volume roads (excluding soils falling in USCS classes SC, ML, MH, CL, & CH).
CATEGORY 3: ADVERSE BEHAVIOUR	Those soil forms containing < 20% clay could undergo collapse settlement under loading or when wet. Formation of a weak perched water table is possible within all of these soil forms, due to inferred interflow hydropedological characteristics. Some clay-rich soils could undergo a slight degree of heave/ shrinkage with changes in moisture content. Soil forms with > 20% clay, or > 15% when a humic topsoil horizon is present, could undergo slight to significant consolidation settlement under loading, especially when wet, in particular those soil forms with a humic topsoil horizon (El & Ne).
CATEGORY 4: EXCAVATABILITY PROBLEMS	Hard plinthic sub-surface horizons (e.g., Lc) occurring at depth could hamper the excavation of engineering service trenches, and road and foundation trenches where present close to the surface.

SEG-IV

WEAKLY STRUCTURED SOILS (NOT GLEYED)

SOIL GROUPINGS according to Fey, 2010	**HUMIC SOILS** soils with a humic horizon.	**CALCIC SOILS** apedal soils underlaid by a soft carbonate or hard carbonate horizon.	**OXIDIC SOILS** relatively thick red structured soils.	**INCEPTIC SOILS - CUMULIC** relatively young soils.		
SOIL FORMS according to the Natural & Anthropogenic Soil Classification System (NASCS). Corresponding soil forms of the Binomial Soil Classification System (BSCS) underlined in red.	He - Henley: humic, neocutanic, lithic Sr - Sweetwater: humic, neocutanic (thick)	Et - Etosha: orthic, neocutanic, soft carbonate Gm - Gamoep: orthic, neocutanic, hard carbonate Mb - Makgoba: orthic, neocutanic, neocarbonate Sv - Soutvloer: orthic, neocutanic, gypsic	Md - Magudu: orthic, red structured, lithic Ns - Nshawu: orthic, red structured, hard rock <u>Sd - Shortlands</u>: orthic, red structured (thick)	Be - Bethesda: orthic, neocutanic, hard rock <u>Oa - Oakleaf</u>: orthic, neocutanic (thick) Qf - Quaggafontein: orthic, neocutanic, alluvial Tb - Tubatse: orthic, neocutanic, lithic <u>Vf - Vilafontes</u>: orthic, albic, neocutanic		
SOIL CHARACTERISTICS (based on Fey, 2010):						
CLIMATIC REGIME:	Cool, humid (sub-tropical) climate with high rainfall (Weinert N-value: <5).	Predominantly semi-arid (Weinert N-value: 5-7.5) and arid (Weinert N-value: >7.5) areas.	Highly variable, with red soils more prevalent in warmer, drier climatic conditions, and yellowish soils in cooler, moister areas.	Highly variable, but with soils containing a neocarbonate horizon limited to arid areas (Weinert N-value: >7.5).		
PARENT MATERIAL:	Mainly hillwash, invariably enriched by an accumulation of organic material.	Variable, but mainly associated with lime-rich soil, rocks, colluvial / alluvial deposits, or lateral sheet flow or wind-blown dust.	Highly variable, with red soils generally associated with weathered basic igneous rocks (e.g., basalt, diabase, dolerite, gabbro, etc.), and Karoo Supergroup mudrocks.	Typically, alluvial, colluvial, or aeolian deposits.		
MORPHOLOGY:	Highly variable, but mainly along gentle slopes.	Variable, but predominantly nearly level or gently sloping plains / erosion terraces.	Predominantly along gentle slopes, with red soil along ridge crests, and yellow soils along mid slopes.	Youthful landscapes: mainly concave foot slopes and valley floors, pans, and vleis, with fluvic deposits occurring along flood plains, and arenic soils present as littoral and desert dunes and leeward fluvial deposits.		
HYDROPEDOLOGY:	RECHARGE - Deep (Sr) RECHARGE - Shallow (He)	RECHARGE - Shallow	RECHARGE - Deep (Sd) RECHARGE - Shallow (Md, Ns)	RECHARGE - Deep (Oa, Qf) RECHARGE - Shallow (Be, Tb) INTERFLOW - A / B Horizon (Vf)		
WRB CLASSES:	Cambisols: Sr Cambisols / Lithosols: He	Calcisols: Et, Gm, Mb Gypsisols: Sv	Ferralsols: Md, Ns Acrisols / Luvisols / Nitisols: Sd	Cambisols: Oa, Vf Unclassified: Be, Qf, Tb		

INFERRED GEOTECHNICAL CHARACTERISTICS:

CATEGORY 1: POOR TRAFFICABILITY	Most of these clayey soil forms, excluding those with a humic topsoil horizon (He & Sr), could become 'sticky'/ slippery when wet. Most of the soil forms are expected to undergo loss of cohesion under loading when wet, while the soil form with an albic horizon (Vf) could form 'quicksand' conditions when seepage present.
CATEGORY 2: MATERIAL RE-USE POTENTIAL	Soil forms indicated to contain < 6% clay could be suitable for use as pipe-bedding and/or backfill material (excluding soils falling in USCS classes SC, ML, MH, CL, & CH). Soil forms indicated to contain > 6% clay or those with a humic topsoil horizon (He & Sr) are expected to be unsuitable for use in engineered fills without treatment (including soils falling in USCS classes SC, ML, MH, CL, & CH). Soil forms with a lithic horizon (He, Md, & Tb) could yield small volumes of soil-rock mixtures suitable for use as backfill material with removal of potentially plastic fines and large rock fragments.
CATEGORY 3: ADVERSE BEHAVIOUR	Formation of a weak perched water table is possible within the soil form exhibiting interflow hydropedological characteristics (Vf). All of these soil forms are expected to undergo slight to moderate heave/ shrinkage with changes in moisture content. Most of the soil forms could undergo slight to moderate consolidation settlement under loading, especially when wet, in particular those soil forms with a humic topsoil horizon (He & Sr). Some of the soil forms, particularly those with a gypsic, neocarbonate or soft carbonate horizon (Et, Mb, & Sv), could be potentially dispersive, especially when located along relatively steep slopes or in areas where sheetwash occurs. Could become waterlogged / undergo flooding for a short period of time.
CATEGORY 4: EXCAVATABILITY PROBLEMS	Hard rock or hard carbonate underlying some soil forms (Be, Gm, & Ns) could hamper the excavation of engineering service trenches, and very occasionally road and foundation trenches where close to the surface. Some lithic horizons (He, Md, & Tb) could grade into hard rock at relatively shallow depth hampering the excavation of engineering service trenches, and very occasionally road and foundation trenches, while others could be several metres thick, albeit containing occasional large corestones of relatively fresh rock that could be challenging to remove during the excavation of service trenches.

