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Using pedological information in preliminary stage geotechnical investigations for strategic urban planning in South Africa

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Urban development in South Africa should be preceded by a preliminary stage geotechnical investigation to facilitate decision-making regarding site selection and project feasibility, and to aid the Environmental Impact Assessment process. These desk studies generally rely on information obtained from published sources, including regional geotechnical maps, typically only available for major urban centres. It is proposed that use be made of pedological information contained in published land type inventories available for most of the country, or resulting from detailed soil mapping surveys. The proposed refined Soils Effects Grouping (SEG) system provides a relatively simple scientifically based tool that allows conversion of pedological information into the relevant geotechnical parlance in accordance with industry-standard parameters suitable for use in preliminary stage geotechnical investigations. Application of this system over a period of more than a decade has provided cost-effective and reasonably accurate results in support of urban planning and Environmental Impact Assessments.

INTRODUCTION

All residential development within the Republic of South Africa must by law (Republic of South Africa, *National Building Regulations and Building Standards Act 103 of 1977*, as amended) be preceded by at least a preliminary stage geotechnical assessment, i.e. a desk study, during which the suitability of a parcel of land earmarked for development is evaluated in terms of the available geological, geotechnical and geomorphological information (Calitz & Hattingh 2007; SANS 2012). The results of this type of study are essential elements in the decision-making processes that form part of initial planning regarding the optimum placement of urban development in relation to soils and geology (Partridge *et al* 1993). The Code of Practice of the Geotechnical Engineering 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 desk study, with results generally verified by means of a site inspection or walkover survey.

Additionally, although not specifically mentioned by the National Environmental Management Act (NEMA) (Republic of South Africa, *National Environmental Management Act 107 of 1998*, as amended), generalised geotechnical information is regularly requested as specialist input for the compilation of the Basic Assessment Report (BAR) that forms part of the Environmental Impact Assessment process according to NEMA (Republic of South Africa, *National Environmental Management Act 107 of 1998*, as amended).

DEFINING A PRELIMINARY STAGE GEOTECHNICAL INVESTIGATION

Preliminary stage geotechnical investigations (PSGIs) as defined by SANS 634

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Some acronyms used in the text:

AGEs	Adverse Geotechnical Effects
BAR	Basic Assessment Report
BSCS	Binomial Soil Classification System
PSGI	Preliminary Stage Geotechnical Investigation
SEG	Soils Effects Grouping
STCs	Soil Type Categories
TSCS	Taxonomical Soil Classification System

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Table 1 Geotechnical classification for urban development (after Partridge *et al* 1993; as included in SANS 634 (SANS 2012))

	Constraint	Most favourable (1)	Intermediate (2)	Least favourable (3)
A	Collapsible soil	Any collapsible horizon or consecutive horizons less than 750 mm thick (in total)	Any collapsible horizon or consecutive horizons more than 750 mm thick (in total)	A 'least favourable' situation for this constraint does not occur
B	Seepage	Permanent / perched water table > 1.5 m deep	Permanent / perched water table < 1.5 m deep	Swamps and marshes
C	Active soil	Low soil-heave potential	Moderate soil-heave potential	High soil-heave potential
D	Highly compressible soil	Low soil compressibility	Moderate soil compressibility	High soil compressibility
E	Erodibility of soil	Low	Intermediate	High
F	Difficulty of excavation to 1.5 m depth	Scattered to occasional boulders < 10% of total volume	Rock or hardpan pedocretes 10% – 40% of total volume	Rock or hardpan pedocretes > 40% of total volume
G	Undermined ground	Undermining at depth of > 240 m (except where total extraction has not occurred)	Old undermining at depth of 90 m – 240 m where stope closure has ceased	Mining within depth of < 90 m – 240 m, or where total extraction mining has taken place
H	Stability: dolomite / limestone	Possibly stable: areas of dolomite overlain by Karoo strata or intruded by silts Anticipated Inherent Risk Class 1	Potentially unstable Anticipated Inherent Risk Classes 2 to 5	Known sinkholes and subsidences Anticipated Inherent Risk Classes 6 to 8
I	Steep slopes	Between 2° and 6° (all regions)	Slopes between 6° and 18° (KwaZulu-Natal and Western Cape) Slopes of between 6° and 12° (all other regions) Slopes of < 2° (all regions)	> 18° (KwaZulu-Natal and Western Cape) > 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

(SANS 2012) comprise the "… *critical evaluation of information, with the aim of guiding decisions of an issue of public interest …*" (Scholes *et al* 2017). The relevant national standards and guidelines pertaining to urban development are led by SANS 634 (SANS 2012) that states the following regarding the conducting of PSGIs:

> "Section 4.2.1 The preliminary investigation is commissioned by the client to establish whether or not a parcel of land is suitable for township development."

SANS 634 (SANS 2012) requires collation and reporting of information and opinions on issues of a geological and geotechnical nature, including:

- 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)
- 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
- 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
- a detailed drawing of the study area showing the resultant preliminary geotechnical zones based on the system proposed by Partridge *et al* (1993).

In some cases, limited field work mainly comprising a walkover survey and the inspection of exposed soil and rock layers within existing trenches or excavations, is conducted to corroborate desk study results, although this could significantly increase the cost of the study.

CURRENT INDUSTRY PRACTICE

The system currently in use by engineering geological practitioners in South Africa to assess regional geological and geotechnical information for urban development was proposed by Partridge *et al* (1993). That system comprises a standardised classification system whereby the results of PSGIs for residential development can be measured using 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 L – severely problematic) (see Table 1). The results of this assessment are summarised for each preliminary geotechnical zone within a study area through pooled 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). According to Kleinhans (2002) this system is endorsed by the South African Institution of Engineering (SAICE), the South African Institute for Engineering and Environmental Geologists

