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A critical appraisal of regional geotechnical mapping in South Africa

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SINOPSIS

Die behoefte na en die voorsiening van vinnige en akkurate ingenieursgeologiese inligting vir grootskaalse beplanning en ontwikkelingsdoeleindes, sal altyd bestaan. Die identifisering van land op 'n regionale skaal word derhalwe genoodsaak, ten einde aan die vereistes van 'n groeiende infrastruktuur en die ontwikkeling van huise oor groot areas te voldoen. Dit is dus belangrik om land te identifiseer wat geologies of geotegnies geskik is vir koste effektiewe dorpsontwikkeling, omgewings volhoubaar is, relatief vry van risiko's geassosieër met natuurlike rampe, asook van hulp sal wees in die soeke na konstruksie materiaal reserwes ten einde te voorkom dat sterilisering van hierdie hulpbronne sal plaasvind.

Die hoeveelheid en tipe van inligting benodig vir die prosessering van 'n ingenieursgeologiese kaart sal hoofsaaklik afhang van die doel, inhoud en skaal van die kaart. Regionale ingenieursgeologiese kaarte kan in terme van gebruik beskryf word as spesiaal of meervoudig. Waar spesiale gebruik kaarte verteenwoordigend is van inligting geevalueer in terme van 'n spesifieke komponent van ingenieursgeologie soos byvoorbeeld die graad van verwering van rots of 'n spesifieke behoefte, en algemene gebruik kaarte verteenwoordigend is van inligting wat voorsien word van 'n hele aantal aspekte van ingenieursgeologie vir 'n verskeidenheid van beplanning en ingenieurs gebruike.

Die akkuraatheid van inligting ingesamel, volgens die land faset benadering, vir regionale ingenieursgeologiese doeleindes, sal van die volgende faktore afhang: 1) Die skaal waarop inligting ingevorder is; 2) Die gekompliseerdheid van die karteringsterrein in terme van geologie en landvorme; 3) Die skaal van die kaart waarop inligting voorgestel word.

Faktore wat in ag geneem moet word gedurende regionale ingenieursgeologiese kartering, is gedefinieër en beskryf in terme van veld en laboratorium identifisering, as ook die implikasies wat verband hou met hierdie faktore. Die doel hiervan was om die verskillende klassifikasie sisteme voorheen en tans in gebruik in Suid Afrika, gebasseer op hierdie terrein evaluasie kriteria, beter te verstaan.

Die ontwikkeling van ingenieursgeologiese klassifikasie sisteme en hul geassosieërde voorstellings op 'n kaart, wat in gebruik is of gebruik word in Suid Afrika, asook die toepassing van hierdie verskillende sisteme, is hersien in terme van doel, klassifikasie en voorstelling van data. Die voorstelling van verskillende ingenieursgeologiese sisteme is met mekaar vergelyk deur gebruik te maak van dieselfde ortofoto (2528CD08). Nadat elke klassifikasie sisteem en die saamstel van elke sisteem op 'n kaart hersien is, was dit duidelik dat sisteme geklassifiseer kon word van baie eenvoudig tot baie kompleks. Geen klassifikasie sisteem kan beskou word as beter as 'n ander, weens die feit dat elk van hierdie sisteme vir 'n spesifieke doel ontwerp is. Alhoewel daar gedurende die toepassing en vergelyking van die verskillende geotegniese klassifikasie sisteme gevind is, dat die sisteem ontwikkel deur Partridge *et. al.* (1993) die mees eenvoudigste en praktiese metode bied vir die klassifikasie van 'n terrein vir beplanning en ontwikkelings doeleindes.

'n Sistematiese benadering word gevolg gedurende die gestandardiseerde prosedure en metode vir regionale ingenieursgeologies kartering en kan in die volgende fases verdeel word: 1) Lessenaar studie; 2) Verkenningsondersoek; 3) Veld kartering; 4) Uitvoering van laboratorium analises; 5) Samestelling van die ingenieursgeologiese kaart; 6) Die skryf van 'n verslag waarin die metodiek en die rede vir die spesifieke kaart uiteen gesit word, asook die beskrywing van toestande gevind gedurende die studie.

Spesiale verwysing word gemaak na die geotegniese klassifikasie sisteem ontwikkel deur Zawada (2000) vir die Raad vir Geowetenskappe. Hierdie sisteem is toegepas op die Rietvlei Dam 2528CD kaart, ten einde die toepaslikheid van hierdie sisteem vir gebruik as regionale ingenieursgeologiese kartering te bepaal. Daar kan verklaar word dat die klassifikasie sisteem voorgestel deur Zawada (2000) toegepas kon word vir regionale geotegniese kartering. Sekere tekortkominge is geidentifiseer gedurende die evaluasie en toepassing van die sisteem en aanbevelings word gemaak ten op sigte van veranderings wat moet plaasvind ten einde die geotegniese klassifikasie sisteem te vereenvoudig en meer gebruikersvriendelik te maak.

Bogenoemde veranderings aan die geotegniese klassifikasie sisteem ontwikkel deur Zwada (2000), het tot gevolg dat die sisteem meer vereenvoudig en verstaanbaar is. As ook voorsien die verandering op kaart meer nuttige inligting aan die ingenieursgeoloog, stads beplanner en/of ontwikkelaar. 'n Addisionele kaart gesoneer volgens ontwikkelings potensiaal vir omgewings sensitiewe areas is aangebring, ten einde dit moontlik te maak om dadelik goeie of swak areas te eien.

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ABSTRACT

A need for the provision of rapid and accurate engineering geological information will always exist for broad planning and development purposes. The identification of land on a regional scale is necessary, to satisfy the growing demand for infrastructure and housing development over large areas. It is therefore important to identify land that is geologically or geotechnically suitable for cost effective urban development, environmentally sustainable, relatively risk free from natural hazards as well as to assist in targeting reserves of construction materials to prevent sterilisation.

The amount and type of information required to produce a geotechnical map, will depend on the purpose, content and scale of the map. Regional scale geotechnical maps can be divided into special purpose or general purpose maps. Special purpose maps refer to maps on which information is evaluated in terms of a specific purpose or only one aspect of engineering geology such as the weathering grade and general purpose maps are maps providing information on many aspects of engineering geology for a variety of planning and engineering purposes.

The accuracy of information for regional geotechnical purposes, based on the principals of the land facet approach will depend on the following factors: 1) The scale on which information has been gathered; 2) The complexity of the terrain mapped, in terms of geology and land form; and 3) The scale on which data is represented on map.

Factors that should be taken into consideration during regional geotechnical mapping are defined and explained in terms of the identification in the field and laboratory and the implications of these factors on development. This was done in order to understand the different classification systems previously and currently used in South Africa.

The development of geotechnical maps and their associated classification systems, previously and currently used in South Africa and the application of these different systems, was reviewed in terms of there purpose, classification and presentation of data. Orthophotograph 2528CD08 was used to represent all the different engineering

geological classification systems, which aided in comparing each system and the representation of information on a map. After revision of each classification system and the compilation of maps based on the associated classification systems, it was clear that these classifications systems range from simple to very complex. No classification system can be regarded as better than another, based on the fact that each of this classifications systems was designed for a specific purpose. Although it was found during the application and comparison of the different geotechnical classification systems, that the geotechnical classification system developed by Partridge *et. al.* (1993) was the most simplified and practical method to use for the classification of terrain for planning and development purposes.

The standardised methodology and procedures of regional geotechnical mapping proposed by the Council for Geoscience follows a systematical approach and can be divided into the following phases: 1) Data gathering or desk study; 2) Reconnaissance survey; 3) Field mapping; 4) Laboratory analysis; 5) Compilation of the engineering geological map; and 6) Report writing.

Special reference was made to the geotechnical classification system developed by Zawada (2000) of the Council for Geoscience and was applied to the Rietvlei Dam 2528CD map sheet in order to determine the applicability of this system for regional geotechnical mapping. It could be stated that the classification system proposed by Zawada (2000) can be applied to regional geotechnical mapping. Certain shortcomings were identified during the evaluation and application of the system and recommendations are given on how the system could be modified to simplify the geotechnical classification system and how to improve the utilization of the geotechnical map. After the above mentioned modifications to the geotechnical classification system of Zawada (2000), the system is much more simplified, understandable and provide more useful information. This map is now of use, not only to the engineering geologist but also to the town planner and/or developer, regarding poor and good areas for potential development (zonation map) and areas with environmental constraints.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The dramatic growth and development of urban and surrounding land in South Africa have resulted in increased demands for natural resources such as clean water, land for housing and/or disposal of increasing levels of waste and a variety of construction materials such as brick-making clay and building sand. The provision of land alone is critically important with 50 000 hectares of suitable land needed to build 2,5 million houses - the current backlog- as well as an additional 4400 hectares to meet the annual housing demand of 220 000 houses (pers. comm. NHBRC, 1999).

The Development Facilitation Act of 1995, states that laws should "ensure the safe utilisation of land by taking into consideration the factors such as geological formations and hazardous undermined areas" and "promote sustained protection of the environment" (SAIEG, 1997). The Development Facilitation Regulations which were published in Government Gazette No. 17395 in 1996 state "The land development applicant shall include in his or her application ...an initial geotechnical assessment" (SAIEG, 1997). These are in support of the Standards and Guidelines of the National Home Builders Registration Council, which are aimed at facilitating the production of housing units in accordance with the Reconstruction and Development Programme (SAIEG, 1997).

Finding suitable land for housing and the development thereof follows a phased approach, with the first phase being a regional engineering geological investigation, providing a broad overview of the suitability of the land for proposed development and to outline obvious constraints to the development of that area. This is followed by an investigation for urban development, providing detailed engineering geological and geotechnical data on the area in order to delineate and define areas of geotechnical constraints. From this information a design and development cost estimate can be provided.

The norm in South Africa as far as geotechnical mapping is concerned, has generally been focussed on site specific investigations, or otherwise mapping has been done for specific applications, such as soil engineering mapping for roads. Only a limited number of maps of engineering geological properties on a regional scale have been attempted. A need therefore exists for the provision of rapid and accurate information to identify land on a regional scale, to satisfy the growing demand for infrastructure and housing development over large areas. It is important to identify land that is suitable for cost effective urban development, environmentally sustainable, relatively risk free from natural hazards as well as to assist in targeting possible future reserves of construction materials to prevent sterilisation.

The purpose of regional geotechnical mapping is to provide basic information for land-use planning and development. It is important to realise that due to the scale at which regional geotechnical mapping is conducted these maps are only useful in planning and as a reference during preliminary stages of a site specific investigation in the regional area. It can not be used to determine the engineering geological properties at site specific level. Geotechnical information gathered on a regional scale can be used to assess the feasibility of a proposed land-use or engineering undertaking, and to assist in the selection of the most appropriate terrain.

Engineering geological research and mapping are therefore mainly directed towards understanding the interrelationships between the geological environment and the engineering situation; the nature and relationships of the individual geological components; the active geodynamic processes and the prognosis of processes likely to result from the changes being made (Commision on Engineering Geological Maps of the International Association of Engineering Geology - CEGM-IAEGC, No. 15, 1976).

The engineering geological conditions of an area can best be presented on a map, including the character and variety of engineering geological conditions, their individual components and their interrelationships. The degree of simplification of a map depends mainly on the purpose and scale, the relative importance of specific engineering geological factors or relationships, the accuracy of the information and on the techniques of representation used (CEGM-IAEGC, No. 15, 1976).