SEG-V

DUAL-CHARACTER SOILS (NOT GLEYED)

SOIL GROUPINGS according to Fey, 2010	HUMIC SOILS overlying PLINTHIC SOILS	VERTIC SOILS overlying CALCIC SOILS	VERTIC SOILS overlying INCEPTIC SOILS - CUMULIC	MELANIC SOILS overlying INCEPTIC SOILS - CUMULIC	DUPLEX SOILS overlying INCEPTIC SOILS - CUMULIC	OXIDIC SOILS overlying INCEPTIC SOILS - CUMULIC
SOIL FORMS according to the Natural & Anthropogenic Soil Classification System (NASCS). Corresponding soil forms of the Binomial Soil Classification System (BSCS) underlined in red.	Um - Umvoti: humic, neocutanic, soft plinthic	Bk - Bakwena: vertic, soft carbonate, lithic Dw - Dwaalboom: vertic, soft carbonate, hard carbonate	Mk - Mkuze: vertic, alluvial (thick)	Pd - Potsdam: melanic, pedocutanic, alluvial	Qt - Queenstown: orthic, pedocutanic, alluvial Ut - Utrecht: orthic, prismacutanic, alluvial	Pm - Palmiet: orthic, yellow-brown apedal, neocutanic Tg - Tongwane: orthic, red apedal, neocutanic

SOIL CHARACTERISTICS (based on Fey, 2010):

	HUMIC SOILS overlying PLINTHIC SOILS	VERTIC SOILS overlying CALCIC SOILS	VERTIC SOILS overlying INCEPTIC SOILS - CUMULIC	MELANIC SOILS overlying INCEPTIC SOILS - CUMULIC	DUPLEX SOILS overlying INCEPTIC SOILS - CUMULIC	OXIDIC SOILS overlying INCEPTIC SOILS - CUMULIC
CLIMATIC REGIME:	Cool, humid (sub-tropical) climate with high rainfall and distinct dry season (Weinert N-value: <5), but absent in areas with very high rainfall.	Predominantly semi-arid with prominent dry season with rainfall mainly during the summer (Weinert N-value: 5-7.5).	Tropical to sub-tropical climate with prominent dry season with rainfall mainly during the summer (Weinert N-value: <7.5).	Semi-arid (Weinert N-value: 5-7.5) to semi-humid (Weinert N-value: 2.5-5) areas, excluding areas with a warm humid climate.	Semi-arid (Weinert N-value: 5-7.5) to semi-humid (Weinert N-value: 2.5-5) areas, excluding areas with a warm humid climate.	Highly variable, with red soils more prevalent in warmer, drier climatic conditions (Weinert N-value: >5), and yellowish soils in cooler, moister areas (Weinert N-value: < 5).
PARENT MATERIAL:	Mainly hillwash, invariably enriched by an accumulation of organic material, predominantly overlying sedimentary rocks, but generally absent on basic igneous rocks (e.g., andesite, basalt, diabase, diorite, dolerite, gabbro, norite, pyroxenite, etc.).	Topsoil generally representing alluvial or colluvial deposits derived from saprolite of basic or ultrabasic igneous rocks (e.g., andesite, basalt, diabase, diorite, dolerite, gabbro, norite, pyroxenite, etc.), while sub-surface materials are associated with lime-rich soil, rocks, colluvial / alluvial deposits.	Topsoil generally representing alluvial or colluvial deposits derived from saprolite of basic or ultrabasic igneous rocks (e.g., andesite, basalt, diabase, diorite, dolerite, gabbro, norite, pyroxenite, etc.), with sub-surface materials associated with colluvial / alluvial deposits.	Topsoil representing alluvial or colluvial deposits derived from basic or intermediate rocks (e.g., andesite, basalt, dacite, diabase, diorite, dolerite, granodiorite, etc.), with parent material of sub-surface materials not specifically differentiated, but specifically of differing origins.	Parent material of upper horizons not specifically differentiated, but generally of differing origins, overlying alluvial deposits.	Highly variable, with red soils generally associated with weathered basic igneous rocks (e.g., basalt, diabase, dolerite, gabbro, etc.), while the neocutanic horizon is considered to have originated from alluvial, colluvial, or aeolian deposits.
MORPHOLOGY:	Mainly along gentle, concave lower slopes where seasonal lateral groundwater movement can be expected.	Variable, but predominantly nearly level or gently sloping plains / erosion terraces.	Youthful landscapes: mainly along flood plains.	Variable, but mainly along concave lower-lying topography and river terraces.	Generally, along youthful, concave lower-lying topography representing flood plains.	Predominantly along present day gentle slopes, with red soil along low ridge crests, and yellow soils along mid to foot slopes and valley floors.
HYDROPEDOLOGY:	INTERFLOW - Soil / Bedrock	RESPONSIVE - Shallow but possibly also STAGNATING	RECHARGE - Deep	RECHARGE - Deep	RECHARGE - Deep	RECHARGE - Deep
WRB CLASSES:	Unclassified	Unclassified	Unclassified	Unclassified	Unclassified	Unclassified

INFERRED GEOTECHNICAL CHARACTERISTICS:

CATEGORY 1: POOR TRAFFICABILITY	Those soils forms with topsoil containing > 15%, especially those with a vertic (Bk, Dw, & Mk) or melanic (Pd) topsoil horizon, expected to become 'sticky'/ slippery when wet. Most of the soil forms, excluding those with a pedocutanic (Pd & Qt) or prismacutanic (Ut) sub-surface horizon, expected to undergo loss of cohesion under loading when wet.
CATEGORY 2: MATERIAL RE-USE POTENTIAL	Soil forms with an apedal (Pm & Tg) or alluvial (Pd, Qt, & Ut) sub-surface horizon indicated to contain < 6% clay could be suitable for use as pipe-bedding and/or backfill material (excluding soils falling in USCS classes SC, ML, MH, CL, & CH). Soil forms with a humic topsoil (Um), or those indicated to contain > 6% clay, especially those with a vertic (Bk, Dw, & Mk) or melanic (Pd) topsoil horizon, are expected to be unsuitable for use in engineered fills without treatment (including soils falling in USCS classes SC, ML, MH, CL, & CH).
CATEGORY 3: ADVERSE BEHAVIOUR	Formation of a weak perched water table is possible within those soil forms exhibiting interflow (Um) or stagnating (Bk & Dw) hydropedological characteristics. Those soil forms with a vertic (Bk, Dw, & Mk) or melanic (Pd) topsoil horizon, or those with a pedocutanic (Pd & Qt) or prismacutanic (Ut) sub-surface horizon, are expected to undergo moderate to significant heave/ shrinkage with changes in moisture content. Most of the soil forms could undergo slight to moderate consolidation settlement under loading, especially when wet. Those soil forms with a pedocutanic (Pd & Qt) or prismacutanic (Ut) sub-surface horizon could be potentially dispersive, especially when located along relatively steep slopes or in areas where sheetwash occurs. Could become waterlogged / undergo flooding (Bk & Dw) for a short period of time.
CATEGORY 4: EXCAVATABILITY PROBLEMS	Hard carbonate underlying some soil forms (Dw) could hamper the excavation of engineering service trenches, and very occasionally road and foundation trenches where close to the surface.

SEG-VI

MODERATELY TO STRONGLY STRUCTURED SOILS

SOIL GROUPINGS **according to Fey, 2010**	**HUMIC SOILS** soils with a humic horizon.	**VERTIC SOILS** soils with a vertic horizon.	**MELANIC SOILS** soils with a melanic horizon.	**DUPLEX SOILS** soils with a distinct accumulation of clay resulting in moderate to strong structure at depth.	
SOIL FORMS according to the Natural & Anthropogenic Soil Classification System (NASCS). Corresponding soil forms of the Binomial Soil Classification System (BSCS) underlined in red, and those only found of the Taxonomical Soil Classification System (TSCS) in blue.	<u>Lu - Lusiki</u> (not in NASCS): humic, pedocutanic, unspecified	<u>Ar - Arcadia</u>: vertic, lithic Gl - Glen: vertic, pedocutanic (thick)	Ab - Abbotspoort: melanic, neocutanic (thick) <u>Bo - Bonheim</u>: melanic, pedocutanic (thick) Da - Darnall: melanic, pedocutanic, lithic Lr - Lauriston: melanic, pedocutanic, gleyic Sg - Stanger: melanic, red structured, lithic <u>Tk - Tambankulu</u> (not in NASCS): melanic, soft plinthic	Ck - Cookhouse: orthic, prismacutanic, hard rock En - Erin: orthic, neocutanic, pedocutanic <u>Es - Estcourt</u>: orthic, albic, prismacutanic Hb - Heilbron: orthic, prismacutanic, pedocutanic Id - Idutywa: orthic, prismacutanic, gleyic Km - Klapmuts: orthic, albic, pedocutanic Sa - Sandile: orthic, prismacutanic, lithic Sb - Spioenberg: orthic, pedocutanic, hard rock <u>Ss - Sterkspruit</u>: orthic, prismacutanic (thick) <u>Sw - Swartland</u>: orthic, pedocutanic, lithic <u>Va - Valsrivier</u>: orthic, pedocutanic (thick) Se - Sepane: orthic, pedocutanic, gleyic	

SOIL CHARACTERISTICS (based on Fey, 2010):

CLIMATIC REGIME:	Cool, humid (sub-tropical) climate (Weinert N-value: <5) with high rainfall.	Tropical to sub-tropical climate with prominent dry season with rainfall mainly during the summer (Weinert N-value: <7.5).	Generally sub-arid (Weinert N-value: 5-7.5) to sub-humid (Weinert N-value: 2-5), but occasionally on young landscapes in humid areas (Weinert N-value: <2).	Semi-arid (Weinert N-value: 5-7.5) to semi-humid (Weinert N-value: 2.5-5) areas, excluding areas with a warm humid climate.	
PARENT MATERIAL:	Mainly hillwash, invariably enriched by an accumulation of organic material.	Generally, originating from saprolite of basic or ultrabasic igneous rocks (e.g., andesite, basalt, diabase, diorite, dolerite, gabbro, norite, pyroxenite, etc.).	Originating from saprolite of basic or intermediate rocks (e.g., andesite, basalt, dacite, diabase, diorite, dolerite, granodiorite, etc.) or its derived alluvial or colluvial deposits.	Not specifically differentiated, but not associated with weathered basic and ultrabasic rocks (e.g., andesite, basalt, diabase, diorite, dolerite, gabbro, norite, pyroxenite, etc.), and Karoo Supergroup mudrocks, with the topsoil and sub-surface horizons generally of differing origins.	
MORPHOLOGY:	Highly variable, but mainly along gentle slopes.	Predominantly present along lower-lying topography.	Variable, but mainly near or along gentle valley floors.	Generally, along concave lower-lying topography and river terraces, with the exception of the Swartland soil form that can be present along convex upper and mid slopes.	
HYDROPEDOLOGY:	RESPONSIVE - Shallow	RESPONSIVE - Shallow (Ar, Rs) but possibly also RECHARGE - Deep (Gl) where vertic topsoil is thin	RECHARGE - Deep	RECHARGE - Deep (En, Hb, Sw, Va) RECHARGE - Shallow (Ck, Sa, Sb) INTERFLOW - A / B Horizon (Es, Km) INTERFLOW - Soil / Bedrock (Id, Se) RESPONSIVE - Shallow (Ss)	
WRB CLASSES:	Acrisols	Vertisols: Ar Unclassified: Gl, Rs	Chernozems: Bo Unclassified: Ab, Da, Lr, Sg, Tk	Luvisols: Se, Sw, Va Stagnasols: Es, Km Solonchaks: Ss Unclassified: Ck, En, Hb, Id, Sa, Sb	