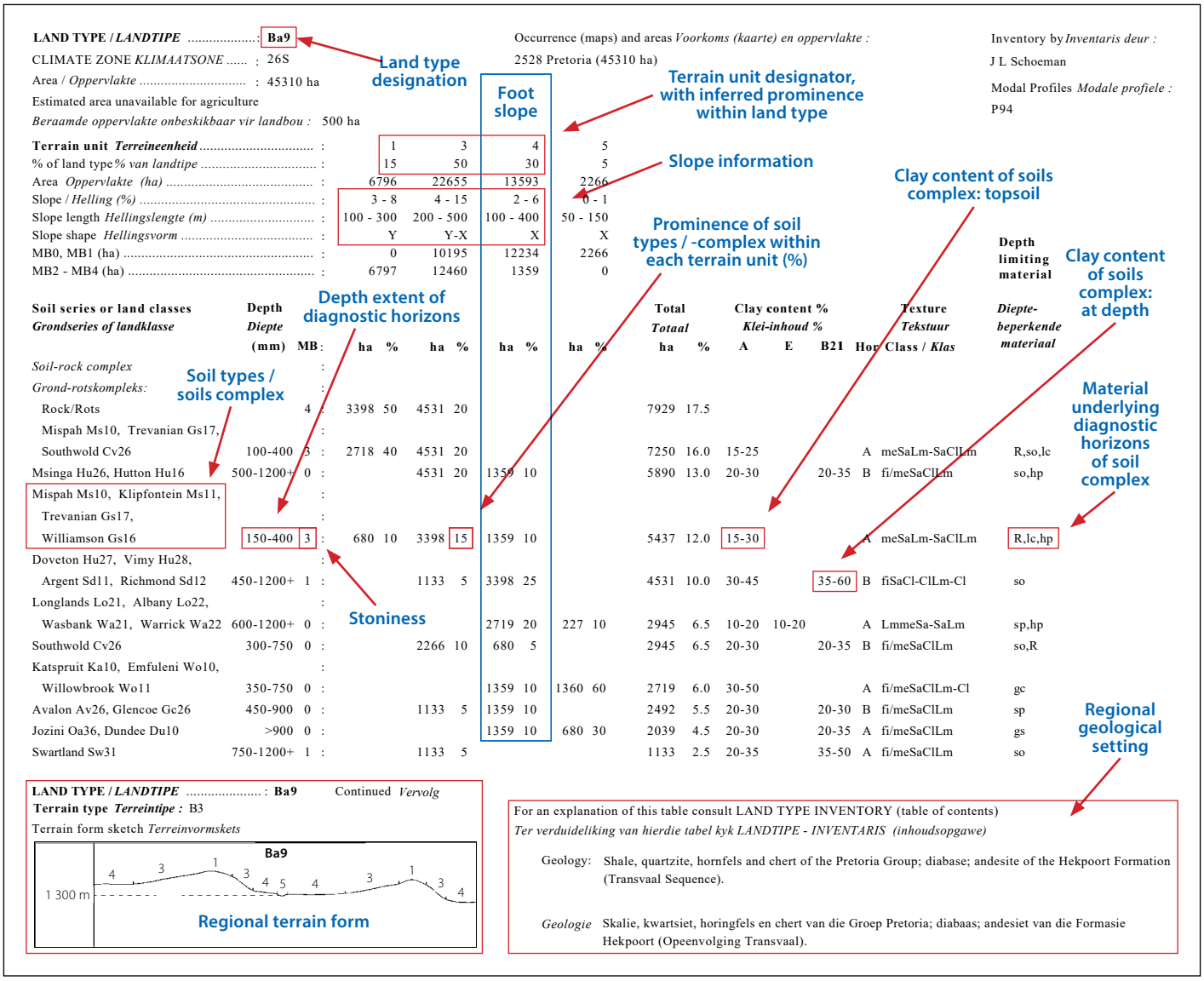

Figure 1 Land type Ba9 as an example of a typical land type inventory, obtained from the defunct AGIS National Resource Atlas website (AGIS National Resource Atlas 2014)

(SAIEG) and the National Home Builders Registration Council (NHBRC 2015), and has been included in the SANS 634 (SANS 2012) standards regarding geotechnical investigations for residential development.

Decision-makers also typically require an assessment of the re-use potential of the natural materials to be encountered during development, and the trafficability of the site during construction. The assumed occurrence of self-mulching soil and/or slaking rock is also of importance. However, the above-mentioned standards do not provide guidance in this regard.

REGIONAL GEOTECHNICAL MAPPING

General

Cost-effective, environmentally sustainable urban development is dependent on the rapid and accurate identification of geologically or geotechnically stable land (Kleinhans 2002). This is generally addressed by means of regional geotechnical mapping, usually conducted at the hand of several systems, ranging from simple to very complex, developed over time for use in South Africa. Kleinhans (2002) concluded that those 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, of which the system developed in-house by the Council for Geoscience is deemed the most comprehensive and useful. However, the 1:50 000-scale maps produced by means of that system at the present number only 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. The Council for Geoscience has recently embarked on a multi-year programme to greatly extend the coverage of the 1:50 000-scale geotechnical maps within the borders of South Africa (Meintjes 2019).

However, a generally overlooked source of information, namely the results of regional soil mapping, primarily available as the 1:250 000-scale land type inventories but occasionally as the results of soils mapping surveys, could provide a readily available source of regional pedological information for most of South Africa. The Department of Agriculture, Land Reform & Rural Development (DALRRD) has recently re-activated an online version of the whole inventory, providing free access to the relevant inventories contained within the Comprehensive Atlas Version 3 available through their webpage (DALRRD 2023).

Application of pedological information

Paige-Green and Turner (2007) define land types as areas that exhibit distinct

uniformity with regard to climate, terrain form and soil types, with sub-division into terrain units defined as areas exhibiting relatively homogeneous form and slope (indicated graphically on the bottom left of Figure 1 on page 21). It must be noted that the above-mentioned terrain units roughly correspond to (albeit on a more simplified level) the landforms 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. The land type inventories provide information on the following factors of interest to initial geotechnical assessments (Figure 1):

- regional terrain form, with a graphical representation of the distribution of terrain units, as well as information regarding slope angles and shapes (bottom left, Figure 1)
- regional geological setting (bottom right, Figure 1)
- dominant soil forms and series for each terrain unit, including soil / rock complexes, with short summaries of the estimated depth ranges, clay content, texture classes (based on regional soils mapping by means of the Binomial Soil Classification System (MacVicar *et al* 1977))
- a generalised indication of the depth-limiting materials and/or factors underlying the succession of soil, rock and/or pedogenic layers comprising the relevant soil form (right-most column, Figure 1).

Pedological information, especially the land type inventories, has to date been erroneously viewed by most geotechnical practitioners as being applicable only in agricultural potential studies. However, several authors (e.g. Fanourakis 1990) have proposed empirical systems to infer geotechnical properties for the different soil types contained in land type classifications, but these have not been adopted by the engineering geological fraternity, mainly due to its generalised nature, and a reliance on intimate knowledge of the principles behind pedological mapping and the different soil classification systems of South Africa that few geotechnical practitioners are familiar with (Paige-Green & Turner 2007). Conversely, the various soil classification systems for South Africa hold great promise in providing information on the nature and behaviour of the soil-like material of specific interest to geotechnical practitioners, provided a suitable system can be devised to allow translation thereof for use within the geotechnical fraternity.

Background on soil classification in South Africa

Binomial Soil Classification System (1977)

The science behind soil formation, rather a separate system for specific applications (e.g. agriculture or engineering) in use in other parts of the world, was used to devise the Binomial Soil Classification System (BSCS) for the mapping of soils in South Africa (MacVicar *et al* 1977). This classification system relies on five diagnostic topsoil and 15 subsoil horizons based on differences in soil structure, texture, appearance, composition and origin stemming from soil-forming processes. A total of 41 soil forms, each comprising a unique vertical succession of diagnostic horizons, were defined. It must be noted that the materials underlying those defining the diagnostic soil forms are not included in the detailed soils description (deemed non-diagnostic materials). Further differentiation based on clay content, lime content, colour and/or discoloration, degree of leaching, and pH describes a total of 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.

Taxonomical Soil Classification System (1991)

A successor to the Binomial Soil Classification System, named the Taxonomical Soil Classification System (TSCS), was published in 1991 (Soil Classification Working Group 1991). This system replaced the Soil Series sub-classification with broader Soil Families based on some of the principles behind the earlier subdivision but adding additional parameters such as the presence or absence of signs of wetness, and a significant increase in clay content with depth (so-called 'luvic' horizons). Additionally, the maximum depth to which diagnostic horizons are mapped was increased to 1.5 m. This new system also introduced several new diagnostic horizons, subsequently defining a total of 73 Soil Forms.

Although the Taxonomical System 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.

Natural Soils and Anthropogenic Materials Classification System (2018)

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 (NASCS) (Soil Classification Working Group 2018). The new system was developed primarily to reflect the importance of soil as a natural entity, and to stimulate the interest of soil scientists in the observation and classification of the soil blanket 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 limit of 1.5 m was selected to represent the maximum extent for soil form classification, but 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 emerging global soil taxonomy insights (Soil Classification Working Group 2018). Soil designations generally comprise the soil form name and family code, followed by any additional diagnostic horizons where present, ending with the limiting depth quoted in brackets (where relevant), for example: Av2210/al/gl (260 cm).