1.2. OBJECTIVE

In the light of the above, this research project was undertaken to evaluate the methods used in South Africa to compile regional scale geotechnical maps in terms of:

- The type and level of information required to produce a 1:50 000 scale geotechnical map.
- Methods to compile relevant information in a manner that is easily accessible, standardised and which can be manipulated.
- Recognition of geotechnical properties and highlighting of critical geotechnical factors on the map.
- The accuracy of the distribution and severity class of geotechnical parameters.
- The usability of these geotechnical maps and information available for future land-use utilization.

1.3 DEFINITION OF A GEOTECHNICAL MAP

Geotechnical mapping is defined in a number of ways by different authors:

- An engineering geological map is a type of geological map which provides a generalized representation of all those components of a geological environment of significance in land-use planning, and in design, construction and maintenance as applied to civil and mining engineering (CEGM-IAEGC, No. 15, 1976). An engineering geological map should fulfil the following requirements (CEGM-IAEGC, No. 15, 1976):

- Reflect the objective information necessary to evaluate the engineering geological criteria of the environment involved in regional planning.
- It should make it possible to predict the potential changes in the geological environment likely to be brought about by a proposed development and provide any necessary preventive measures.
- Information should be presented in such a way that it is understandable for professional users, that may not be engineering geologists.
- Engineering geological maps should be based on geological, geomorphological and hydrogeological information, but should present and assess the basic facts provided by these maps in terms of engineering geology.

- The accumulation of all those components of the geological environment which are significant in land-use planning, in design, construction, and maintenance as applied to civil engineering and related fields. Data so accumulated should not only contain all the engineering geological complexities so often understood only by specialists with geological training, but should be presented in a form simple enough to allow professionals of allied fields to easily evaluate and use the available information (Price, 1981). According to Price (1981), the main purpose of engineering geological mapping on a regional scale is to provide engineers, planners and designers with such information as will help them to create engineering structures and to develop the country in the best possible harmony with the geological environment. The map should show the distribution and spatial relationships of the basic components affecting engineering-based decisions. These basic components include the distribution and characteristics of rock, soil and groundwater, characteristics of relief and present geodynamic processes (Price, 1981). An engineering geological map should fulfil the following requirements (Price, 1981):

- It should present information in such a way that it is easily understood by professional users who may not be geologists.
- It should show the objective information needed to assess the engineering geological aspects of the environment.
- It should facilitate the prediction of changes in the engineering geological environment likely to be brought about by proposed development, such as locking in of construction materials.

- The geological factors that influence priorities for urbanisation are a function of the natural environment and are therefore largely immutable. Thus geological considerations will often determine where it is most appropriate to locate different land uses and how best to use available local technological resources to provide services and to build where adverse conditions prevail (Brink *et al.*, 1982).

- It is one branch of applied geology which, broadly, is the application of geology to industry - not some special type of geology but the whole spectrum of the science. Engineering geology is the discipline of geology applied to civil engineering, particularly to the design, construction and performance of engineering structures interacting with the ground in, for example, foundations, cuttings and other surface excavations, and tunnels (Dearman, 1991).

- The classification of the terrain on the basis of its surface form and considering the processes and influences on the formation and engineering properties of the residual and transported soils overlying the host rock in order to assess the geotechnical or engineering geological suitability of vacant land for development (Stiff, 1994).

- An engineering geological map provides an impression of the geological environment, surveying the range and type of engineering geological conditions, their individual components and their interrelationships for planning (Bell *et al.*, 1986). A map, however, represents a simplified model of the facts and the complexity of various dynamic geological factors can never be portrayed in their entirety (Bell *et al.*, 1986).

- According to Dearman (1991), engineering geological mapping is usually motivated by an engineering purpose: planning for land-use in an urban environment, assessing the distribution of construction materials, selection of motorway alignments, or assessing the environmental impact of mineral development.

- An engineering geological map should evaluate geological conditions relating to the design, construction, and maintenance of engineering structures and should portray the following (U.S. Department of the Interior Bureau of Reclamation, 1994):
  - Recognition of the key geological features in a study area that will or could affect significantly a proposed or existing structure.
  - Integration of all available, pertinent geological data into a rational, interpretive, three-dimensional conceptual model of the study area.
  - Presenting this conceptual model to design and construction engineers, to other geologists, and to contractors in a manner which they can all understand and use.

1.4 COMPONENTS AFFECTING ENGINEERING-BASED DECISIONS

The geological environment is a very complex multi-component dynamic system which cannot be studied in its entirety in connection with construction works or other engineering activities. Using the method of model analysis a simplified picture has to be created of this system comprising only those components of the geological environment which from the point of view of engineering geology are of a decisive significance: namely the distribution and properties of rocks and soils, groundwater, characteristics of the relief and present geodynamic processes. A geotechnical map, showing the distribution and spatial relationships of these basic components, can reflect the history as well as the dynamics of the development of engineering geological conditions. The following is a brief description of the basic components of importance from an engineering geological point of view that are considered during geotechnical mapping (after CEGM-IAEGC, No. 15, 1976 and Dearman, 1991):

- Character of rocks and soils: Boundaries of soil and rock units, delineated as units that are characterized by a certain degree of homogeneity in basic engineering geological properties. The classification of rock and soil should be based on their distribution, stratigraphical, structural and textural arrangement, age, genesis, lithology, mineralogical composition, physical state (moisture content, consistency, degree of weathering and alteration, and jointing to identify strength properties, deformation characteristics, permeability and durability), and their physical and mechanical properties (dependent on the combined effects of mode of origin, subsequent diagenetic, metamorphic and tectonic history, and weathering processes).

- Hydrogeological conditions: That affects land-use, planning, site selection and the cost, durability and safety of engineering structures. Surface and ground water play an important role in geodynamic processes (e.g. weathering, slope movement, suffusion, development of karstic conditions and volume changes of soil), methods of construction (flowing of water in excavations). Therefore, is it necessary to evaluate the distribution of surface and subsurface water, water-bearing soil and rocks, infiltration conditions, zones of saturated open discontinuities, depth to water table and its range of fluctuation, regions of confined water and piezometric levels, storage coefficients, direction and velocity of flow; seepage from water-bearing horizons, springs, rivers, lakes and the limits and occurrence interval of flooding; hydro-chemical properties (e.g. pH, salinity, corrosiveness and the presence of pollutants).

- Geomorphological conditions: Is helpful in explaining the recent history of development of the landscape and the processes active in the landscape at the present time, thus is an essential part of geotechnical mapping and is often a decisive factor in the planning of an investigation. Assessment of geomorphological conditions is more than the description of the surface topography, it should provide the basis for an explanation of:

  - Relation between surface conditions and geology,
  - Origin, age and development of individual geomorphological elements,
  - Influence of geomorphological conditions on hydrology and geodynamic processes,
  - Potential development of geomorphological features, such as the erosion of river banks, movement of dunes, subsidence in karstic or undermined areas.

- Geodynamic phenomena: Geodynamic phenomena are those geological features of the environment resulting from geological processes active at the present time. The geological features include those due to erosion and deposition, aeolian phenomena, permafrost, slope movements, formation of karstic conditions, suffusion, subsidence, volume changes in soil, seismic phenomena including active faults, current regional tectonic movements, and volcanic activity.

1.5 PRINCIPLES OF GEOTECHNICAL MAPPING

The content of a geotechnical map depends largely on the purpose of the map (Dearman, 1991). In turn, purpose controls the scale of the map, and scale dictates what can be shown and therefore the information that needs to be collected to compile the map

(Dearman, 1991).

1.5.1 Categorizing of maps for engineering purposes

The type of maps that may be prepared for engineering or environmental purposes, are many and varied and should be categorized in some way (Dearman, 1991). The criteria used to distinguish between different types or kinds of maps, are purpose, content and scale, of which the interrelationships between these criteria are described in Diagram 1(Dearman, 1991):

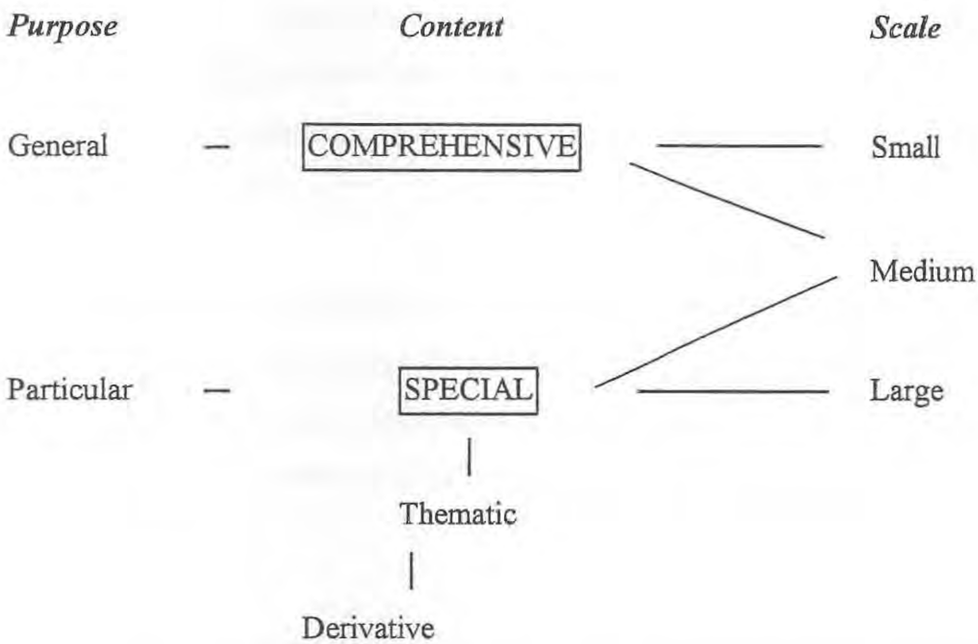

Diagram 1: Interrelationships of the various types of maps (after Dearman, 19991).

- **Comprehensive maps**, attempt to show everything of relevance in the engineering geological environment, which is only possible at small and medium scales (Dearman, 1991). These are of two kinds; they may be maps of engineering geological conditions depicting all the principal components of the engineering geological environment (such as topography with hydrogeology and geotechnical factors); or they may depict on one map sheet those areas which have been grouped for zoning (zoning maps), evaluating and classifying individual territorial units on the basis of the uniformity of their engineering geological conditions, for example the distribution of areas with expansive clays (CEGM-IAEGC, No. 15, 1976).

- Maps dealing with only one component of the geological environment are **specialized** in content and here are called '**thematic**' because they cover only one aspect such as grade of weathering or jointing patterns, these maps are likely to be compiled at medium and large scales (Dearman, 1991). These maps give both details of, and evaluates, an individual component of the geological environment for many purposes. Their content is, as a rule, expressed in the title, for example, map of weathering grades or seismic hazard or slope stability (CEGM-IAEGC, No. 15, 1976).

- **General** purpose maps, are intended to provide information on the many aspects of engineering geology for various planning and engineering purposes and are, almost invariable, comprehensive in scope (Dearman, 1991). These are mostly regional in scale and is more applicable to planning than to design (Bell et al, 1986).

- Maps, and more particularly plans, with specialised content are produced for a **particular** purpose, as for example, the engineering geological conditions at a dam site or along a route way or to show a particular aspect of geology - they may be **thematic**. With **derivative maps**, engineering geological data are required for a specific purpose, for example, prediction of potential hazard and assessment of risk, where the potential hazards depends on the nature of the terrain and the background geological conditions (Dearman, 1991).

- **Documentation maps:** These present factual data and are, for example, documentation maps, structural contour maps and isopach maps (CEGM-IAEGC, No. 15, 1976).