INFERRED GEOTECHNICAL CHARACTERISTICS:

CATEGORY 1: POOR TRAFFICABILITY	All of the soil forms expected to become 'sticky'/ slippery when wet. Most of the soil forms expected to undergo loss of cohesion under loading when wet, while those with an albic horizon (Es & Km) could form 'quicksand' conditions when seepage present.
CATEGORY 2: MATERIAL RE-USE POTENTIAL	All of the soil forms are expected to be unsuitable for use in engineered fills without treatment, due to the moderately to highly plastic clay content (inferred to fall in USCS classes SC, ML, MH, CL, & CH). Soil forms containing a lithic horizon (Ar, Da, Sa, Sg, & Sw) could yield small volumes of soil-rock mixtures suitable for use as backfill material with removal of potentially plastic fines and large rock fragments.
CATEGORY 3: ADVERSE BEHAVIOUR	Formation of a weak perched water table is possible within those soil forms exhibiting interflow hydropedological characteristics (Es, Id, Km, & Se). All of the soil forms expected to undergo moderate (< 35% clay) to severe (≥ 35% clay) heave/ shrinkage with changes in moisture content. Most of the soil forms could undergo moderate (< 35% clay, or soils with a humic topsoil horizon [Lu]) to significant (≥ 35% clay) consolidation settlement under loading, especially when wet. Those soil forms with a pedocutanic (Bo, Da, Gl, Lu, Sw, & Va) or prismacutanic (Ck, Es, Hb, Id, & Ss) sub-surface horizon could be potentially dispersive. Those soil forms exhibiting a responsive hydropedological character (Ar, Lu, Rs, & Ss) are considered prone to erosion, especially when located along relatively steep slopes or in areas where sheetwash occurs. Those soil forms exhibiting a responsive hydropedological character (Ar, Lu, Rs, & Ss) are considered prone to periodic waterlogging.
CATEGORY 4: EXCAVATABILITY PROBLEMS	Hard rock underlying some of the soil forms could hamper the excavation of engineering service trenches, and very occasionally road and foundation trenches where close to the surface. Some lithic horizons (Ar, Da, Sa, Sg, & Sw) could grade into hard rock at relatively shallow depth hampering the excavation of engineering service trenches, and very occasionally road and foundation trenches, while others could be several metres thick, albeit containing occasional large corestones of relatively fresh rock that could be challenging to remove during the excavation of service trenches.

SEG-VII

OUTCROPS/ SUB-OUTCROPS OF ROCK AND HARDPAN PEDOCRETES

SOIL GROUPINGS **according to Fey, 2010**	**HUMIC SOILS** soils with a humic horizon.	**VERTIC SOILS** soils with a vertic horizon	**MELANIC SOILS** soils with a melanic horizon.	**PLINTHIC SOILS** soils with an orthic horizon underlaid by a soft or hard plinthic horizon.	**INCEPTIC SOILS - LITHIC** relatively young soils overlying either bedrock or luvic rock/soil mixture (> 70% fragments).	
SOIL FORMS according to the Natural & Anthropogenic Soil Classification System (NASCS). Corresponding soil forms of the Binomial Soil Classification System (BSCS) underlined in red.	Gp - Graskop: humic, hard rock	Rs - Rustenburg: vertic, hard rock Wv - Waterval: vertic, hard carbonate	<u>Mw - Milkwood</u>: melanic, hard rock	<u>Wa - Wasbank</u>: orthic, albic, hard plinthic	Is - Iswepe: orthic, albic, hard rock <u>Ms - Mispah</u>: orthic, hard rock R - Rock: hard rock	
SOIL CHARACTERISTICS (based on Fey, 2010):						
CLIMATIC REGIME:	Cool, humid (sub-tropical) climate (Weinert N-value: <5) with high rainfall.	Tropical to sub-tropical climate with prominent dry season with rainfall mainly during the summer (Weinert N-value: <7.5).	Generally sub-arid (Weinert N-value: 5-7.5) to sub-humid (Weinert N-value: 2-5), but occasionally on young landscapes in humid areas (Weinert N-value: <2).	Mainly sub-humid (Weinert N-value: 2-5) to humid (Weinert N-value: <2) areas, with distinct dry season, and absent in with very low or very high rainfall.	Mainly sub-arid (Weinert N-value: 5-7.5) to arid (Weinert N-value: >7-5), but occasionally in more humid areas (Weinert N-value: <5).	
PARENT MATERIAL:	Mainly hillwash, invariably enriched by an accumulation of organic material.	Generally, originating from saprolite of basic or ultrabasic igneous rocks (e.g., andesite, basalt, diabase, diorite, dolerite, gabbro, norite, pyroxenite, etc.).	Originating from saprolite of basic or intermediate rocks (e.g., andesite, basalt, dacite, diabase, diorite, dolerite, granodiorite, etc.) or its derived alluvial or colluvial deposits.	Variable, but more prominently associated with sedimentary rocks, generally absent on basic igneous rocks (e.g., andesite, basalt, diabase, diorite, dolerite, gabbro, norite, pyroxenite, etc.).	Highly variable.	
MORPHOLOGY:	Highly variable, but mainly along gentle slopes.	Predominantly present along lower-lying topography.	Variable, but mainly near or along gentle valley floors.	Generally gentle, concave lower slopes where seasonal lateral groundwater movement can be expected.	Typically occurs along convex ridge crests and relatively steep slopes, but occasionally present along concave foot slopes in areas where erosion and deposition are in balance.	
HYDROPEDOLOGY:	RECHARGE - Shallow (unbleached topsoil overlying not hard rock) RESPONSIVE - Shallow (bleached topsoil overlying hard rock)	RESPONSIVE - Shallow	RECHARGE - Shallow (unbleached topsoil overlying not hard rock) RESPONSIVE - Shallow (bleached topsoil overlying hard rock)	INTERFLOW - A / B Horizon	RECHARGE - Shallow (unbleached topsoil overlying not hard rock) RESPONSIVE - Shallow (bleached topsoil overlying hard rock)	
WRB CLASSES:	Unclassified	Unclassified	Leptosols	Plinthosols	Leptosols: Ms Unclassified: Is, R	