Changes regarding the principles and structure of the new soil classification system include the following, deemed of interest to the geotechnical practitioner:

- Natural soils and anthropogenic materials are differentiated.
- Classification of soil forms relies on an 'open system' that allows inclusion of additional soil horizons beyond those comprising the standard soil forms, thus facilitating description of both whole and partially observable 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.
- Introduction of a peat horizon.
- Prominence is given to indications of soil wetness and/or prolonged saturation (gleying) within soil diagnostic horizons.

- The bleached character of certain subsurface 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.
- Podzolic characteristics have been granted more prominence.
- Lithic characteristics have been subdivided into saprolithic, geolithic and gleylithic materials.
- Hard rock is classified as either fractured, or 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.

Contributions from hydropedology

Recent studies in the relatively new field of hydropedology have expanded understanding of the presence and movement of soil moisture, as well as defining its influence on the character of the different soil forms. Work by Van Tol and Le Roux (2019) have led to the grouping of the Taxonomic Soil Classification System (TSCS) soil forms into the following four classes:

- Recharge soils, characterised by the presence of shallow or fractured rock, or deep freely draining soils, where vertical flow through and out of the material dominates.
- Interflow soils, where lateral movement of soil moisture occurs along either the contact between the topsoil and subsurface soil horizons, or between the soil / bedrock interface.
- Responsive soils, typically responsible for overland flow due to the presence of relatively impermeable material or soils that undergo prolonged saturation close to the surface.
- Stagnating soils, where the outflow of soil moisture is limited or restricted.

In this light it is evident that application of hydropedological principles could play an important role during the assessment of the geotechnical properties of natural materials occurring within a study area, especially regarding the determination of periodic or prolonged saturation thereof.

A new approach

In light of the apparent importance of regional pedological information, including the readily available land type maps and memoirs, the proposed refined Soils Effects Grouping (SEG) system utilising a standardised and diagrammatical reporting format was developed to allow use thereof during the conducting of PSGIs. This system provides an easy-to-use bridge between the pedological and geotechnical worlds of particular use in areas where more detailed regional geotechnical maps are not available.

Presentation of the initial version of the resultant SEG system was well received at an international conference in 2007 (Calitz & Hattingh 2007), and has since been in use in practice by several geopractitioners. However, establishment of the NASCS, and updated industry standards and legislation have necessitated refinement thereof. The processes and principles behind this new system were discussed in detail in the author's PhD thesis (Calitz 2022), but embodies a volume of work too large to include in this document without significant reworking; hence the following section provides a summary of these processes and principles.

THE REFINED SOILS EFFECTS GROUPING (SEG) SYSTEM

Considering the (sometimes) highly variable nature of the different soil forms comprising any given land type, it is essential to define a series of data groupings to facilitate the collation of the inferred soil characteristics across the area without allowing the behaviour of the dominant soil forms from drowning out those of less prominent soil forms. For example, the inundated character of a localised occurrence of clayey soil that undergoes prolonged saturation could be as important to the investigation as a large volume of sandy apedal soil material.

Empirical experimentation over time led to the definition of 12 unique Soil Type Categories (STCs), numbered from I to XII (see Table 2) formed by the grouping together of the NASCS soil forms (and by implication the less refined soil forms of the BSCS) exhibiting roughly similar geotechnical characteristics regarding urban development, such as soil structure, degree of ferruginisation, or gleyic characteristics, and allowing for the presence of scattered to extensive bedrock outcrop. Definitions of the various STCs were primarily influenced by the following:

- soil groups, based on the BSCS soil forms, defined by Fey (2010)
- 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)
- classification of the various soil forms according to hydropedological principles (Van Tol & Le Roux 2019).

It must be noted that further assessment of the anthropogenic soils (Categories XI and XII) was not conducted, as the adverse characteristics generally exhibited by these types of soil do not readily allow cost-effective residential development, and more specifically low-cost housing, that forms the main aim for application of the refined SEG system.

In order to rank the perceived impacts of each of the STCs on urban development, it was necessary to define a series of ten Adverse Geotechnical Effects (AGEs), ranked from *least costly* to *most costly* according to the succession of parameters as stated by SANS 634 (SANS 2012) based on Partridge *et al* (1993) (see Table 1), but expanded to include parameters regarding poor trafficability and material re-use potential, and placing more importance on the effects of prolonged saturation. These AGEs were grouped into categories with a weighting system (Variable A, Table 2) devised to broadly reflect an increase on the perceived level of impact of each AGE on the ease and cost of development (for example, the occurrence of boulders at surface deemed relatively easy to remediate is assigned the lowest weight value of 0.5, while the very high cost of mitigating the effects of prolonged saturation is reflected by the highest weight value of 12). The following AGE categories were defined:

- Category 1: Poor trafficability
- Category 2: Material re-use potential
- Category 3: Adverse soil behaviour
- Category 4: Excavatability problems
- Category 5: Miscellaneous geological, geotechnical, and geomorphological parameters.

NOTE: These factors cannot be assessed in terms of regional soils information, and as such do not form part of the following discussion.

A diagrammatical representation of this weighting system, with the resultant maximum realisation values for each AGE (Variable B), is provided in Figure 2.

A simple matrix (Table 2) was devised to rank the various STCs by plotting the list

Table 2 Resultant ranking of the soil type categories (STC) defining the Soils Effects Groupings (SEG)

		Adverse Geotechnical Effects (AGEs)													
		Boulders at surface	*Sticky* / slippery conditions when wet	Loss of cohesion when wet / *quick* conditions	Poor material re-use potential	Collapse settlement	Periodic seepage	Heave / shrinkage	Consolidation settlement / *soft* clays	Erodibility	Excavatability problems: service trenches	Excavatability problems: foundation trenches	Waterlogged	Total impact scores	Resultant soils effects grouping (SEGs)
	Allocated weights (Variable A)	**0.5**	**1**	**1.5**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**		
Soil type categories (STCs)	Apedal soils – freely draining soils exhibiting little to no structure		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 – soft and hardpan ferricrete		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) – soils where the character of the topsoil and subsurface materials varies significantly		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 or hardpan pedocrete	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 and organic soils			7.5	20	10	30	7	40		30	11	60	**215.5**	**XI**