- **Complementary maps:** These include geological, tectonic, geomorphological, pedological, geophysical and hydrogeological maps. They are maps of basic data which are sometimes included with a set of geotechnical maps for the sake of clarity and positioning (IAEGC, 1976).

1.5.1.1 Geotechnical maps based on scale

The selection of an appropriate scale will depend on the purpose for which the map is intended and the amount of detail that has to be shown (Dearman, 1991). Map scale is more often than not directly related to the range of map scales conventionally used for topographic maps in a country (Dearman, 1991). An international scale range was proposed by the UNESCO guidebook (CEGM-IAEGC, No. 15, 1976) and is as follows:

- Large-scale maps (1:10 000 and larger).
- Medium-scale maps (less than 1:10 000 and greater than 1:100 000).
- Small-scale (1:100 000 and less).

1.5.2 Types of geotechnical maps used in South Africa

Geotechnical maps and text are designed primarily for use by engineers, architects, planners, real estate developers and property owners, with the level of technical sophistication incorporated in the report decreasing from engineering through to owner (Price, 1981).

A literature survey of geotechnical mapping, conducted by Price (1981) revealed that a vast variety of geotechnical maps exist. These include maps for regional planning, land development, construction, protection and rational exploitation of resources, hazard risk maps, maps of geomorphology, climate, hydrography, hydrogeology, mechanical classification of rock and soil, slope stability, soil engineering suitability maps, maps of soil thickness, agricultural, geological, urban suitability, land systems, earthquake intensity, seismic risk, landslide susceptibility, etc. (Price, 1981).

Distinction can be made between two kinds of maps based on purpose and scale, namely site specific and regional geotechnical maps (Bester,1981).

Site specific maps provide information for specific design purposes of development on a large scale (1:10 000 and greater) and although out of the scope of this thesis, for example could be:

- Foundation design maps prepared for civil and structural engineers, with the main characteristics being detailed geology and structures, hydro-geology and vertical and lateral distribution of soils and rocks (Price, 1981).

- Land-use and township development maps prepared for town planners, developers and civil engineers, with the main characteristics being the same as above, but also includes a land-use zoning and problem anticipation (Price, 1981).

- Dam construction and irrigation maps for civil and structural engineers with the main characteristics again as above and including the distribution of construction material and defining the agricultural potential (Price, 1981).

- Geotechnical and soil engineering maps for civil engineers. Their characteristics include the assessment of geotechnical aspects, detailed data of the centre-lines of possible roads, proven and reserve material sources, construction hazards and the vertical and lateral distribution of soils (Price, 1981).

- Dolomite maps for township development, are characterised by geophysical information, percussion-borehole and a risk zonation.

Regional geotechnical maps should, by virtue of the fact that it is a general purpose map, representing information on a medium scale (less than 1:10 000 and greater than 1:100 000), incorporating all the above requirements and should be of a general rather than a specific use to engineers, architects, planners, developers and property owners (Price, 1981). According to Bester (1981), regional geotechnical maps cover larger areas as those for proposed structures or developments and provide engineering geological information for the planner, developer and civil engineer to evaluate the area as a whole.

1.6 INFLUENCE OF SCALE ON REGIONAL GEOTECHNICAL MAPPING

The choice of scale for the processing of a regional geotechnical map will depend on the following criteria:

- The most important factor in the selection of an appropriate scale, as already been mentioned, will depend on the purpose for which the map is intended and the amount of detail that has to be shown (Dearman, 1991). As already been mentioned, regional geotechnical mapping are used for general purposes and therefore information are provided on the many aspects of engineering geology for various planning and engineering purposes and are, comprehensive in scope and for thus will be represented on a medium scale (1:10 000 - 1:100 000) (Dearman, 1991).

- The second factor that should be taken into consideration to determine the mapping scale during regional geotechnical mapping, is the size of the country that must be mapped on a regional scale (Price, 1981). Very large countries such as the United States of America (USA) and Russia (USSR), would in general use a small scale (less than 1:100 000) for mapping. According to Price (1981), the USSR uses a "general" scale of 1:200 000, "simple" map scale of 1:500 000 and a "complex" map scale of 1:100 000. In small countries such as Spain a medium to large scale (1:10 000) will be used. Maps presented on a larger scale is more beneficial and can provide better quality information than small scale maps, this is because mapping can be done more accurately based on the amount of information gathered and represented, boundaries between mapping units are more detailed being a function of printing scale and the delineation of contacts (Price, 1981). It should be stated that the meaning of larger maps in thus contexts is not the same as the enlargement of small scale maps to a larger scale, such change of scale is referred to as 'empty enlargement', where additional detail doesn't appear on the larger scale map (Dearman, 1991).

- The third criteria of importance in the choice of mapping scale, is the complexity of the terrain to be mapped (Price, 1981). The complexity of an area will depend on the geology and land-form from where the geotechnical map is derived. If an area is complex, care should be taken in the choice of scale, if the scale is to small the map will contain no meaningful information and will be a waste of time and money or chosen too large the map loses its regional credibility.

- Fourthly, the factor of scale will be influenced by complementary maps available for the area, such as geology, topographical sheets, aerial photographs, orthophotos and soil maps (Price, 1981). As mentioned already, map scale is more often than not directly related to the range of map scales conventionally used for topographic maps in a country (Dearman, 1991).

Data accuracy is primarily determined by the accuracy of data collection and the scale on which the data are represented on map. The tolerances for various scales will differ and care must be taken that the right set of tolerances are applied for a given scale at which features are represented (Croukamp, 1996). When working with data at a scale of 1:50 000, a 1 millimetre thick line on the map already represents 50 metres on the ground. However, if the scale of investigation is 1:10 000, 50 metres accuracy will not be acceptable (Croukamp, 1996).

According to Price (1981), the most beneficial scale for regional geotechnical mapping in South Africa is a medium scale of 1:50 000. This is because most complementary maps (e.g. topographical sheets) are available on this scale. For accuracy, information could be gathered on 1:10 000 scale ortho-photographs, transferring this information over to a 1:50 000 scale topographical sheet for presentation purposes and still maintaining accuracy.

CHAPTER 2

TERRAIN EVALUATION CRITERIA

2.1 INTRODUCTION

In order to understand the different geotechnical classification systems previously and currently used in South Africa that will be discussed in the following chapters, the factors which should be taken into consideration during a regional geotechnical mapping process should be defined and explained. It is important to know how such features are recognized and classified. This will include geotechnical factors, construction materials and environmental considerations.

2.2 GEOTECHNICAL FACTORS

The different geotechnical factors are explained below in alphabetical order. This include a definition of each geotechnical factor, identification of the factor by means of field observation, laboratory testing and the associated implications of the factor on development.

2.2.1 Active, Expansive or Swelling soil

Expansive clays are probably the most widespread of problem soils in South Africa (Williams *et al.*, 1985). Damage to structures placed on potentially active soils may occur where the expansiveness has not been quantified and remedial measures not employed (Weaver, 1990). Most clayey soils change in volume as their moisture content changes seasonally where the amount of volume change depends on the type and amount of swelling clay in the soil. Shrinkage occurs mainly during the dry season and swelling during the wet season. Clay minerals can be broadly divided into swelling and non-swelling clays. Non-swelling clays are associated with regions of high temperature and high rainfall, where the bases are removed as soluble compounds and transported from the soil to leave an insoluble weathered residue of silicates in which kaolinite is the dominant, non-swelling, 1:1 lattice type clay mineral (Williams *et al.*, 1985). With decreasing rainfall or impeded drainage, chemical weathering becomes less intense and soluble bases released by weathering are not leached from the soil. This leads to the formation of the 2:1 lattice clay minerals in which successive sheets in the crystal structure contain varying amounts of water molecules (Williams *et al.*, 1985). It is the change in the amount of this water which causes swelling or shrinkage of the sheet structure and hence of the soil mass as a whole (Williams *et al.*, 1985). Soils with a large proportion of the smectite group clay minerals (e.g. montmorillonite) have the greatest shrinkage and swelling characteristics.

Expansive soils are usually recognized in profile by their colour and structure being often black, dark grey, red or mottled yellow-grey but seldom light grey, brown or white. They show slickensiding or shattering, which is distinctive evidence for heaving conditions (Williams *et al.*, 1985). The parent material, climate and landform is the most important factors in the formation of expansive soils. Expansive soils are associated mainly with areas where the underlying bedrock geology is basic in composition (e.g. andesite and dolerite) and with low-lying areas, such as flood-plains, pans and drainage channels. The amount of expected heave also generally increases downward from a hill crest to a gully. A factor that may reduce the influence of heave on potential development is the presence of a ferricrete layer overlying residual expansive soils (Carr, 1995).

The potential expansiveness of a soil depends upon its clay content, the type of clay mineral, its chemical composition and mechanical character (Van der Merwe, 1964). The plasticity index and linear shrinkage of soil samples can be used to indicate the soils potential expansiveness. A material is potentially expansive if it exhibits the following properties (Kantey and Brink, 1952):

- a liquid limit of more than 30%,

- a plasticity index of more than 12%,
- a linear shrinkage of more than 8% and
- a clay content greater than 12%.

The method of Van der Merwe (1964) can be used to determine the potential heave of soil samples. The expected potential heave ranges from low, medium, high to very high. Although this method is widely used in South Africa, it may over estimate the potential for expansion. This is ascribed to it's reliance on the plasticity index and clay percentage (fraction of soil passing the 2 micron sieve) of the soil, where the clay fraction can comprise a significant amount of non-swelling minerals such as quartz and calcite. Other laboratory tests that could be conducted on expansive clays include the double oedometer test and Brackley's Equation (Brackley, 1975), where the swell percentage is expressed as a function of the plasticity index, original moisture content, external load and the original void ratio. Brackley also developed a second empirical relationship where swell is expressed as a function of the plasticity index, moisture content, density and soil suction (Brackley, 1980).

Williams et al. (1995) determined that there is a linear relationship between percentage swell and the natural logarithm of applied load both for when swell takes place under constant load and under decreasing load, during studies of the volume change behaviour of various undisturbed soil samples in oedometers. The following generalized swell equation was derived from these studies:

$$\text{Swell \%} = \text{Free swell \%} \left(1 - \frac{\log_{10} P}{\log_{10} Ps} \right)$$

The free-swell is measured on a sample under a nominal 1 kPa applied pressure (P). Ps is the swelling pressure of the soil. The percentage swell can therefore be determined under any applied pressure once the free-swell and swelling pressure of the soil have been established.

2.2.2 Collapsible soils

Collapsible soils are soils, which can withstand relatively large imposed stresses with small settlements at a low in situ moisture content but will suddenly decrease in volume causing relatively large settlements when wetting occurs under a load, with no increase in the load. This volume change is associated with a change in the structure of the soil. The following four conditions need to be simultaneously satisfied before collapse will occur according to Schwartz (1985):

- The soils exhibit a collapsible fabric. A collapsible fabric may occur in any open structured silty, sandy soil with a high void ratio (low dry density).
- Partial saturation of the soil is required as collapse settlement will not occur in soils below the water table.
- There must be an increase in moisture content. The bridging colloidal material undergoes a loss of strength and the soil grains are forced into a denser state of packing with a reduction in void ratio.
- The soils need to be subjected to an imposed pressure (e.g. single storey house) greater than their natural overburden pressure.

According to Brink *et al.* (1982) the collapse phenomenon could be associated with colluvial sediments situated on straight slopes, plains and residual soils on well-drained hill slopes, that are derived from weathered granite, sandstone or quartzite.