INFERRED GEOTECHNICAL CHARACTERISTICS:

CATEGORY 1: POOR TRAFFICABILITY	Boulders possible at the surface where outcrops of the hard rock, hard carbonate, or hard plinthic horizons occur (i.e., without a sufficiently thick covering topsoil). Soil forms where the topsoil horizon contains > 15% clay, especially those with a vertic (Rs & Wv) or melanic (Mw) topsoil horizon, could become 'sticky'/ slippery when wet. The relatively thin topsoil horizons could undergo loss of cohesion under loading when wet to a degree, while those with an albic horizon (Is & Wa) could form localised 'quicksand' conditions when seepage present, albeit of little consequence, due to the absence of a sufficiently thick topsoil.
CATEGORY 2: MATERIAL RE-USE POTENTIAL	The very small volumes of material present above hard rock, hard carbonate, or hard plinthic sub-surface horizons indicate that these soils do not represent viable sources of potential pipe bedding or backfill material.
CATEGORY 3: ADVERSE BEHAVIOUR	Formation of a perched water table is possible within the soil form exhibiting interflow hydropedological characteristics (Wa). Those soil forms with a vertic (Rs & Wv) or melanic (Mw) topsoil horizon could undergo slight heave/ shrinkage with changes in moisture content. Those soil forms containing < 15% clay could undergo slight consolidation settlement under loading, especially when wet, in particular the soil form with a humic topsoil horizon (Gp). Those soil forms exhibiting a responsive hydropedological character (Gp, Is, Ms, Mw, & Wv) are considered prone to erosion, especially when located along relatively steep slopes or in areas where sheetwash occurs. Those soil forms exhibiting a responsive hydropedological character (Gp, Is, Ms, Mw, & Wv) are considered prone to periodic waterlogging.
CATEGORY 4: EXCAVATABILITY PROBLEMS	Hard rock, hard carbonate and hard plinthic horizons occurring at shallow depth expected to severely hamper the excavation of both engineering service and road and foundation trenches. However, hard carbonate horizons (Wv) could be underlaid by soft carbonate or neocarbonate horizons and as such should be considered during assessment of founding and excavatability conditions.

SEG-VIII

SHALLOW LITHIC SOILS

SOIL GROUPINGS according to Fey, 2010	HUMIC SOILS soils with a humic horizon.	MELANIC SOILS soils with a melanic horizon.	INCEPTIC SOILS - LITHIC relatively young soils overlying either bedrock or luvic rock/soil mixture (> 70% fragments).			
SOIL FORMS according to the Natural & Anthropogenic Soil Classification System (NASCS). Corresponding soil forms of the Binomial Soil Classification System (BSCS) underlined in red.	<u>No - Nomanci</u> humic lithic	<u>My - Mayo</u> melanic lithic	<u>Cf - Cartref</u> orthic albic lithic <u>Gs - Glenrosa</u> orthic lithic			
SOIL CHARACTERISTICS (based on Fey, 2010):						
CLIMATIC REGIME:	Cool, humid (sub-tropical) climate (Weinert N-value: <5) with high rainfall.	Generally sub-arid (Weinert N-value: 5-7.5) to sub-humid (Weinert N-value: 2-5), but occasionally on young landscapes in humid areas (Weinert N-value: <2).	Mainly sub-arid (Weinert N-value: 5-7.5) to arid (Weinert N-value: >7-5), but occasionally in more humid areas (Weinert N-value: <5).			
PARENT MATERIAL:	Mainly hillwash, invariably enriched by an accumulation of organic material.	Originating from saprolite of basic or intermediate rocks (e.g., andesite, basalt, dacite, diabase, diorite, dolerite, granodiorite, etc.) or its derived alluvial or colluvial deposits.	Highly variable, with soils containing < 15% clay generally originating from sandstone, siltstone, and granite, while that with > 15% clay originating from basic igneous rocks (e.g., andesite, basalt, diabase, diorite, dolerite, gabbro, norite, pyroxenite, etc.), metamorphic rocks, and mudrocks.			
MORPHOLOGY:	Highly variable, but mainly along gentle slopes.	Variable, but mainly near or along gentle valley floors.	Typically occurs along convex ridge crests and relatively steep slopes, but occasionally present along concave foot slopes in areas where erosion and deposition are in balance.			
HYDROPEDOLOGY:	RECHARGE - Shallow (unbleached topsoil overlying not hard rock) RESPONSIVE - Shallow (bleached topsoil overlying hard rock)	RECHARGE - Shallow (unbleached topsoil overlying not hard rock) RESPONSIVE - Shallow (bleached topsoil overlying hard rock)	RECHARGE - Shallow (unbleached topsoil overlying not hard rock) RESPONSIVE - Shallow (bleached topsoil overlying hard rock)			
WRB CLASSES:	Acrisols	Lixisols	Leptosols / Acrisols / Lixisols / Cambisols			

INFERRED GEOTECHNICAL CHARACTERISTICS:

CATEGORY 1: POOR TRAFFICABILITY	Soil forms where the topsoil horizon contains > 15% clay, especially those with a melanic (My) topsoil horizon, could become 'sticky'/ slippery when wet. The relatively thin topsoil horizons could undergo loss of cohesion under loading when wet to a degree, while those with an albic sub-surface horizon (Cf) could form localised 'quicksand' conditions when seepage present, albeit of little consequence, due to the absence of a sufficiently thick topsoil.
CATEGORY 2: MATERIAL RE-USE POTENTIAL	Assessment of re-use potential must take the relatively small volumes of soil-like material present above the lithic horizon into account. Those soil forms with an orthic topsoil horizon (Cf & Gs) could yield soil-rock mixtures suitable for use as backfill material with removal of potentially plastic fines and large rock fragments.
CATEGORY 3: ADVERSE BEHAVIOUR	The soil form with a melanic topsoil horizon (My) could undergo slight heave/ shrinkage with changes in moisture content. Some of the topsoil horizons, especially the humic topsoil horizon (No), could undergo slight consolidation settlement under loading, especially when wet. Those soil forms exhibiting a responsive hydropedological character (Cf, Gs, My, & No) are considered prone to erosion where underlaid by hard rock, especially when located along relatively steep slopes or in areas where sheetwash occurs. Those soil forms exhibiting a responsive hydropedological character (Cf, Gs, My, & No) are considered prone to periodic waterlogging where underlaid by hard rock.
CATEGORY 4: EXCAVATABILITY PROBLEMS	Some lithic horizons could grade into hard rock at relatively shallow depth hampering the excavation of engineering service trenches, and very occasionally road and foundation trenches, while others could be several metres thick, albeit containing occasional large corestones of relatively fresh rock that could be challenging to remove during the excavation of service trenches.