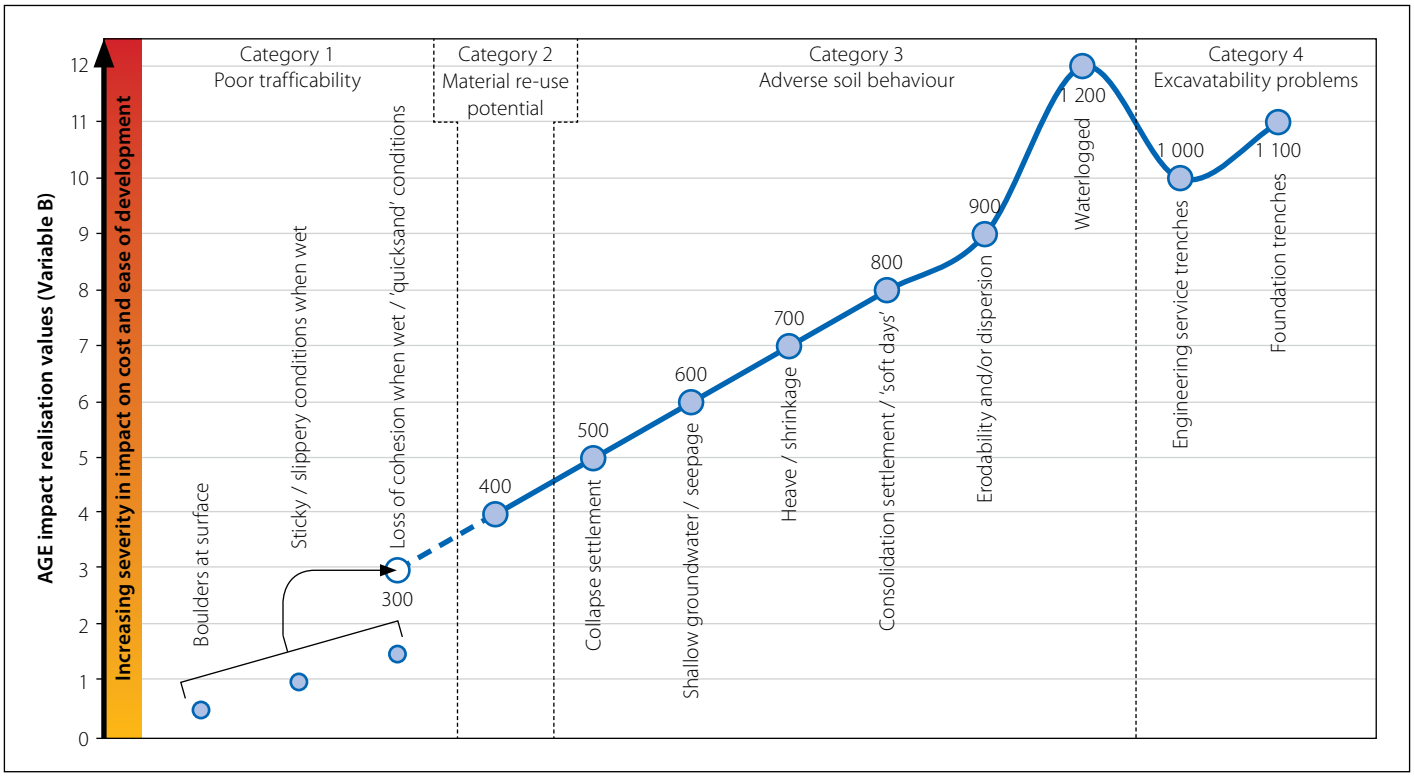

Figure 2 Diagrammatical depiction of the weighting of the Adverse Geotechnical Effects (AGEs) with regard to the cost and ease of development; bolded values depict the maximum realisation score for each AGE (Variable B) (after Partridge *et al* (1993))

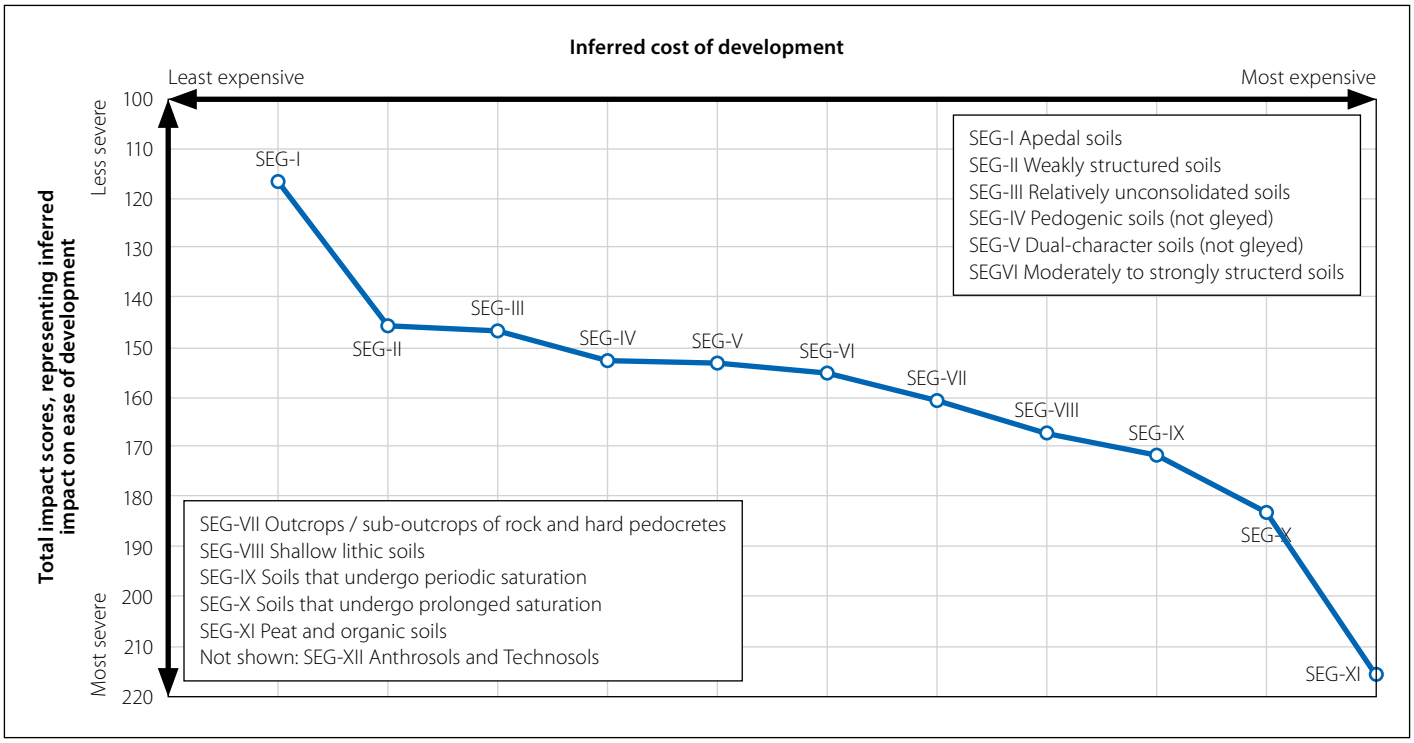

Figure 3 Diagrammatical representation of decision matrix scores for the refined Soils Effects Groupings

of STCs (rows) against the AGEs (columns). The value of each cell was calculated as the product of the following two factors:

- a value from 1 to 12 assigned to each of the twelve AGEs (as indicated by the AGE sub-header in Table 2) broadly based on its inferred effect on the cost of development (from Partridge *et al* 1993), with the exception of the AGE waterlogged (typically grouped under Category 3) considered a worst-case scenario and as such assigned a value of 12
- the inferred prominence of each AGE within a specific STC, given as a value graded on a scale from 0 to 5 as follows:
  - 0: effect exhibited by none of the soils within the specific STC
  - 1: effect exhibited by only a very few soils within the specific STC, or occurs very occasionally
  - 2: effect exhibited by some soils within the specific STC, or occurs infrequently
  - 3: effect exhibited in roughly half of the soils within the specific STC, or occurs occasionally
  - 4: effect exhibited by most of the soils within the specific STC, or occurs frequently
  - 5: effect exhibited by all of the soils within the specific STC, or invariably occurs.

The resultant total impact scores for each of the STCs were obtained by the sum of the individual matrix scores (reflected by the second-to-last column in Table 2). By plotting the inferred impact against the inferred cost of development, the STCs could be ranked from the lowest total impact score, deemed to define those soil forms that have the smallest impact on development, to the highest total impact score, expected to be the most costly and difficult to remedy (Figure 3). The outcomes were used to rearrange the STCs according to their ranking, and as such define the series of 12 Soils Effects Groupings (SEGs), numbered from SEG-I to SEG-XII (last column of Table 2, as illustrated diagrammatically in Figure 3). This numbering system forms the basis of the proposed refined method to facilitate use of pedological information in the conducting of PSGIs.

APPLICATION

Framework

Implementation of the refined SEG system relies on the efficient collation of land type information or the results of more detailed soil mapping surveys. The implementation process involves the following steps (illustrated in Figure 4):

- Input, comprising:
  - dissemination of pedological information for each relevant mapping unit
  - assignment of contribution weights per AGE within each relevant SEG to define the overall geotechnical character
- Output, rendering of results in tabular and diagrammatical format
- Implementation, comprising reworking of the disseminated information to facilitate:
  - geotechnical clustering and delineation of preliminary geotechnical zones
  - identification of flag issues for planning purposes
  - furnishing of geotechnical information for Basic Assessment Reports (BARs).