Collapsible soils can be recognized in profile by a dry to slightly moist moisture content indicative of partial saturation, a loose to very loose consistency, open structure, silty sand to sandy silt soil matrix and the presence of colloidal coatings and clay bridges. Another way to identify soils with a collapsible grain structure in the field, is the reduction in volume that will be observed when a test pit is backfilled. If the soil has a collapsible grain structure it will fail to fill the pit completely, whilst with other soils one would find a bulking factor.

A collapsible fabric could be diagnosed in several ways by means of laboratory procedures. Analysis of the particle size distribution could be done in two ways, 1) If the particle size distribution reveals silty or sandy soils with a low clay content (< 20 %) not enough clay is present as cement between grains to support the soil structure and a potential for collapse exist (Brink *et al.*,1982), 2) An indication of the collapse potential of the soils is obtained by comparing the grading curves of the material with a set of grading limits defined by the grading curves of samples proven to be collapsible as determined by Knight (1961) and Errera (1977). Any soil with a dry density of <1600 kg/m^3 should be regarded as potentially collapsible, the high void ratio of collapsible soils impart low dry densities in the range of 900 - 1600 kg/m^3 (Brink *et al.*,1982). The collapse potential test is an index test, which assists in the identification of potentially collapsible soils during regional geotechnical mapping. This method however is widely used to quantify the severity class of collapse. The severity classes range from no problem, moderate trouble, trouble, severe trouble, to very severe trouble. The most reliable method to determine the amount of collapse is by means of the double oedometer test (Brink *et al.*,1982).

2.2.3 Compressible soils

Poorly consolidated or highly compressible soils are liable to consolidate under applied loads, leading to settlement (Brink *et al.*, 1982). The compressibility of a soil depends on the structure of the soil (arrangement of the soil particle packing) and the hydrostatic pressure. Compressible soils usually have a high moisture content and unorientated loose packing, so if pressure is applied, the particles re-align themselves and disperses most of the water - hence compression occurs (Price, 1981).

This type of settlement is commonly associated with recent alluvial deposits (e.g. soft clays in flood plains) which have not been significantly desiccated or compressed by temporary loads (e.g. deep sedimentary mantles subsequently removed by erosion) and have consolidated only under their own overburden pressure (Brink *et al.*, 1982). Poorly consolidated soils can also develop on plains or very gentle straight slopes.

The amount of settlement is dependent on the applied load (e.g. single-storey house), the moisture content and the structure of the soil. The amount of settlement of a soil can be determined by means of testing an undisturbed sample in a consolidometer.

Poorly consolidated soil gives shear strength problems (low bearing capacity), compressibility and time related settlement problems, especially in embankments. The most practical foundation technique available for this problem is conventional piling where the load of the structure is transmitted by piles to deeper and stronger horizons or the use of *in situ* densification methods in more sandy deposits.

2.2.4 Dispersive soils

Dispersive soils are prone to disaggregation or deflocculation in contact with water. This could cause failure of slopes, earth dams and embankments where piping erosion of dispersive clay soils starts along zones of high soil permeability (e.g construction planes, desiccation cracks, etc.).

The dispersivity of a soil is a measure of its susceptibility to erosion. The tendency for dispersive erosion in any given soil depends upon such variables as the mineralogy and chemistry of the clay and the dissolved salts in the soil water and the eroding water (Elges, 1985). High exchangeable sodium percentage (ESP) values and piping potential exist in soils where the clay fraction is largely composed of smectite and other 2:1 clays (e.g. montmorillonite). Dispersion occurs when the repulsive forces (electrical surface forces) between individual clay particles exceed the attractive (van der Waal's) forces so that when the clay mass is in contact with water individual clay particles are progressively detached from the surface and go into suspension (Elges, 1985). If the water is flowing the dispersed clay particles are carried away. The main property of the clay governing the susceptibility to dispersion piping is the percentage absorbed sodium cations on the surface of the clay particles relative to the quantities of other poly-valent cations (calcium, magnesium or aluminium) (Elges, 1985). The second factor governing the susceptibility of the clay mass to dispersion piping is the total content of dissolved salts in the carrying water. The lower the content of dissolved salts in the water, the greater the susceptibility of sodium saturated clay to dispersion (Elges, 1985).

Dispersive soils are typical of certain areas and certain geological settings and will develop under the following circumstances (Elges, 1985):

- Low-lying areas where the rainfall is such that seepage water has high SAR (sodium absorption ratio) values and in regions with a N-value >2. Soils developed on granite are especially prone to the development of high ESP values in low-lying areas.
- Areas where the original sediments contain large amounts of 2:1 clays (montmorillonite, vermiculite) with high ESP values. Particularly with mudstones and siltstones of the Beaufort Group and the Molteno Formation in regions with a N-value >2. In these regions soils in low-lying areas will virtually without exception be dispersive.
- The development of dispersive soils in the more arid parts (N-value > 10) is inhibited by the presence of free salts, despite high SAR values. Highly dispersive soils can develop, should the free salts with high SAR values be leached out.

According to Elges (1985) dispersive soils can be recognised in the field by the following features:

- Gully erosion (dongas) and field tunnelling (piping and jugging).
- Washed-out clay fans with a very pale colour.
- Areas of poor crop production indicative of high saline soils which are dispersive.
- Calcrete formations above a clay horizon, observed from exposed cuttings.
- A clay soil which softens rapidly with a greasy feel, on contact with water.
- Dispersive soils with a high content of smectite clays and a PI>30, have a fairly high swell potential and are very impervious. If the soil layer is wetted only to a depth of 4 centimetres after heavy rains, one may suspect a dispersive soil.

Laboratory tests include the Soil Conservation Services double hydrometer test, the Emerson crumb test, the pin-hole test, test of dissolved salts in the pore water and the chemical (ESP based) test. The most reliable test being used is the chemical test (ESP based). The Emerson crumb test (index test) is normally used during regional geotechnical mapping and consists of a 15 mm cube specimen placed in 250 ml distilled water. As the soil crumb begins to hydrate the tendency for colloidal sized particles to deflocculate and to go into suspension is observed. Four grades are discernable: 1-no reaction, 2-slight reaction, 3-moderate reaction, and 4-strong reaction. The crumb test generally gives a good indication of the potential erodibility of clay soils.

2.2.5 Excavatability of ground

The ease of excavation is a critical financial factor for development when installing underground services and placement of foundations. The excavatability of ground is described in terms of the ease with which ground can be excavated or dug out to a depth of 1,5m. The ease of excavation depends on the consistency (e.g. very stiff clays are difficult to excavate), type of material, presence of boulders and bedrock weathering depth. The severity classes of excavatability range from slight (can be hand dugged), moderate (back-actor is required), to severe (blasting and/or power tools required). The excavatability is determined during fieldwork, whilst digging test pits or augering of boreholes.

Weaver (1975) utilized the geomechanical classification system of Bieniawski (1973) and developed a rippability rating chart, during which the geological factors that are significant in the evaluation of characteristics of earth and rock materials are described and a guide to the assessment of rippability by tractor mounted rippers are given. The geological factors taken into consideration include: Rock class, seismic velocity (m/s), rock hardness and weathering, joint spacing (mm), joint continuity, joint gouge, strike and dip orientations. Each of this geological factors have specific ratings, a total rating are determined by adding the points of the different factors together and from there a rippability assessment can be made.

The South African Bureau of Standards (SABS) has a specific subclause on the classification of materials for excavation, during contract cost estimates. According to SABS 0120: Part 5, Section D-1982, the following classes of excavation must be used during cost estimates:

- Soft excavation: Material capable of sustaining plant life and removed to a depth of 150 mm or as otherwise ordered, for use as topsoil, is classified as soft excavation.
- Hard rock excavation: Unweathered or undecomposed rock in thick ledges, bedded deposits, or conglomerate deposits so firmly cemented together as to present all the characteristics of solid rock that cannot be efficiently loosened, dislodged, or excavated without the use of explosives is generally classified as hard rock excavation.
- Boulder excavation Class A: The inclusion in the definition of boulder excavation Class A of the phrase "40% by volume of boulders" is an important criterion which has the effect of changing the classification of a particular material from "boulder Class A" to "hard rock" as the plan dimensions of the excavation change from those of a large open area such as a road cutting or a foundation for a major structure to those of a confined area or trench-like shape such as the individual footings for a structure or a pipe trench.

Both the criteria of Weaver and the SABS is applicable to site specific investigations and not for use during regional geotechnical mapping.

2.2.6 Inundation (flooding)

Inundation affects the use of low, flat lying areas, confined to drainage channels and flood plains. Floods are natural events that have to be taken into account where development encroaches on or close to stream channels. Therefore most residential development, such as houses, cannot be erected in areas below the 1:100 year flood line (DFA, 1995) and these areas should be indicated on the geotechnical map. Note should be taken however, that certain developments may have significant affects on the flood behaviour of a river. Factors such as changed hydrology, sediment loads and river diversions can have significant impacts to the extent that areas before development with a low risk of flooding can become high risk areas after development. Development planning also should be aware of the impact of altered flow and flood patterns on the abiotic and biotic life in sensitive environments such as wetlands.

2.2.7 Pseudokarst

Granitic soils are susceptible to pseudokarst formation because their particle distribution allows for the washing out of fine material given a sufficient hydraulic gradient (Brink, 1979). This phenomenon is produced by the mechanical and chemical action of water through which finer materials are washed out from between coarser particles by selective mechanical suffosion or piping (Brink, 1979). The dispersiveness of the soil contributes to this particular problem. This problem is associated predominantly with the flow of water along side roads and drainage channels. Pseudokarst conditions can only be determined by the excavation of test pits during site specific investigations.

2.2.8 Shallow water table

A shallow water table is 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 higher than the regional water table.

A shallow water table could occur in alluvial plains and topographical flat areas. During the wet summer months, these areas may be inundated with water, thus reducing the bearing capacity of the soils and / or providing for seasonal problems relating to cyclic shrink-swell effects occurring within swelling clays. It is advised that precautionary measures be taken to allow for the drainage of water from excavations during construction to prevent instability in cut clay slopes. A shallow water table is also vulnerable to contamination by incorrectly sited facilities such as waste sites, pit latrines and cemeteries. It can also be regarded as a cost factor, due to the negative impact on structures resulting from rising damp and possible damage to sub-surface services due to a bouancy effect.

A fluctuating water table could be recognized in test pits as pedogenic concretions (e.g. ferricrete) tends to develop at the base of a current or previous perched water table.

2.2.9 Sinkhole formation

Areas underlain by dolomite exhibit a potential for sinkhole or doline formation, which is a serious geological hazard that can lead to structural damage, draining of water features, the contamination of groundwater and loss of life. Dolomitic land is defined as areas, which are directly underlain by dolomite or where dolomite is found within 100m of the surface (Buttrick *et al.*, 2001).

Triggering mechanisms in the formation of sinkholes are the downward percolation of water from leaking services and the lowering of the groundwater table (e.g. mining activities and municipal use). This enhances the weathering and dissolution process of the dolomite to form unstable cavities which are left unsupported when the groundwater is lowered. Sinkholes are formed by dissolution weathering of the carbonate minerals within the rock mass by groundwater containing carbon dioxide (Brink, 1979). These voids enlarge with time as the weathering process continues. Fractures in the rock are enlarged and eventually results in sinkholes.

A sinkhole can be defined as a surface subsidence which occurs suddenly, as a cylindrical and very steep-sided hole in the ground, usually but not always, circular in plan (Brink, 1979). A compaction subsidence or doline can be defined as a surface depression which appears slowly over a period of years (Brink, 1979). It may be circular, oval or linear in plan.