SEG-IX

SOILS THAT UNDERGO PERIODIC SATURATION

SOIL GROUPINGS according to Fey, 2010	MELANIC SOILS soils with a melanic horizon.	SILICIC SOILS soils underlaid by a soft carbonate or hard carbonate horizon.	CALCIC SOILS apedal soils underlaid by a soft carbonate or hard carbonate horizon.		PLINTHIC SOILS soils underlaid by a soft or hard plinthic horizon.	INCEPTIC SOILS - CUMULIC relatively young soils.
SOIL FORMS according to the Natural & Anthropogenic Soil Classification System (NASCS). Corresponding soil forms of the Binomial Soil Classification System (BSCS) underlined in red.	Im - Immerpan: melanic, hard carbonate	Gr - Garies: orthic, red apedal, dorbank	Ad - Addo: orthic, neocarbonate, soft carbonate	Pr - Prieska: orthic, neocarbonate, hard carbonate	Dr - Dresden: orthic, hard plinthic	Ag - Augrabies: orthic, neocarbonate (thick)
	Sn - Steendal: melanic, soft carbonate	Kn - Knersvlakte: orthic, dorbank	Ak - Ashkam: orthic, yellow-brown apedal, hard carbonate	Py - Plooysburg: orthic, red apedal, hard carbonate	Gc - Glencoe: orthic, yellow-brown apedal, hard plinthic	Bg - Burgersfort: orthic, neocarbonate, lithic
		Ou - Oudtshoorn: orthic, neocutanic, dorbank	Br - Brandvlei: orthic, soft carbonate	Ro - Rooiberg: orthic, gypsic		Hf - Hofmeyr: orthic, neocarbonate, hard rock
		Tr - Trawal: orthic, neocarbonate, dorbank	Cg - Coega: orthic, hard carbonate	Sf - Sendelingsdrift: orthic, neocarbonate, gypsic		Mt - Motsane: orthic, neocarbonate, alluvial
			Ks - Koiingsnaas: orthic, soft carbonate, gypsic			Pl - Palala: orthic, neocarbonate, pedocutanic
			Ky - Kimberley: orthic, red apedal, soft carbonate			
			Mp - Molopo: orthic, yellow-brown apedal, soft carbonate			
			Oh - Olienhout: orthic, soft carbonate, hard carbonate			

SOIL CHARACTERISTICS (based on Fey, 2010):

	MELANIC SOILS	SILICIC SOILS	CALCIC SOILS	PLINTHIC SOILS	INCEPTIC SOILS - CUMULIC
CLIMATIC REGIME:	Generally sub-arid (Weinert N-value: 5-7.5) to sub-humid (Weinert N-value: 2-5), but occasionally on young landscapes in humid areas (Weinert N-value: <2).	Generally sub-arid (Weinert N-value: 5-7.5) to sub-humid (Weinert N-value: 2-5), but occasionally on young landscapes in humid areas (Weinert N-value: <2).	Predominantly semi-arid (Weinert N-value: 5-7.5) and arid (Weinert N-value: >7.5) areas.	Mainly sub-humid (Weinert N-value: 2-5) to humid (Weinert N-value: <2) areas, with distinct dry season, and absent in with very low or very high rainfall.	Limited to arid areas (Weinert N-value: >7.5).
PARENT MATERIAL:	Originating from saprolite of basic or intermediate rocks (e.g., andesite, basalt, dacite, diabase, diorite, dolerite, granodiorite, etc.) or its derived alluvial or colluvial deposits.	Originating from saprolite of basic or intermediate rocks (e.g., andesite, basalt, dacite, diabase, diorite, dolerite, granodiorite, etc.) or its derived alluvial or colluvial deposits.	Variable, but mainly associated with lime-rich soil, rocks, colluvial / alluvial deposits, or lateral sheet flow or wind-blown dust.	Variable, but more prominently associated with sedimentary rocks; generally absent on basic igneous rocks (e.g., andesite, basalt, diabase, diorite, dolerite, gabbro, norite, pyroxenite, etc.).	Typically, alluvial, colluvial, or aeolian deposits.
MORPHOLOGY:	Variable, but mainly near or along gentle valley floors.	Variable, but mainly near or along gentle valley floors.	Variable, but predominantly nearly level or gently sloping plains / erosion terraces.	Generally gentle, concave lower slopes where seasonal lateral groundwater movement can be expected.	Youthful landscapes: mainly concave foot slopes and valley floors, with fluvic deposits occurring along flood plains, and arenic soils present as littoral and desert dunes and leeward fluvial deposits.
HYDROPEDOLOGY:	STAGNATING	STAGNATING	STAGNATING	STAGNATING	STAGNATING
WRB CLASSES:	Chernozems: Sn Phaeozems: Im	Durisols	Calcisols: Ad, Ak, Br, Cg, Ky, Mp, Oh, Pr, Py Gypsisols: Ks, Ro, Sf	Plinthosols	Luvisols / Lixisols / Arenosols / Cambisols: Ag, Pl Lithosols: Bg, Hf Fluvisols: Mt

INFERRED GEOTECHNICAL CHARACTERISTICS:

CATEGORY 1: POOR TRAFFICABILITY	Those soil forms where the topsoil horizon contains > 15% clay, especially those with a melanic horizon (Im & Sn), could become 'sticky'/ slippery when wet. Most of the soil forms expected to undergo loss of cohesion under loading when wet, while those with a sandy yellow-brown apedal (Ak, Gc, & Mp) or red apedal horizon (Gr, Ky, & Py) could form 'quicksand' conditions when seepage present.
CATEGORY 2: MATERIAL RE-USE POTENTIAL	Soil forms indicated to contain < 6% clay could be suitable for use as pipe-bedding and/or backfill material (excluding soils falling in USCS classes SC, ML, MH, CL, & CH). Soil forms indicated to contain > 6% clay, especially those with a melanic topsoil horizon (Im & Sn), are expected to be unsuitable for use in engineered fills without treatment (including soils falling in USCS classes SC, ML, MH, CL, & CH). Mixtures of sandy topsoil and a soft carbonate (Ad, Br, Ks, Ky, Mp, Oh, & Sn), or dorbank (Gr, Kn, Ou, & Tr) sub-surface horizon could be suitable for use in compacted engineered fills, especially beneath floor slabs and in low volume roads.
CATEGORY 3: ADVERSE BEHAVIOUR	Soil forms with a sandy red apedal (Gr, Ky, & Py), yellow-brown apedal (Ak, Gc, & Mp), or neocarbonate (Ad, Ag, Bg, Hf, Mt, Pl, Pr, Sf, & Tr) sub-surface horizon containing < 15% clay could undergo collapse settlement under loading or when wet. All of these soil forms exhibit stagnating hydropedological characteristics, and as such are considered prone to the formation of well-defined perched water tables with associated seasonal saturation of sub-surface materials. Those soil forms containing a melanic topsoil (Im & Sn), or neocutanic or pedocutanic sub-surface horizon (Ou & Pl) could undergo slight to moderate heave/ shrinkage with changes in moisture content. All of these soil forms could undergo slight to moderate consolidation settlement under loading, especially when wet, in particular those soil forms with a sandy red apedal, yellow-brown apedal, or neocarbonate horizon (Ak, Gc, Gr, Ky, Mp, & Py). All of these soil forms regularly become waterlogged for short periods of time.
CATEGORY 4: EXCAVATABILITY PROBLEMS	Hard rock (Hf), hard carbonate (Ak, Cg, Im, Oh, Pr, & Py), dorbank (Gr, Kn, Ou, & Tr), and hard plinthic (Dr & Gc) sub-surface horizons occurring at shallow depth expected to severely hamper the excavation of both engineering service and road and foundation trenches. However, hard carbonate sub-surface horizons (Ak, Cg, Im, Oh, Pr, & Py) could be underlaid by soft carbonate or neocarbonate horizons and as such should be considered during assessment of founding and excavatability conditions.

SEG-X

SOILS THAT UNDERGO PROLONGED SATURATION

SOIL GROUPINGS according to Fey, 2010	**VERTIC SOILS** soils with a vertic horizon.	**MELANIC SOILS** soils with a melanic horizon.	**CALCIC SOILS** apedal soils underlaid by a soft carbonate or hard carbonate horizon.	**PODZOLIC SOILS** soils with a podzol horizon.	**GLEYIC SOILS** soils containing a gley horizon	**INCEPTIC SOILS - CUMULIC** relatively young soils.
SOIL FORMS according to the Natural & Anthropogenic Soil Classification System (NASCS). Corresponding soil forms of the Binomial Soil Classification System (BSCS) underlined in red.	Rg - Rensburg: vertic, gley	Wo - Willowbrook: melanic, gley	Ko - Kolke: orthic, soft carbonate, unconsolidated material with wetness Zo - Zondereinde: vertic, soft carbonate, gley	Lt - Lamotte: orthic, albic, podzol/ unconsolidated material with wetness Wf - Witfontein: orthic, podzol, unconsolidated material with signs of wetness	Ka - Katspruit: orthic, gley Kd - Kroonstad: orthic, albic, gley	Lp - Lepellane: orthic, unconsolidated material with wetness (thick) Mu - Montagu: orthic, neocarbonate, unconsolidated material with wetness To - Tshiombo: orthic, neocutanic, unconsolidated material with wetness
SOIL CHARACTERISTICS (based on Fey, 2010):						
CLIMATIC REGIME:	Tropical to sub-tropical climate with prominent dry season with rainfall mainly during the summer (Weinert N-value: <7.5).	Generally sub-arid (Weinert N-value: 5 - 10) to sub-humid (Weinert N-value: 2 - 5), but occasionally on young landscapes in humid areas (Weinert N-value: < 2).	Predominantly semi-arid (Weinert N-value: 5-7.5) and arid (Weinert N-value: >7.5) areas.	Predominantly in high rainfall areas with mainly winter rainfall; very occasionally in humid areas with summer rainfall.	Variable, with low plasticity soils more prevalent in sub-humid areas with relatively high rainfall (Weinert N-value: <5), while moderately to strongly structured, plastic soils occur in sub-arid areas (Weinert N-value: 5-7.5).	Highly variable, but with soils containing a neocarbonate horizon limited to arid areas (Weinert N-value: >7.5).
PARENT MATERIAL:	Generally, originating from saprolite of basic or ultrabasic igneous rocks (e.g., andesite, basalt, diabase, diorite, dolerite, gabbro, norite, pyroxenite, etc.).	Originating from saprolite of basic or intermediate rocks (e.g., andesite, basalt, dacite, diabase, diorite, dolerite, granodiorite, etc.) or its derived alluvial or colluvial deposits.	Variable, but mainly associated with lime-rich soil, rocks, colluvial / alluvial deposits, or lateral sheet flow or wind-blown dust.	Mainly arenaceous sedimentary rocks, and extensive sandy colluvial, alluvial, and aeolian deposits.	Generally, associated with shale and sandstone, and acidic igneous rocks (e.g., granite, etc.), but not basic igneous rocks (e.g., basalt, diabase, dolerite, gabbro, etc.).	Typically, alluvial, colluvial, or aeolian deposits.
MORPHOLOGY:	Predominantly present along lower-lying topography in flood plains, pans, and vleis.	Variable, but mainly near or along gentle valley floors along flood plains, pans, and vleis.	Variable, but predominantly nearly level or gently sloping plains / erosion terraces.	Variable, but mainly along mid and foot slopes.	Predominantly associated with wetlands, vleis, and pans along low-lying topography, but can occur anywhere enhanced infiltration of water onto an impermeable layer occurs.	Youthful landscapes: mainly concave foot slopes and valley floors, with fluvic deposits occurring along flood plains, and arenic soils present as littoral and desert dunes and leeward fluvial deposits.
HYDROPEDOLOGY:	RESPONSIVE - Saturated	RESPONSIVE - Saturated	INTERFLOW - Soil / Bedrock	INTERFLOW - Soil / Bedrock	RESPONSIVE - Saturated (Ka) INTERFLOW - A / B Horizon (Kd)	INTERFLOW - Soil / Bedrock
WRB CLASSES:	Vertisols	Gleysols	Unclassified: Ko, Zo	Podzols	Gleysols: Ka Stagnosols: Kd	Luvisols / Lixisols / Arenosols / Cambisols: Mu Unclassified: Lp, To