Input

- Tier 1: Regional pedological information based on the BSCS can readily be obtained by means of the published 1:250 000-scale land type series maps and accompanying memoirs, available either as printed copies, or in digital format from the AGIS website of the Department of Agriculture (AGIS Natural Resource Atlas 2014). More localised soil maps based on the newer soil classification systems could, however, be obtained from landowners or other stakeholders, yielding more accurate and comprehensive pedological information.
- Tier 2: The primary mapping unit for data entry is defined by terrain morphological units typically provided in columnar format by the land type inventory (as indicated in Figure 1). The following primary terrain units are defined:

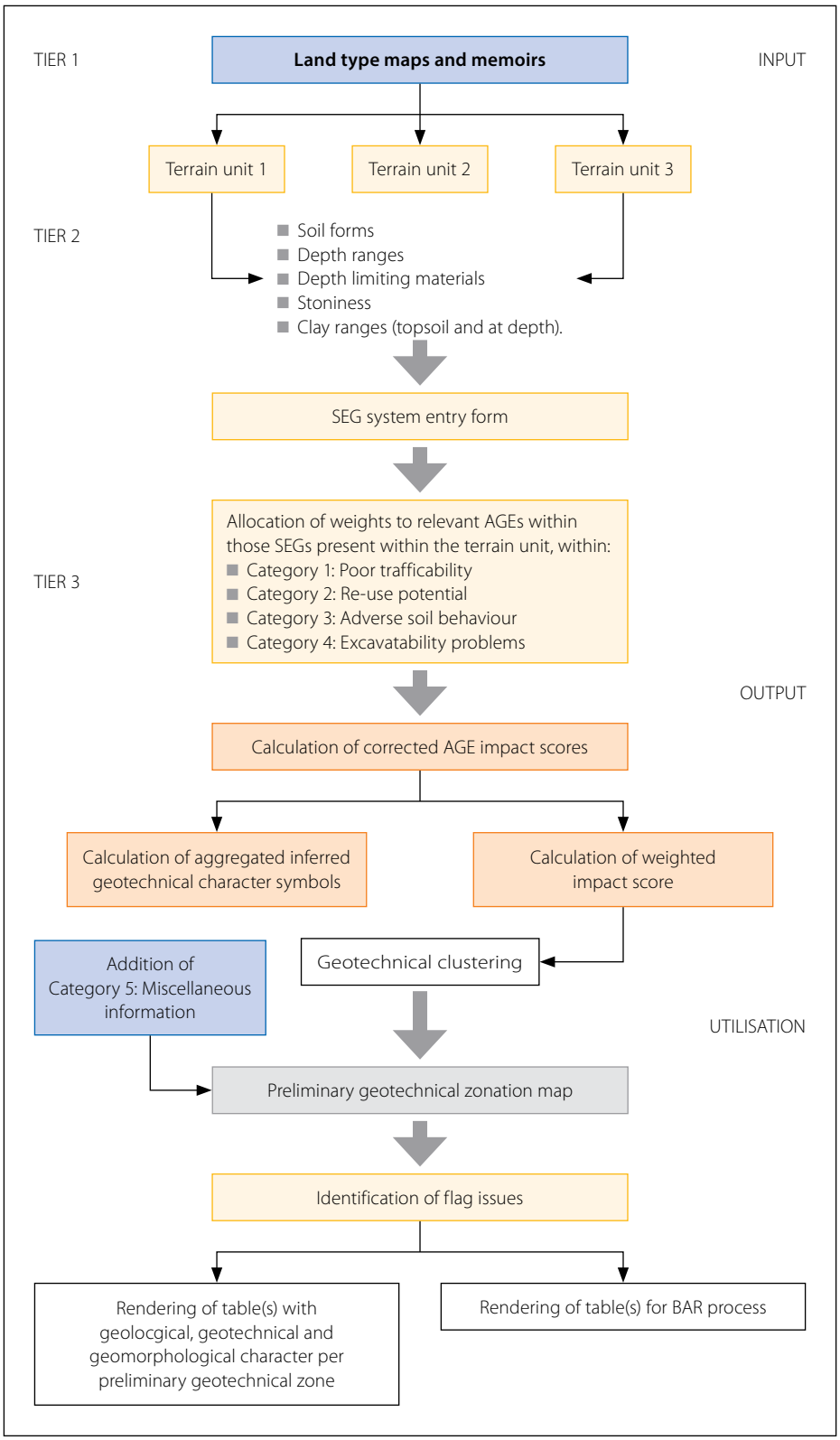

Figure 4 Flow diagram depicting application of the refined SEG system

- ridge crests
- scarp edges
- mid slopes
- foot slopes
- valley floors.

These terrain units can be readily mapped using remote-sensing images and regional surface elevation information. Although the land type inventories provide an indication of the prominence of the different terrain units within the landscape, expressed as a percentage of the total surveyed area, these should preferably only be applied to very large sites, as smaller-scale development could be located wholly within only one or two terrain units. This parameter is not deemed a critical factor but is of value during the weighting of the aggregated soils information during the delineation of preliminary geotechnical zones at the culmination of PSGIs.

Regional soils information obtained either from the relevant land type memoirs or from other sources of regional soils mapping surveys is subsequently collated separately for each terrain unit under the relevant SEGs, with the following information entered:

- 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 (Variable C, noted as a number representing a fraction of 100), entered as separate entities under the relevant SEG with its inferred spatial prominences classified according to the empirically derived categories provided in Table 3
- soil depth range, including both the stated minimum and maximum depths
- the depth limiting material(s) underlying the diagnostic horizons (where noted)
- the stoniness of the soil, representing the volume of coarse particles and/or clasts within the soil matrix
- the minimum and maximum clay content for the topsoil and subsurface layers respectively (where noted).

- Tier 3: Dissemination of the pedological information is followed by the allocation of contribution scores based on decisions made by the geopractitioner reflecting the importance of the AGE within either of the following prominence categories:
  - inferred temporal importance (i.e. time-dependent effects, e.g. seasonal waterlogging)
  - inferred spatial importance (i.e. distribution within the surface area but also accounting for vertical variations in geotechnical character, e.g. the occurrence of gleyed clay beneath sandy topsoil)
  - inferred fractional importance (i.e. allowing inclusion of less prominent but important effects not limited to spatial distribution, e.g. the occurrence of weak perched water tables).

The chosen contribution scores (Variable D) for AGEs within AGE categories 1, 3 and 4 are classified as follows (upper portion of Table 4):

1. nearly negligible
2. very slight contribution
3. slight contribution

Table 3 Prominence categories utilised to aid dissemination and assessment of regional soils information

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
Spatial extent of Soils Effects Groupings (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

4. moderate contribution
5. strong contribution
6. significant contribution
7. very significant contribution.

A contribution score (Variable D) for AGE Category 2 is depicted using a different scale with the following values (lower portion of Table 4):

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

It must be noted that the assignment of contribution scores is highly dependent on the personal experience of the geopractitioner regarding the expected behaviour of the different soil types and the geotechnical and hydropedological character of soils occurring in the area in which the site is located.