The scale on which regional geotechnical mapping is conducted doesn't permit the determination of sinkhole formation severity classes for any particular area. A detailed site investigation including gravity surveys, drilling and test pits with a risk assessment, is required for areas underlain by dolomite before development can proceed. Precautionary measures and specified founding methods should be employed in areas that are underlain by dolomite.

2.2.10 Slope stability

Residential development is favoured on slopes with a gradient of less than 12°, with the exception of the Kwazulu-Natal and Mpumalanga provinces where a gradient of less than 18° is allowable.

Slope instability could be defined as areas comprising unstable geological materials that could move down slope either gradually (creep) or suddenly as a slump or a slide. The risk of slope instability is determined by natural or induced factors. Natural factors include, the nature of the slope (solid rock or soil-density, angle of internal friction, cohesion), gradient of the slope, role of water (height and fluctuation), type and nature of vegetation cover, orientation of linear structures (e.g. joints, fault zones, fracture zones, dykes) and seismicity. Induced factors are those which are as a result of human activities (e.g undermining of a slope during excavation of roads or structural developments). Induced slope instability can also be caused by mining activities such as mine dumps, opencast mines and quarries, where the height of the slope and the angle of the slope exceeds the angle of internal friction of the natural material.

During geotechnical mapping areas are also mapped according to their risk of becoming unstable due to human activity (e.g. road cuts).

2.3 CONSTRUCTION MATERIALS

When locating potential quarries for construction and building materials the following should be considered (Zawada, 2000):

- Their close proximity to urban areas, to keep transport costs to a minimum.
- Close liaison with town and regional planners to relate the operational life of the quarry with the long term land use and development plans of adjoining areas.
- The environmental implications of establishing a quarry close to an area of rapid development such as the aesthetic impact, dust, smoke, water and noise pollution, excessive traffic and the legal restrictions of an operating quarry.
- Urban encroachment has led to the sterilization of potential construction material resources in the past. It is therefore important for planners to be aware of the occurrence of potential construction materials during land-use planning.

All existing quarries (non-operational and operational), as well as potential resources should be indicated on the map. If the potential resources are not indicated, it should be defined and described in the report/explanation accompanying the map. The environmental aspects of disused quarries should also be discussed.

Potential natural resources consisting of brick-making clays, aggregates (fine and coarse), road material, dimension stone and mineral deposits, should be defined in terms of suitability, quality and available reserves. The requirements as set out for brick-making clays, coarse aggregates and building sand, should be used to determine the suitability and quality of materials (Morrison, 1980). The evaluation of sound construction materials to be used in roads, should be done according to the reference work by Weinert (1980).

2.4 ENVIRONMENTAL CONSIDERATIONS

The assessment of facilities such as cemetery sites, waste disposal sites and ground based sanitation systems (pit latrines/septic tanks) should take specific soil conditions into account, that could have a negative impact on the environment (e.g. contamination of water, groundwater, soil and air by organic and inorganic pollutants). Comment is given on the general soil conditions of these environmentally sensitive facilities. The requirements for each facility are discussed in the following paragraphs.

2.4.1 Cemetery sites

A number of requirements have to be met for a particular area to be suitable for use as a potential cemetery site. These include the following (Fisher, 1994):

- Surface gradient of between 2° and 6° (up to 9° in extreme cases) to ensure adequate site drainage, minimum erosion and to promote human and mechanical mobility on site.
- A deep soil profile of at least 1,80 metres for ease of excavation (preferably hand tool excavation).
- A soil consistent enough so that the stability of grave walls is maintained for a few days. Soil consistency of at least medium dense for non-cohesive soils and/or firm for cohesive soils.
- A low permeability (10^{-5} cm/s to 10^{-6} cm/s) of underlying soils to prevent ground water contamination.
- A particular location such that the site is situated at least 100 metres from the 50 year flood-line of drainage channels.
- Ground water level, perched or permanent, must be deeper than 4 metres.
- A buffer zone of at least 2,5 metres below the base of the graves and top of the ground water level.
- No drainage channels through the proposed area.
- Dolomite should not occur as the underlying geology.
- Borehole drinking water at a minimum safe distance of 500 metres from the terrain.
- Large enough area for future extensions (3000 graves per hectare).

2.4.2 Waste disposal sites

Requirements for waste disposal sites as outlined by the Department of Water Affairs and Forestry (DWAF, 1998). There are a number of requirements that have to be met, for a particular area to be suitable for use as a potential waste disposal site. These include the following:

- A deep soil profile of at least 1,5 metres for excavation and provision of adequate cover material.
- Soil cover material must be of good quality (USCS soil classes: CL, SC or GC) and sufficient volume for 10 to 15 centimetres compacted cover per day.
- The underlying material should be of moderate permeability (10^{-3} to 10^{-5} cm/s) to ensure sufficient attenuation of leachate.
- Aesthetical placing of the site, preferably out of sight and downwind of residential and urban areas.
- The site must be secure from flooding (above the 1:100 year flood-line) and away from drainage channels and surface water bodies.
- A vertical buffer zone of 2,0 to 3,0 metres between the bottom of the waste and the highest groundwater level and 500 metres from the nearest borehole.
- A large enough site for the expected volume of waste for at least the next 10 to 15 years.
- Limited or controlled entry to prevent risk to humans.

2.4.3 Ground based sanitation systems (pit latrines / septic tanks)

Pit latrines (wet system) are normally adopted were the volume of liquid waste is small and evaporation is high, septic tanks (semi-wet system) are installed for large volumes of liquid waste.

Both require soils of suitable permeability, since both involve a subsoil percolation disposal system. Magni and du Cann (1978), state that approximate permeability limits of soil in which pit latrines are to be dug should be less than 4×10^{-3} cm/s to prevent pollution and more than 5×10^{-4} cm/s to be sufficiently permeable to allow for attenuation of the effluent. A higher permeability value may be permissible where the water table is very deep or where there are no water supply boreholes in the immediate vicinity. These ground based systems should not be sited in highly permeable sandy or impermeable clayey soils.

Apart from permeability, there are a number of other requirements that also have to be met to prevent excessive pollution occurring in areas that utilise ground based sanitation systems. Sanitation systems should not be sited in areas were the following conditions occur (after De Villiers, 1987):

- Within shallow bedrock or difficult excavation conditions. At least 2 metres of suitably permeable and excavatable soil is required from the surface to the base.
- Located uphill or within 30 metres of a groundwater source.
- Sited within 6 metres of a house.
- Preferably, dolomite should not occur as the underlying geology.
- Within a perched or shallow water table.
- In the immediate vicinity of drainage features and drinking water extraction points.
- Sited in soils of loose or soft consistency, that can cause unstable pit walls.

CHAPTER 3

DEVELOPMENT OF REGIONAL GEOTECHNICAL CLASSIFICATION SYSTEMS IN SOUTH AFRICA

3.1 INTRODUCTION

This chapter will mainly deal with geotechnical maps and associated classification systems developed in South Africa. Each geotechnical classification system will be reviewed considering the purpose, classification and presentation of data. All these classification systems are based on the land system approach, after Brink *et al* (1982). The 1:10 000-scale orthophoto map area 2528CD08, will be used as a base to represent the land system approach that forms an integral part of regional geotechnical mapping. The different geotechnical classification systems, will be compared using the above mentioned area, which will aid in the evaluation of the uses and presentation of each classification.

3.2 LAND SYSTEM APPROACH

A recurrent pattern of genetically linked land facets is known as a land system, thus a land facet represents a sub part of a land system. The principles of modern day terrain evaluation techniques for engineering geological purposes, are based on the Land Facet approach, discussed and advocated by various authors (Price (1981), Brink *et al* (1982), Lawrens *et al* (1993)). This approach serves as a basis for the collection of terrain information, that can be structured, modelled or interpreted in a Geographical Information System (GIS) for land-use planning.

The Land Facet approach to terrain evaluation is a cost-efficient and accurate technique to adopt as it endeavours to consider all the processes and influences on the engineering properties of soil (Stiff, 1994). It allows an area of terrain which has a similar host lithology and has undergone similar soil-forming processes to be compared to analogues in other areas (Stiff, 1994). Sampling points need therefore to be less frequent (limited resources), allowing large tracts of terrain to be mapped in a shorter time span and at much lower costs to identify areas of suitable land for urban development (Stiff, 1994). The major factors which influence the engineering properties of a soil are as follows (Stiff, 1994):

- land form,
- geology (host rock type),
- climatic situation
- geomorphological process (erosional cycle)
- geomorphological province

The basic unit of this classification is the land facet, which is an area of ground with a simple surface form, a specific succession of soil profile horizons (each with reasonably uniform properties, but with varying thickness) and a characteristic groundwater regime (Partridge, 1994). In undisturbed areas the land facet is characterized also by a locally distinctive plant association (Partridge, 1994). A land facet may be delineated on aerial photographs at scales between 1:10 000 and 1:50 000 (scale of regional engineering geological mapping), although in arid areas it may be possible to do so at scales as small as 1:80 000 (Partridge, 1994). Characteristically, land facets are small units and usually correspond to individual physiographic features, such as outcrops and free rock faces, talus slopes, alluvial fans, and alluvial terraces (Partridge, 1994).

Underlying the definition of this unit is the idea of prediction: by knowing and being able to recognize a land facet one may predict, from one occurrence of it to another (Partridge, 1994).

During regional geotechnical mapping (1:10 000 or 1:50 000), because of the scale criteria, many of the facets are too small to form part of the regional map, so that some form of regrouping is required (Price, 1981). This regrouping is known as the facet group analysis (Price, 1981). A facet group may be described as a number of facets grouped together to form one mapping unit, which should be similar in soil profiles, engineering behaviour, regional land form and geology (Price, 1981). These facet groups will consist of areas of outcrop and no outcrop, with the "no outcrop" areas further sub-divided into facet group areas of similar soil profile and engineering parameters (Price, 1981).

Having explained the land facet approach it would be appropriate to give an example to illustrate the construction of such maps. Figure 1 and Figure 2 represent the geology and land form map respectively. These two maps are then combined to produce a land facet map, on which all potential mapping units are delineated (Figure 3). Each land form was coded, based on the codes used by Croukamp (1996) for presentation purposes (Table 1).

Table 1: Classification of landforms based on the codes used by Croukamp (1996).