INFERRED GEOTECHNICAL CHARACTERISTICS:

CATEGORY 1: POOR TRAFFICABILITY	Those soil forms where the topsoil horizon contains > 15% clay, especially those with a vertic (Rg) or melanic (Wo) topsoil horizon, could become 'sticky'/ slippery when wet. Those soil forms with an albic (Kd & Lt), unconsolidated material (Ko, Lp, Lt, Mu, To, & Wf), or podzol (Lt) sub-surface horizon are expected to undergo loss of cohesion under loading when wet.
CATEGORY 2: MATERIAL RE-USE POTENTIAL	Soil forms indicated to contain < 6% clay could be suitable for use as pipe-bedding and/or backfill material (excluding soils falling in USCS classes SC, ML, MH, CL, & CH). Soil forms indicated to contain > 6% clay especially those with a vertic (Rg) or melanic (Wo) topsoil horizon, are expected to be unsuitable for use in engineered fills without treatment (including soils falling in USCS classes SC, ML, MH, CL, & CH).
CATEGORY 3: ADVERSE BEHAVIOUR	Formation of a well-defined perched water table is possible within those soil forms exhibiting interflow hydropedological characteristics (Kd, Ko, Lt, Lp, Mu, To, Wf, & Zo). Those soil forms containing a vertic (Rg) or melanic (Wo) topsoil horizon, or gley (Ka, Kd, Rg, Wo, & Zo) sub-surface horizon could undergo moderate to significant heave/ shrinkage with changes in moisture content. Those soil forms with an albic (Kd & Lt), unconsolidated material (Ko, Lp, Lt, Mu, To, & Wf), or podzol (Lt) sub-surface horizon could undergo slight to moderate consolidation settlement under loading, especially when wet. Those soil forms exhibiting a responsive hydropedological character (Rg, Ka, & Wo) are considered prone to erosion where underlaid by hard rock, especially when located along relatively steep slopes or in areas where sheetwash occurs. Those soil forms exhibiting a responsive hydropedological character (Rg, Ka, & Wo) are considered prone to prolonged waterlogging.
CATEGORY 4: EXCAVATABILITY PROBLEMS	Although not specified, it is possible that the gley horizon is underlaid by some impervious layer, typically hard rock or hard pedocrete horizon, that could hamper the excavation of engineering service trenches, and very occasionally road and foundation trenches where close to the surface.

SEG-XI

PEAT AND ORGANIC SOILS

SOIL GROUPINGS **according to Fey, 2010**	**ORGANIC SOILS** soils comprising peat or containing an organic horizon.					
SOIL FORMS according to the Natural & Anthropogenic Soil Classification System (NASCS). Corresponding soil forms of the Binomial Soil Classification System (BSCS) underlined in red.	<u>Ch - Champagne</u> organic gley Dd - Didema organic hard rock Kr - Kromme peat hard rock Mf - Mfabeni peat gley Mg - Manguzi organic albic Mh - Makishana organic hard carbonate Mz - Muzi peat hard carbonate Nh - Nhlangu peat albic					
SOIL CHARACTERISTICS (based on Fey, 2010):						
CLIMATIC REGIME:	Cool to cold climate, or in areas with high rainfall and low evapotranspiration, but absent in similar areas exhibiting hot summers (Weinert N-value: <5).					
PARENT MATERIAL:	Predominantly decomposing vegetation and organic alluvium.					
MORPHOLOGY:	Generally, highly localized pockets in low-lying areas, typically exhibiting wetland or vlei conditions.					
HYDROPEDOLOGY:	RESPONSIVE - Saturated					
WRB CLASSES:	Gleysols: Ch, Mf Histosols: Mg, Nh Unclassified: Dd, Kr, Mh, Mz					
INFERRED GEOTECHNICAL CHARACTERISTICS:						
	NOT SUITABLE FOR DEVELOPMENT without additional investigations, remediation and/or removal and replacement of the organic layers. However, these soils typically occur within environmentally sensitive and protected areas where development is not encouraged.					

SEG-XII

ANTHROSOLS AND TECHNOSOLS

SOIL GROUPINGS according to Fey, 2010	**INCEPTIC SOILS - ANTHROPIC** soils affected by human activities.						
SOIL FORMS according to the Natural & Anthropogenic Soil Classification System (NASCS). Corresponding soil forms of the Binomial Soil Classification System (BSCS) underlined in red.	Cu - Cullinan	anthropogenic open excavation technosols					
	Gb - Grabouw	physically disturbed anthrosols					
	In - Industria	chemically polluted technosols					
	Jo - Johannesburg	urban technosols					
	Mr - Maropeng	archaeological technosols					
	St - Stilfontein	hydric technosols					
	Wb - Witbank	transported technosols					
SOIL CHARACTERISTICS (based on Fey, 2010):							
CLIMATIC REGIME:	N/A						
PARENT MATERIAL:	N/A						
MORPHOLOGY:	N/A						
HYDROPEDOLOGY:	RECHARGE - Shallow						
WRB CLASSES:	Anthrosols: Gb Technosols: Cu, In, Jo, Mr, St, Wb						
INFERRED GEOTECHNICAL CHARACTERISTICS:							
	NOT SUITABLE FOR DEVELOPMENT without additional investigations, remediation and/or removal and replacement of the man-made or contaminated layers.						

ANNEXURE B: ARTICLE

USING PEDOLOGICAL INFORMATION IN PRELIMINARY STAGE GEOTECHNICAL INVESTIGATIONS FOR STRATEGIC URBAN PLANNING IN SOUTH AFRICA

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