Output

The expected severity level at which each AGE is expected to affect the cost and ease of development, expressed as a fraction of 100%, can be calculated as follows for each terrain unit present within a study area (see Figure 5):

- STEP 1: Calculation of the relative importance of each AGE within the relevant SEG:

Table 4 Prominence descriptors and contribution scores utilised to guide user inputs regarding Adverse Geotechnical Effects (AGEs) during assessment of regional soils information

	AGE prominence descriptors		
Contribution scores	**Temporal** used to describe time-dependent (e.g. seasonal) effects	**Spatial** used to describe effects limited to its distribution over surface area, while also allowing for vertical variation in character	**Fractional** used to describe less prominent but important effects not limited to its spatial distribution (e.g. weakly developed perched water tables)
AGE category 1: Poor trafficability AGE category 3: Adverse soil behaviour AGE category 4: Excavatability problems			
1 nearly negligible	Very occasionally	Highly localised, but at depth only	*
2 very slight contribution	Occasionally	Very highly localised	*
3 slight contribution	Sporadically	Highly localised	To a lesser degree / less important
4 moderate contribution	Intermittently	Localised, but at depth only	*
5 strong contribution	Regularly	Localised to over roughly half of the area	To a degree / moderately important
6 significant contribution	Very regularly	Widespread, but at depth only	To a significant degree / important
7 very significant contribution	Always	Widespread	Prominent / very important
* Assigning prominence values to these contribution categories is considered unnecessary			
AGE category 2: Material re-use potential			
1	Possibly suitable		
2	Marginally suitable		
3	Unlikely to be suitable		
4	Unsuitable		

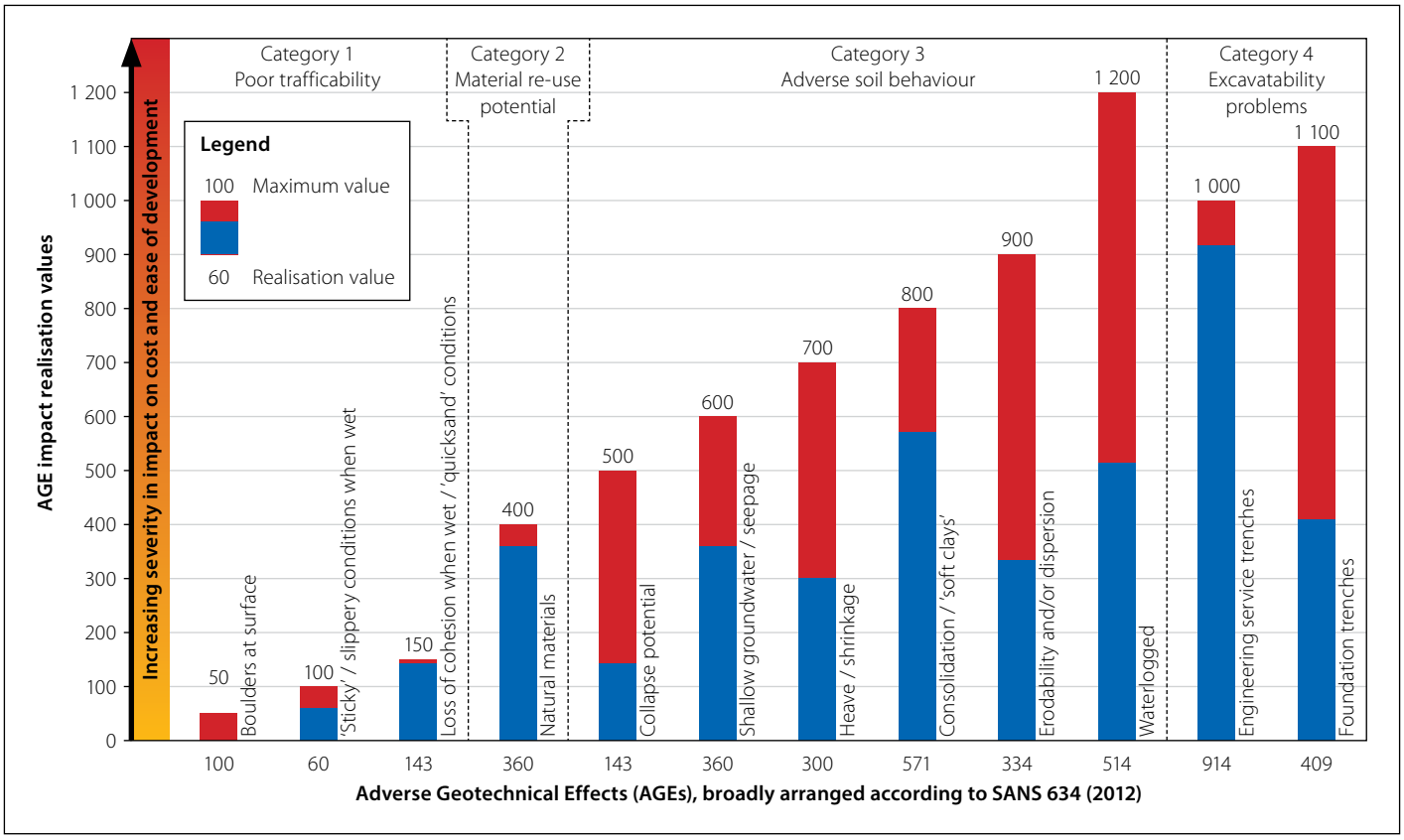

Figure 5 An example of the diagrammatical depiction of the level of realisation (cross-hatched bars) of the maximum inferred impact (outlined bars) for each AGE

- Weighted AGE contribution value (Variable E) = Variable D × (Variable C/100).

- STEP 2: Calculation of AGE severity values collated for the whole terrain unit:
  - (Variable F) = Maximum possible contribution value for the AGE obtained from Table 4 (either 4 or 7).
  - (Variable G) = Sum of weighted AGE contribution scores (Variable Es) across all relevant SEGs present within the terrain unit.
  - AGE severity value (Variable H) = Variable G / Variable F. NOTE: yields a non-integer percentage.
- STEP 3: Calculation of the expected level at which the impact of each AGE, weighted to represent the inferred contribution of that specific characteristic on the overall cost and ease of development, has been realised, that can be measured against the total inferred severity value for that AGE, as follows:
  - AGE impact realisation value = Variable H × Variable A.
    NOTE: yields an integer value.

A low level of realisation is considered to indicate 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.

Comparison of these fractions with statistically determined limits for specifically potentially active and/or compressible soils allows allocation of inferred NHBRC geotechnical site classes for these AGEs. This determination was based on an assessment of the results of laboratory tests conducted on samples obtained from 32 development sites across South Africa measured against the reported NHBRC site classification (e.g. H2, S1, etc) where the AGE impact realisation values representing each of the relevant site classes readily clustered together, allowing the definition of limits that can be used to infer the NHBRC site classification for these AGEs. A similar method was used to define classification limits for potentially erodible soils, while limits for the other AGEs (Table 5) were determined according to their perceived impact graded according to the impact categories defined by Partridge *et al* (1993). These limits are provided in Table 5.

Implementation

The inferred NHBRC site classes, together with supplementary classification resulting from the assessment of other geological, geotechnical and morphological factors obtained from other sources, allow grouping of terrain units exhibiting similar geotechnical characteristics into preliminary geotechnical zones – one of the primary products resulting from application of the refined SEG system.

Additionally, PSGIs utilising the refined SEG system yields a list of 'flag' issues of a geological, geotechnical and morphological nature (Table 5) of importance to facilitate comparison between different terrain units for site selection purposes, as well as to furnish relevant information required as specialist input for BARs as part of Environmental Impact Assessment processes. Results are typically rendered by means of a series of tables and diagrams, as well as GIS-based maps, also available via Cloud-based platforms.

Although this process sounds complex, the establishment of a relatively basic spreadsheet should easily manage the required data inputs and calculations, thus providing a simple, yet effective, overview of the overall geotechnical character of the different soils comprising each terrain unit.