CODE	LAND FORM	CODE	LAND FORM	CODE	LAND FORM
1	Crest	19	Plains & dunes	37	Bog
2	Mountain crest	20	Plain	38	Delta
3	Hill crest	21	Shifting dunes	39	Sand bank
4	Ridge crest	22	Stabilised dunes	40	River channel
5	Plateau crest	23	Drainage features	41	Drainage channel
6	Mesa ("Tafel koppie")	24	Gully head	42	Dam
7	Tor ("Castle koppie")	25	Gully/donga	43	Spring
8	Bornhardt ("Kaal koppie")	26	Rill erosion	44	Lake
9	Free face/cliff	27	Sheet erosion	45	Solution features
10	Slopes	28	Pan	46	Subsidence area (doline)
11	Talus slope	29	Pan floor	47	Sinkhole
12	Convex slope	30	Pan side	48	Coast
13	Concave slope	31	River terrace	49	Lagoon
14	Straight slope	32	River bank	50	Raised beach
15	Pediment	33	Levee	51	Beach
16	Dissected pediment	34	Flood plain	52	Estuary
17	Land slide	35	Swamp	53	Excavation
18	Fan	36	Vlei/marsh	54	Disturbed land

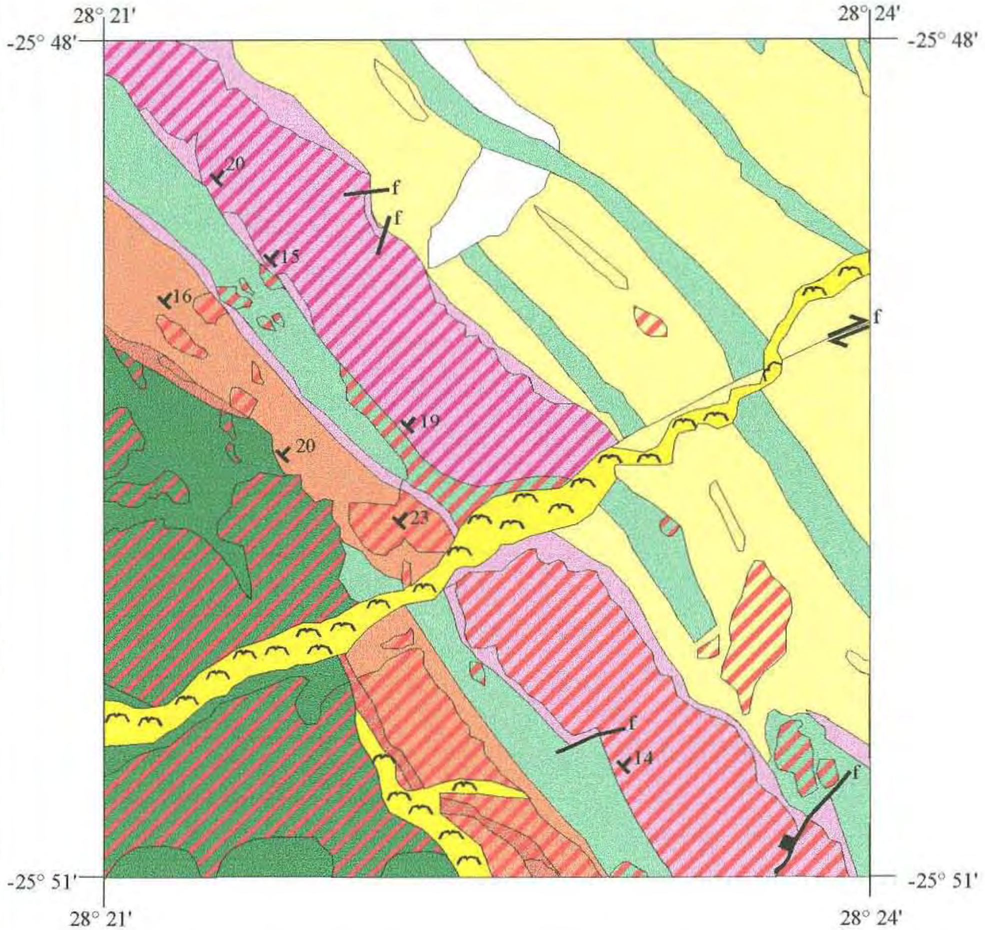

Figure 1 : Geology of Rietvleidam 2528CD08

Scale : 1 : 50 000

Council for Geoscience

GEOLOGICAL LEGEND

LITHOLOGY	FORMATION	GROUP	SUPERGROUP
Alluvium			
Ground soil, gravel, conglomerate, shale, clay			Surficial deposits
Shale with inter-bedded chert	Silverton		
Quartzite	Daspoort		
Ferruginous shale with basal ferruginous quartzite and conglomerate	Strubenkop	Pretoria	Transvaal
Quartzite and subordinate shale	Dwaalheuwel		
Andesite	Hekpoort		
Diabase dykes and sills			
Syenite dyke			

LEGEND SYMBOLS

- Fault
- Dip & Strike
- Outcrop
- Fault with downthrow side

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Date : October 2001

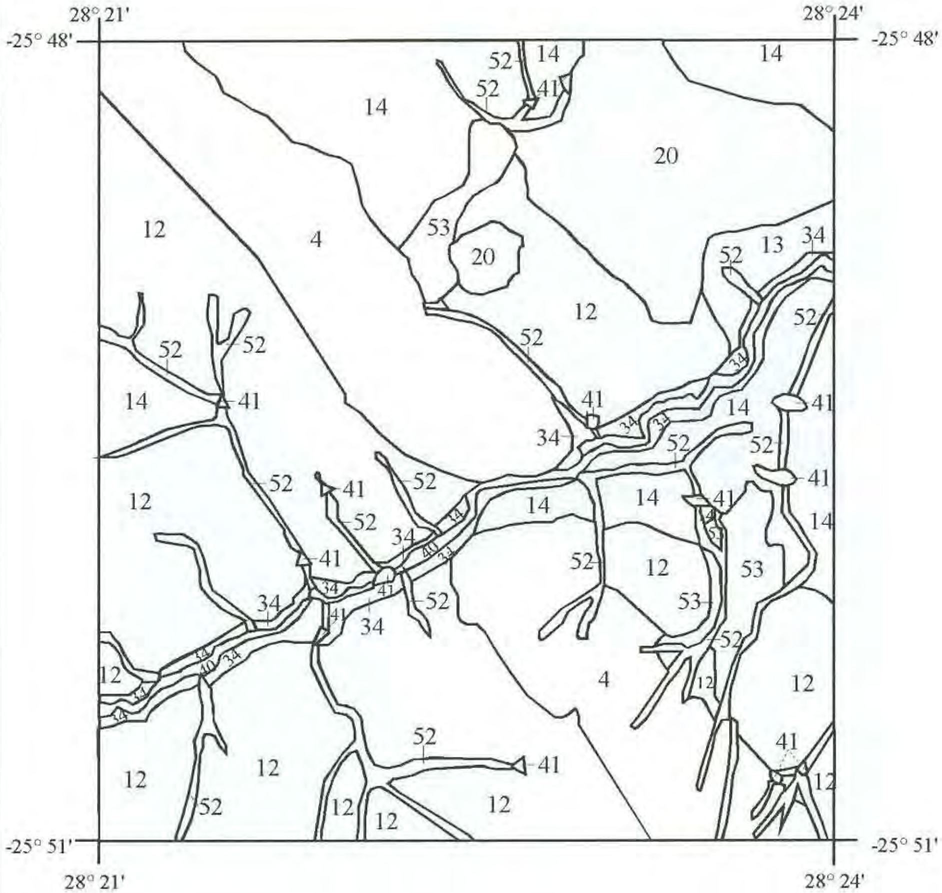

Figure 2 : Land form map of Rietvleidam 2528CD08

Scale : 1 : 50 000

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LAND FORM / LAND FACET LEGEND

CODE	LAND FORM	LAND FORM GROUP	LAND FORM GROUP CODE
4	Ridge crest	Ridge crest	4
12	Convex slope	Convex slope	12
13	Concave slope	Concave slope	13
14	Straight slope	Straight slope	14
20	Plain	Plain	20
34	Flood plain	Flood plain	34
40	River channel		
41	Dam		
52	Drainage channel		
53	Excavation	Excavation	53

Land form codes after Croukamp (1996)

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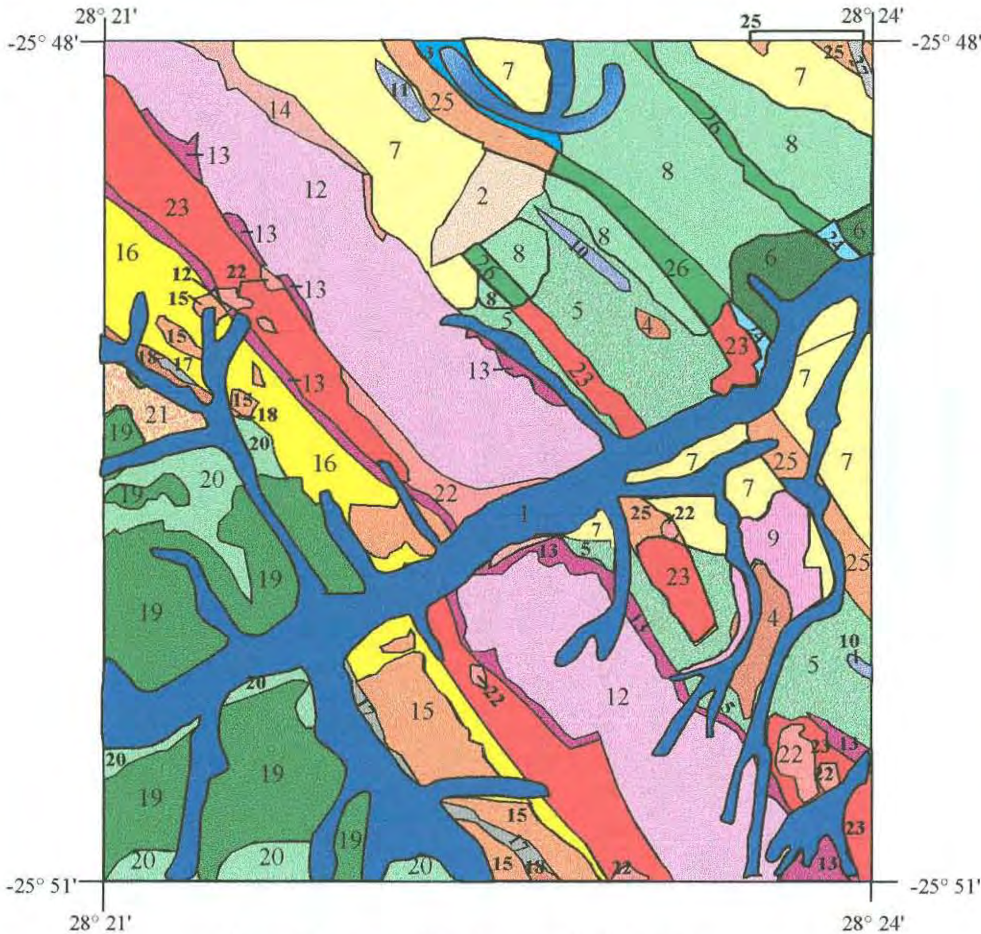

Figure 3 : Mapping Units based on the Land Facet approach for Rietvlei Dam 2528CD08

Scale : 1 : 50 000

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LAND FACET No	GEOLOGY		LAND FORM (CODE)
1			Flood - plain (34)
2	Surficial deposit (ground, soil, gravel, conglomerate, shale, clay)		Excavation (53)
3			Straight slope (14)
4	Silverton shale	Outcrop	
5			Convex slope (12)
6			Concave slope (13)
7			Straight slope (14)
8			Plain (20)
9			Excavation (53)
10	Silverton shale with inter-bedded chert		Convex slope (12)
11			Straight slope (14)
12	Daspoort quartzite	Outcrop	
13			Convex slope (12)
14			Straight slope (14)
15	Strubenkop shale with basal quartzite and conglomerate	Outcrop	
16			Convex slope (12)
17	Dwaalheuwel quartzite and sub-ordinate shale	Outcrop	
18			Convex slope (12)
19	Hekpoort andesite	Outcrop	
20			Convex slope (12)
21			Straight slope (14)
22	Diabase dykes and sills	Outcrop	
23			Convex slope (12)
24			Concave slope (13)
25			Straight slope (14)
26			Plain (20)
27	Syenite dyke		Straight slope (14)

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Date : October 2001

These codes were derived from the TRH2 (1978) land form classification system, which is generally used in South Africa for the classification of land forms.