AN EXAMPLE

Description of the study area

A PSGI utilising the refined SEG system was conducted on a land parcel

Table 5 List of limits to aid assessment and classification of the AGE impact realisation values

AGEs		Inferred impacts on development		
		1–Most favourable	2–Intermediate	3–Least favourable
Category 1 – Poor trafficability	Occurrence of boulders at the surface	N/A	2_{supp} Boulders expected at the surface / scattered bedrock outcrops expected to occur	3_{supp} Extensive bedrock outcrops expected
	'Sticky' / slippery conditions when wet	N/A	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	1_{supp} Topsoil expected to lose cohesion in localised areas after rain	2_{supp} Topsoil expected to lose cohesion when saturated	3_{supp} 'Quick' conditions expected after rain / in inundated areas
Category 2 – Materials re-use potential		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	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	N/A	Class 2_B Seepage associated with permanent or perched water tables expected at a depth of < 1.5 m	Class 3_B Soils inferred to be occasionally waterlogged AND/OR swamps and marshes
	Heave / shrinkage	Class 1_C AGE impact realisation value ≤ 55	Class 2_C AGE impact realisation value > 55 and ≤ 280	Class 3_C AGE impact realisation value > 280
	Compressibility / 'soft clays'	Class 1_D AGE impact realisation value ≤ 100	Class 2_D AGE impact realisation value > 100 and ≤ 300.	Class 3_D AGE impact realisation value > 300
	Erodibility / dispersion	Class 1_E AGE impact realisation value ≤ 135	Class 2_E AGE impact realisation value > 135 and ≤ 355.	Class 3_E AGE impact realisation value > 355
Category 4 – Excavatability problems		Class 1_F Pockets of bedrock / hardpan pedocrete expected to comprise < 10% of total profile up to 1.5 m AGE impact realisation value < 100	Class 2_F Pockets of bedrock / hardpan pedocrete expected to comprise between 10% and 40% of total profile up to 1.5 m AGE impact realisation value ≥ 100 and ≤ 400	Class 3_F Bedrock / hardpan pedocrete expected to comprise > 40% of total profile up to 1.5 m AGE impact realisation value > 400
Category 5 – Miscellaneous geological, geotechnical & geomorphological factors	Undermining	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	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	N/A	Class 2_I Slopes of < 2°	N/A
	Steep slopes	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	Class 1_J Low risk	Class 2_J Intermediate risk	Class 3_J High risk, especially in areas subject to seismic activity
	Seismicity	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	N/A	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 widespread ponding of surface water after precipitation events AND/OR located within known drainage channel or flood plain

Table 6 Example – extracted pedological information (Tier 2) for foot slopes within land type Ba9 (data from Figure 1, and SEG classes from Figure 2)

Soil types / soil complexes	Prominence	Depth range	Stoniness	Underlying material	Clay content	
					Topsoil	At depth
SEG-I: Hu–Hutton	10%	0.5 – 1.2+ m	0 – no mechanical limitations	so – saprolite hp – hardpan ferricrete	20% – 30%	20% – 35%
SEG-VII: Ms–Mispah SEG-VIII: Gs–Glenrosa	5% 5%	0.15 – 0.4 m	3 – shallow soil on rock	R – rock lc – saprolite hp – hardpan ferricrete	15% – 30%	
SEG-I: Hu–Hutton SEG-IV: Sd–Shortlands	12.5% 12.5%	0.45 – 1.2+ m	1 – some stones, but ploughable	so – saprolite	30% – 45%	35% – 60%
SEG-VII: Wa–Wasbank SEG-IX: Lo–Longlands	10% 10%	0.6 – 1.2+ m	0 – no mechanical limitations	sp – soft/nodular ferricrete hp – hardpan ferricrete	10% – 20%	
SEG-I: Cv–Clovelly	5%	0.3 – 0.75 m	0 – no mechanical limitations	so – saprolite R – rock	20% – 30%	20% – 35%
SEG-X: Ka–Katspruit Wo–Willowbrook	10%	0.35 – 0.75 m	0 – no mechanical limitations	gc – gleyed	30% – 50%	
SEG-I: Gc–Glencoe SEG-IX: Av–Avalon	5% 5%	0.45 – 0.9 m	0 – no mechanical limitations	sp – saprolite	20% – 30%	20% – 30%
SEG-II: Du–Dundee SEG-IV: Oa–Oakleaf	5% 5%	0.9+ m	0 – no mechanical limitations	gs – gleyed	20% – 30%	20% – 35%

approximately 25 ha in size located in the eastern suburbs of the City of Tshwane to assess its suitability for residential development. The study area exhibits the following relevant characteristics:

- The area exhibits a humid climate, as evidenced by a Climatic N-value of approximately 2.4 (Weinert 1980).
- Analysis of the available regional surface elevation information (JAXA 2021) reveals that the land parcel represents a northeastwardly facing foot slope with natural slopes of less than 2°.
- According to the published 1:250 000-scale 2528 Pretoria (CGS 1978) geological

Table 7 Example – allocated contribution scores for geotechnical characteristics (Tier 3) for soils along foot slopes within land type Ba9 (based on data from Table 6)

Adverse geotechnical effects (AGEs)	SEG-I	SEG-II	SEG-III	SEG-IV	SEG-V	SEG-VI	SEG-VII	SEG-VIII	SEG-IX	SEG-X
Total prominence per SEG (%)	**32.5**	**5**		**17.5**			**15**	**5**	**15**	**10**
Category 1: Poor trafficability										
Boulders at surface										
'Sticky' / slippery conditions when wet	5			5			5	5	5	7
Loss of cohesion when wet / 'quick' conditions	3	5		3			3	3	5	5
Category 2: Material re-use potential										
Soil-like material	4	4		4			4	4	4	4
Category 3: Adverse soil behaviour										
Collapse settlement										
Shallow groundwater / seepage		3		3					3	5
Heave / shrinkage	6			6				1		7
Consolidation settlement / 'soft' clays	5	5		5			3	5	5	5
Erodibility and/or dispersion		2							2	2
Waterlogged										2
Category 4: Excavatability problems										
Engineering service trenches	2	1		1			5	2	1	1
Roads and foundation trenches	1						5	2		

map, the site is expected to be underlain by andesite of the Hekpoort Formation that forms part of the Pretoria Group, Transvaal Supergroup, that typically decomposes into a highly expansive residual soil with occasional spheroidal boulders in a relatively humid climatic setting (Brink 1979). The area is not considered dolomite land or affected by undermining and is not located in an area at risk of significant seismic events.

- The published 1:50 000-scale 2528CD Rietvlei Dam (CGS 2001) geotechnical map identifies the inferred occurrence of moderately expansive material with an expected heave in the order of between 5 mm and 30 mm, slight excavatability problems, and low soil permeability in the area.
- Using information from the 1:250 000 scale 2528 Pretoria (Land Type Survey Staff 1987) land type inventory, the study area is inferred to be covered by soils of land type Ba9 typically representing plinthic (i.e. ferruginized) catenas dominated by the presence of leached red and/or yellow apedal soils, but without duplex or moderately structured soils in the uplands (predominantly comprising ridge crests and mid slopes).

Example – data input

The PSGI commenced with identification and dissemination of the relevant pedological information required to allow use of the refined SEG system. The following actions were taken:

- Tier 1: The study area wholly comprises a foot slope covered by soils of land type Ba9, with regional pedological information available from the relevant published land type inventory (marked with a blue box in Figure 1) with soil descriptions according to the BSCS.
- Tier 2: Dissemination of the available pedological information yielded results as detailed in Table 6. It is evident that a variety of soil forms representing several of the SEGs, ranging from apedal soils to soils that undergo prolonged saturation, can be expected to occur within the study area.
- Tier 3: The inferred contribution of the different soil forms with regard to the list of AGEs was subsequently allocated for each SEG by an experienced geo-practitioner (Table 7).

Example – output

The AGE contribution scores resulting from the previous step were then used to calculate AGE severity and AGE impact realisation values (second column in Table 8, with an example of the calculations provided for AGE excavatability problems – roads and foundation trenches) that describe the inferred behaviour of the various soil forms considered present within the study area as a whole.

Table 8 Example – *AGE severity* and *AGE impact realisation values* calculated from the disseminated pedological information (Table 6) and use-defined AGE contribution scores (Table 7), with resultant preliminary geotechnical classification (from Table 5)

Adverse Geotechnical Effects (AGEs)	AGE severity values expressed as percentage of 100% contribution		AGE impact realisation values measured against max value representing 100% realisation of weighted impact		Preliminary geotechnical classification		
					1 – most favourable	2 – intermediate	3 – least favourable
Category 1: Poor trafficability							
Boulders at surface	0	–	0	max 50			
'Sticky' / slippery conditions when wet	71	Expected to occur	71	max 100		2_{supp}	
Loss of cohesion when wet / 'quick' conditions	51	Expected to occur	77	max 150			
Category 2: Material re-use potential							
Soil-like material	100	Unsuitable	400	max 400			3_{supp}
Category 3: Adverse soil behaviour							
Collapse settlement	0	-	0	max 500			
Shallow groundwater / seepage	23	Could occur	139	max 600		2_B	
Heave / shrinkage	54	Expected to occur	375	max 700			3_C
Consolidation settlement / 'soft clays'	67	Expected to occur	537	max 800			3_D
Erodibility and/or dispersion	9	Slight risk	77	max 900	1_E		
Waterlogged	0	-	0	max 1 200			
Category 4: Excavatability problems							
Engineering service trenches	28	Could occur	282	max 1 000		2_F	
Roads and foundation trenches	17	Slight risk	185	max 1 100			
Example of calculations: Score for SEG-I (32.5% of area) = 1 Score for SEG-VII (15% of area) = 5 Score for SEG-VIII (5% of area) = 2 Max contribution value = 7 Max realisation score = 1 100	$1 \times 0.325 = 0.325$ $5 \times 0.15 = 0.75$ $2 \times 0.05 = 0.1$ $(0.325 + 0.75 + 0.1) / 7 = 0.168 \sim 17\%$		$0.168 \times 1\,100 = 185$				
Category 5: Miscellaneous geological, geotechnical and geomorphological parameters							
Steep slopes: slopes of less than 2°						2_I	
Seismicity: 10% probability of an event less than 100 cm/s^2 within 50 years					1_K		

Table 9 Example – list of relevant flag issues according to SANS 634 (SANS 2012) based on AGE severity values (data from Table 8)

FLAG ISSUES		Inferred impacts on development according to SANS 634 (SANS 2012), supplemented where indicated, based on AGE severity values
		Zone A*
Category 1 – Poor trafficability	Occurrence of boulders at the surface	
	'Sticky' / slippery conditions when wet	Class 2_{supp} 'Sticky' / slippery conditions expected after rain
	Topsoil expected to lose cohesion when saturated / 'quick' conditions	Class 2_{supp} Topsoil expected to lose cohesion when saturated
Category 2 – Materials re-use potential		Class 3_{supp} Most to all natural materials expected to be unsuitable for re-use
Category 3 – Adverse soil behaviour	Collapse settlement	
	Groundwater seepage and/or waterlogging	Class 2_B Seepage associated with weak perched water tables expected at a depth of < 1.5 m
	Heave / shrinkage	Class 3_C High soil-heave expected, with an AGE impact realisation value of > 280
	Compressibility / 'soft clays'	Class 3_D High soil compressibility expected, with an AGE impact realisation value of > 300
	Erodibility / dispersion	Class 1_E Low, with an AGE impact realisation value of ≤ 135
Category 4 – Excavatability problems		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	
	Dolomite land	
	Very gentle slopes to nearly flat-lying areas	Class 2_I Slopes of < 2°
	Steep slopes	
	Unstable natural slopes	
	Seismicity	Class 2_K Area exhibiting a risk of mining-induced seismicity with a peak ground acceleration of > 100 cm/s^2
	Periodic flooding	
	Other adverse characteristics (soil and/or strata)	

These values indicate that the soils covering the study area can be expected to exhibit the following adverse geotechnical characteristics:

- poor trafficability when wet, including 'sticky' or slippery conditions and loss of cohesion
- soil-like overburden (i.e. material typically described as a soil when using the MSSCTO profile geotechnical logging system, and could include saprolite) is considered unsuitable for re-use as backfill material in its natural state
- soil-like overburden is expected to exhibit a significant risk of heave / shrinkage and consolidation settlement, with a slight risk of erodibility and groundwater seepage
- a slight risk of difficulties with the excavation of roads and foundation trenches, as well as a more significant risk of problems during the excavation of deep service trenches.

Results obtained by means of the refined SEG system allowed classification of the above-mentioned adverse characteristics according to the proposed system by Partridge *et al* (1993) as enhanced by the refined SEG system (Table 8).

Example – implementation

A list of 'flag' issues, now including Category 5 (miscellaneous geological, geotechnical and geomorphological information from non-pedological sources, as well as supplemental parameters resulting from application of the refined SEG system) is provided in Table 9.

In this light, the preliminary geotechnical classification for the foot slope comprising the whole study area can thus be expressed as follows (symbols explained in Table 9):

$1_{E,K}\ 2_{B,F,I}\ 3_{C,D}$

Additionally, the results of the PSGI were used to provide responses of a geotechnical nature for the BAR process. These responses and the relevant 'flag' issues on which these were based for the preliminary geotechnical zone comprising the whole study area are provided in Table 10.

Table 10 Example – list of responses (dark background) to questions of a geotechnical nature for the whole study area as required for the compilation of a BAR based on the results of the PSGI; class designations are according to SANS 634 (SANS 2012)

Questions of a geotechnical nature as specialist input for bar purposes	Whole study area		
	Responses		Relevant flag issues From Table 9
Shallow water table (less than 1.5 m deep)	Yes	No	Class 2_B Groundwater seepage
Dolomite, sinkhole, or doline areas	Yes	No	Area not indicated to be underlain by dolomitic strata
Seasonally wet soils (often close to water bodies)	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
Dispersive soils (soils that dissolve in water)	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 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 Class 2_F Excavatability problems
An area sensitive to erosion	Yes	No	Class 1_E Low erodibility indicated

CONCLUSIONS

The proposed refined Soils Effects Grouping system defines 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.

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.

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, with the anticipated adverse soil behaviour helping to guide planning of the number and type of expensive field and laboratory tests required.

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 (Table 7). 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.

Use of the proposed system in practice over a period of more than a decade revealed a number of limitations, especially with regard to the use of pedological information from the land type inventories where the depth limit of 1.2 m hampers accurate interpolation of geotechnical information at depth, while the accuracy of the land type boundaries should be assessed prior to use thereof.

It must be noted that the refined SEG system is not intended to replace, but rather enhance, the regional geotechnical maps being compiled by the Council for Geoscience, with results specifically engineered for ease of use by decision-makers not necessarily knowledgeable in geotechnical matters. Conversely, the published geotechnical maps, where available, are of great value to verify the spatial accuracy of pedological information.

Although there are considerable time and cost benefits in obtaining preliminary geotechnical zones by the use of the refined SEG system, it is imperative to note that these should be considered of strategic value suitable for planning and/or informing the Environmental Impact Assessment process only.

In closure, the availability of more accurate pedological information resulting from soils mapping based on the new Natural and Anthropogenic Soil Classification System is eagerly awaited in order to feed more accurate soils information into the refined SEG system.

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