3.3 HISTORY OF THE DEVELOPMENT OF REGIONAL GEOTECHNICAL MAPPING IN SOUTH AFRICA

The first real geotechnical map based on the land facet approach was conducted by Brink (1957) for a proposed route between Vryburg and Manchester in the Northwest province (Price, 1981). The then National Institute for Transport and Road Research (NITRR) of the South African Council for Scientific and Industrial Research (CSIR), as well as the University of Oxford-Military Engineering Experimental Establishment (MEXE) Group in Britain began developing a Terrain Evaluation System for road-route planning and military engineering purposes respectively (Stiff, 1994). The NITRR (represented by A.B.A. Brink) and the Oxford-MEXE Group and Australian Group (represented by J.A. Mabbutt) met in 1965 in Oxford and jointly refined the technique, systemised the approach and established the nomenclature for the preparation of soil engineering maps during road construction projects (Stiff, 1994).

The climax of soils engineering mapping for roads in South Africa was reached with the publication of the TRH2 (Technical Recommendation for Highways) draft in 1976 by the CSIR, giving technical recommendations to contributors on the presentation of the maps and data for input into the roads database system. This data store became known as the Roads Data Bank as most of the contributors and users were involved in road construction projects (Stiff, 1994). Unfortunately, the construction of new roads slowed down towards the end of the 1970's and the need for soil engineering maps apparently faded. Because the mapping skills remained available, it became necessary to seek other opportunities for mapping. It was realised that engineering geological mapping on a regional scale could make an effective contribution to the planning of developing areas. A more refined draft of TRH2 was then published in 1978 by the CSIR, introducing a geotechnical map that accompanied the soil engineering map. Support for the Roads Data Bank waned due to technical disputes in the 1970's and lead to its closure in 1980 (Mountain, 1994). The soil engineering map for construction and design, as well as data banking for roads will not be discussed further as it falls outside the scope of this research and attention will only be given to geotechnical mapping for route location (TRH2, 1978).

In the early 1980's the Council for Geoscience recognized the great need for regional engineering geological maps to facilitate urban expansion. This has led to the mapping of areas around some of the larger cities by workers like Bester (1981), Price (1981) and Mountain(1994).

Van Schalkwyk and Price (1990) did some further research on the regional geotechnical mapping method proposed by Price (1981). This included a site classification system to distinguish between good, fair and poor site class areas for residential development. Partridge, Wood and Brink (1993) introduced a geotechnical classification system for township development, to be used during urban planning in the PWV (Pretoria, Witwatersrand & Vereeniging) Metropolitan Region, currently known as the Gauteng Province of South Africa. This classification system was endorsed by the South African Institute for Engineering Geologists (SAIEG) in association with the South African Institution of Civil Engineers (SAICE). It is also supplemented by the *Standards and Guidelines* of the National Home Builders Registration Council (NHBRC, 1995) for Urban Planning, which are aimed at facilitating the production of housing units in accordance with the Reconstruction and Development Programme of the African National Congress (ANC, 1996).

In 1996 the Division of Building Technology of the CSIR in partnership with a consulting firm Partridge, Maud and Associates published a series of 1:50 000-scale maps considering the geotechnical suitability of vacant land in the central Gauteng Province. The descriptors of relevant constraints and the severity thereof, was based on the classification system of Partridge *et. al.* (1993), with minimal modification.

Croukamp (1996) designed an engineering geological geographical information system

(EGGIS) model and classification criteria for a development potential map for urban development. This was based on the integration of a number of data sources intended to be used for land-use planning by town planners and / or developers.

In 2000, the Council for Geoscience (CGS) embarked on a regional geotechnical mapping programme, with the aim to provide geotechnical maps on a 1:50 000 scale of areas, which are important for future development.

Geotechnical mapping specifically for dolomite land-use was developed in the CGS by Buttrick (1992) and falls outside the scope of this project and will not be discussed further.

Evaluation of classification systems used for regional geotechnical mapping from the 1970's to date, revealed that most of these systems are based on work previously done in the field of engineering geological mapping, with little or no modification. There was a decrease in interest in the development of/or research in geotechnical classification mapping systems, from 1981 to 1993. No standardised geotechnical classification system existed and the TRH2 system, although not designed for this purpose, was used for urban development planning. Partridge, Wood and Brink (1993) developed a standardised method to conduct urban engineering geological investigations, which is still regarded by the engineering geological fraternity as the accepted standard of practice in South Africa. This method is also endorsed by SAICE, SAIEG and the NHBRC

3.4 CLASSIFICATION SYSTEMS

The various mapping systems mentioned above, with the exception of the system developed by Zawada (2000), are described in detail below in chronological order, with an example of each end-product applied to the same area. The system developed by Zawada will be explained, evaluated and is presented in Chapter 5.

3.4.1 TRH 2 (Technical Recommendations for Highways, 1978) - Geotechnical mapping for route location

3.4.1.1 Purpose

The objective was to provide the necessary information to define the best possible location for a route of a planned road. The engineering geological map covers a large area including areas of future urban development. The information gathered should enable the planner to take cognizance of potential geotechnical properties in addition to the following criteria, when selecting possible routes:

- Existing land-use
- Population densities.
- Archaeological and historical sites.
- Land values and parcel size (areas held by private land).
- Potential land-use (development or agricultural).
- Environmental considerations (wildlife, vegetation, endangered species, areas of recognized scenic beauty).

The geotechnical map and report are used only to assess geotechnical aspects. These in conjunction with other criteria, such as land-use are studied, to determine a final road corridor. Soil profiling or testing is not required for route location mapping.

3.4.1.2 Classification

No classification criteria was applied to these maps and geotechnical properties were based on the land facet system (Brink *et al.*, 1982).

3.4.1.3 Map presentation

The geotechnical map (Figure 4) was done on a 1:50 000-scale, using the topographical sheet as base map to allow for easy orientation. The following were also indicated on the geotechnical map (Figure 4):

- Geological contacts, faults, joints, brecciated zones, strike and dip, all transferred from the published geological maps.
- Only those mapping units (lithostratigraphic units) which are of direct significance to route location.
- The drainage system, transferred from the 1:50 000 tophographical sheet, including rivers, lakes, pans, flood plains, marshy areas, areas with a shallow water table and dams.
- Any anticipated problem areas, such as sinkholes, expansive clays, or collapsible soils, delineated by map symbols for "Problem areas" which are of significance to route location.
- Potential sources of construction materials, are delineated by map symbols for "Materials".
- All major existing quarries and borrow pits which contain material of proven quality.

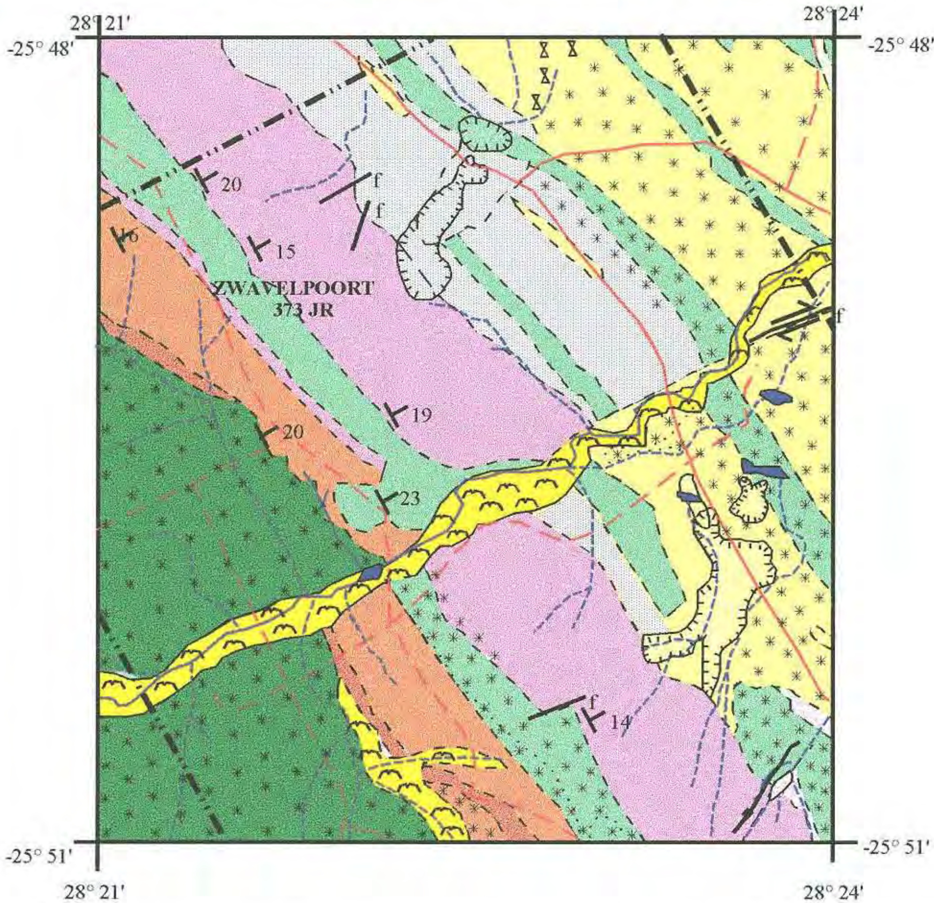
3.4.2 Engineering geological land-use classification system developed by Price & Bester (Geological Survey, 1981)

3.4.2.1 Objective

The objective of the mapping was to develop techniques to produce geotechnical maps on a regional scale, and to apply them in practice.

3.4.2.2 Land-use Classification

The classification consists of a matrix with two rows for development categories and six columns for influencing factors, presented in Table 2A (after Price, 1981) and Table 2B (after Bester, 1981). After completion of a mapping project, each facet group is classified



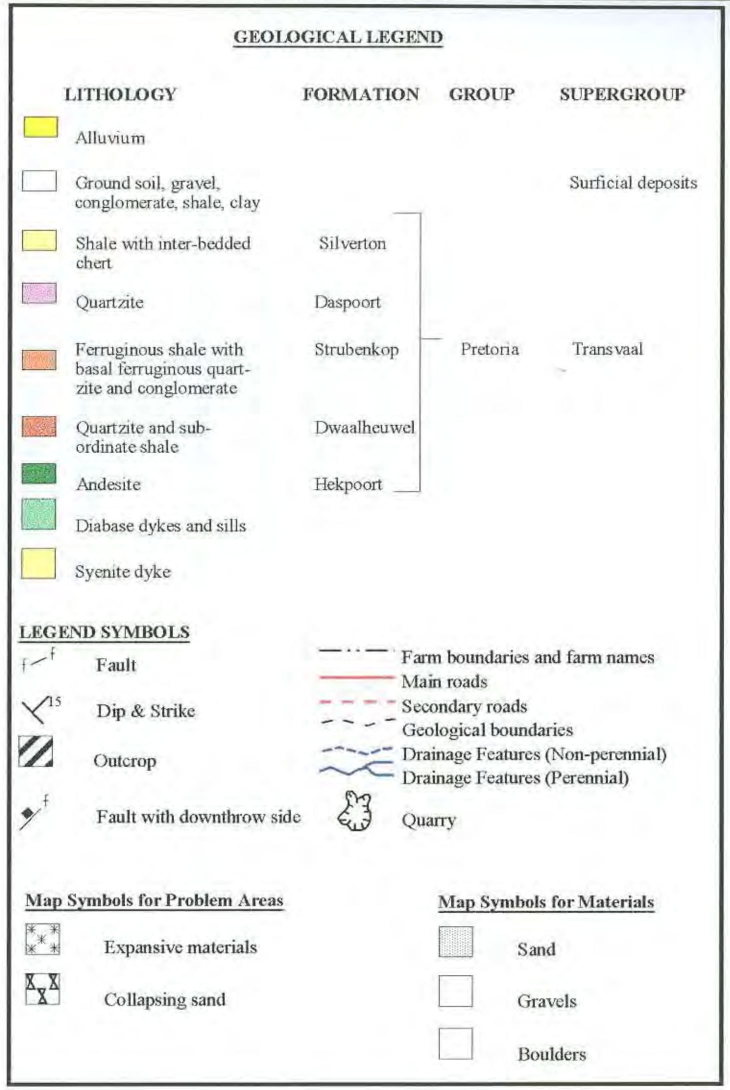


Figure 4 : Geotechnical map constructed using the TRH2 (1978) method

1 : 50 000

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individually. Table 2A (Price, 1981) and Table 2B (Bester, 1981) are the controlling matrix tables with the maximum rating (MR) indicated and a space provided for the rating as assessed by the user. The assessed rating is obtained from Table 3, where each influencing factor is sub-divided into five classes of decreasing merit from one to five, each with its own rating.

The influencing factor "Potential Natural Resources" (Table 3) were further divided into the different types of construction materials (Table 4a-c). These construction materials, defined by type and quality are each divided into five sub-classes. The sub-class from which a mapping unit is recognised as a potential natural resource or not, is then transferred to the corresponding class of the influencing factor in Table 3.

The column "Overriding positive or negative aspects" (Table 2A) or "Critical influencing factors" (Table 2B) was introduced to remedy a situation where one factor overrules all the others, in spite of a high total rating value. For example, an area may be geologically sound but situated in a flood plain. In this way a rating for an area situated in a flood plain, or on dolomitic karst with known subsidence potential, would be drastically reduced to account for the negative overruling factor.

The accumulated rating out of a maximum of 100 is then compared, for each development category, as to its land-use potential in Table 5 and some idea is formed as to the engineering geological condition of an area. The benefit of the classification is that the general suitability of an area for development is immediately indicated and also whether an area is suited to both, only one, or none of the development categories.

During the implementation of the classification system certain problems and shortcomings were identified by Bester which needed to be revised, including:

- The classification of a mapping unit's excavatibility potential will depend on the type of development that will take place. Distinction should be made between light structures (excavatability < 1,0m), services and deep excavations (> 1,0m),

Table 2A: Control table: Rating allocated to influencing factors with regard to development categories (after Price, 1981).

INFLUENCING FACTORS	1	2	3	4	5	6	OVERRIDING POSITIVE OR NEGATIVE ASPECTS	TOTAL RATING	CONSTRUCTION MATERIAL DESCRIPTION
	DRAINAGE CONDITION	SUITABILITY OF FOUNDATIONS	EASE OF EXCAVATION	SLOPE STABILITY CONDITIONS	LAND FORM AND ACCESSIBILITY	POTENTIAL NATURAL RESOURCES			
DEVELOPMENT CATEGORY	MR* 15	25	22	20	12	6		100	
TOWNSHIP DEVELOPMENT FOR LIGHT STRUCTURES									
	MR* 15	10	10	20	30	15		100	
SURFACE TRANSIT SYSTEMS									

MR* **Maximum Rating**

Table 2B: Control table: Rating allocated to influencing factors with regard to development categories (after Bester, 1981).

INFLUENCING FACTORS	1	2	3	4	5	6	AWARDED VALUE	7	8
	DRAINAGE CONDITION	SUITABILITY OF FOUNDATIONS	EASE OF EXCAVATION	SLOPE STABILITY CONDITIONS	LAND FORM AND ACCESSIBILITY	CONSTRUCTION MATERIAL		EXISTING DEVELOPMENT	CRITICAL INFLUENCING FACTORS
DEVELOPMENT CATEGORY	MR* 15	25	22	20	12	6	100		
TOWNSHIP DEVELOPMENT									
	MR* 15	10	10	20	30	15	100		
TRANSPORT SYSTEMS									

MR* **Maximum Rating**

Table 3: Rating of each influencing factor, sub-divided into five classes of decreasing merit from one to five (Price & Bester, 1981).

Influencing factor	Class	Description	Rating: Township development for light structures P	Rating: Township development for light structures B	Rating: Surface Transit Systems P	Rating: Surface Transit Systems B
Drainage conditions	I	Almost continuously dry land or land with excellent drainage conditions (high permeability, granular soil). Soils: GW, GP, GM, SW.	15	15	15	10
	II	Well-drained ground even under an extremely high precipitation rate. Soils: SP, SM.	12	12	12	8
	III	Ground with good run-off but with a deficiency in deep drainage (only drains under less than moderate rainfall). Soils: GC, SC.	8	8	8	6
	IV	Poor drainage in depth and at surface. High water table. Soils: ML, CL, OL.	3	3	3	2
	V	Extremely poor drainage. Very high water table. Marsh areas, bogs and continual ponding even under minor precipitation. Soils: MH, CH, OH, Pt.	1	1	1	1
Suitability of foundations	I	Compact, well-graded mixes of granular and cohesive soils in zones of soil profile >2,0m. Continuous rock at depth below surface in excess of 2,0m. Rock sound, hard, massive with high to very high strength. Slake durability 95-100%, Plasticity Index<6, Grading Modulus>2, Linear Shrinkage<6%. Low water table. Soils: GW, GM, SW, SM.	25	35	10	10
	II	Poorly graded but dense granular/cohesive soils. Continuous or scattered rock of a minimum depth below surface of 2,0m. Rock fractured and slightly to moderately weathered. Closely spaced joints; tight. Rock of medium to high strength. Slake durability 80-95%, PI: 6-12, GM: 1.75-2.0, LS: 6-8%. Low water table. Soils: SP, GP, GC, SC.	20	30	8	8
	III	Some scattered outcrop. Rock highly to very highly weathered and of moderate strength, at surface. Slake durability 50-80%. Rock quality increases with depth. Joints close, gouge filled. Poorly graded soil of medium density. Consistency stiff to very stiff. PI: 12-18, GM: 1.4-1.75, LS: 8-10. Water table <3m. Soils: CL, ML, OL.	13	20	5	5
	IV	Loose transition soils, plastic clays and silts. Localised areas of collapsing, dispersive or expansive soils. PI: 18-24, GM: 1-1.4, LS: 10-15. High water table. Soils: MH, CH.	6	10	3	3
	V	Turf, highly compressible and expansive clays. Refuse, landfill, dispersive soils, collapsible sands. PI: >24, GM: <1, LS: 15%. Highly fluctuating water table. Soils: CH, OH, Pt.	3	5	1	1
Ease of excavation	I	Very loose - moderately dens granular and very soft - firm cohesive soil of at least 2.0m depth with <10% boulders. Low water table and no outcrop.	22	12	10	15
	II	Dense - very dense granular and stiff - very stiff cohesive soil of at least 1.0m and with 10-30% boulders or core stones.	18	10	8	12
	III	Bedded or foliated moderately to highly weathered, highly fractured soft rock with soil profile as above, but with >30% boulders or core stones. High % of clay with a high moisture content.	11	6	5	8
	IV	Continuous outcrop of moderately weathered, fractured, soft to hard rock or scattered outcrop of slightly - unweathered rock with soil as in II & III. Extremely clayey material with a high moisture content.	7	4	4	6
	V	Massive, hard, slightly - unweathered rock, mostly outcrop or covered by a thin layer (0.5m) of soil, description as in I & II; deep soil loose - moderately dense with water table very close to surface. Saturated clays.	3	2	2	3

P - Price B - Bester

Table 3 (cont.): Rating of each influencing factor, sub-divided into five classes of decreasing merit from one to five (after Price & Bester, 1981).

Influencing factor	Class	Description	Rating			
			Township development for light structures		Surface Transit Systems	
			P	B	P	B
Slope stability conditions	I	Soil profile with competent and stable ground even in high slopes. Rock massive or horizontally bedded and of high strength. Stable soil conditions. Strata dips steeply into the natural slope (no wedge failure). Soils: GW, GM, SW, SM.	20	20	20	20
	II	Minor stability problems (debris on slope base) but with little effect on development. Rock massive but at times slightly weathered with moderately spaced joints. Stable soil. Strata dipping mostly into slope (no wedge failure). Soils: SP, GC, GP, SC.	15	15	15	15
	III	Areas of moderate slope erosion, localized swelling, collapsing or dispersive soils (minor). Fluctuating water table. Rock highly weathered in places, joints open or clay-filled; some slaking. Strata dipping partially out of slope. Soils: ML, CL, OL.	10	10	10	10
	IV	Ground susceptible to changes in moisture content. Some risk of sliding and mass movement. High water table. Rock weathered, close and very closely-spaced joints, gouge-filled, steep dip slope. Soils as in III not uncommon. Strata dipping out of slope. Soils: OL, MH.	3	3	3	3
	V	Slopes highly susceptible to slides and flows. High and fluctuating water table; large deposits of talus; known landslide area. Rock highly fractured, weathered and disintegrates easily when exposed. Very steep dip slope. Subsidence or collapsing ground, dispersive soil or soft organic or expansive soils. Strata with high dip out of slope. Soils: CH, OH, Pt.	1	1	1	1
Land forms & accessibility	I	Few rivers and streams with road bridges. National and provincial tarred road provide access. Gravel roads and farm tracks common. Land forms: Constant slope, pediment, plain.	12	12	30	25
	II	No steep slopes. Mainly gravel and farm roads, some provincial roads. Land forms: Plateau crest, bump, fan, dry pan floor.	10	10	24	20
	III	Some ravine and gully development. Few gravel roads, mainly farm tracks. Land forms: Hill crest, ridge crest, talus slope, dune street, gully, river terrace, raised beach.	8	8	18	15
	IV	Prominent gully development. Very few gravel roads or farm tracks. No national or provincial roads. Land forms: Mountain crest, stabilized dunes, gully, water-filled pan floor.	4	4	10	8
	V	Low to high mountains and escarpments - high to very high relief (>300m). Deeply incised rivers or gorges with no existing roads only a few tracks or paths. Land forms: Cliff, free face, ledge, landslide, shifting dunes, flood plain, swamp, delta, river channel, doline, sinkhole, beach.	2	2	4	3
Potential natural resources	I	At least one natural resource for at least on of the three criteria being evaluated, and if it conforms to the sub-class 1 of the natural resources.	6	6	15	20
	II	Resource available. Conforms to sub-class 2.	5	5	12	16
	III	Resource available. Conforms to sub-class 3.	2	2	5	6
	IV	Resource available. Conforms to sub-class 4.	1	1	1	2
	V	No natural resources.	0	0	0	0

Table 4a-4c: Natural Resources

Table 4a: Classification of road material.

SUB CLASS	LAYER	LIQUID LIMIT (%)	PLASTICITY INDEX	GRADING MODULES	CBR	DENSITY (%)
1	Unstabilised base	≥ 30	≥ 6	≤ 2	≤ 80	≤ 98% mod.
2	Unstabilised sub-base	-	≥ 10	≤ 1,5	≤ 45	≤ 97% mod.
3	Unstabilised selected sub-grade	-	≥ 3 G.M. + 10	≤ 0,5	≤ 10	≤ 93% mod.
4	Unstabilised fill	-	≥ 35	≤ 0,5	≤ 3	≤ 90% mod.

Table 4b: Classification of coarse aggregate.

SUB CLAS S	STRENGTH	UCS (MPa)	RQD %	DURABILITY %	P.L.S.I. (MPa)
1	Very high strength	> 200	90 - 100	95 - 100	> 8
2	High strength	100 - 200	75 - 90	80 - 95	4 - 8
3	Medium strength	50 - 100	50 - 75	50 - 80	2 - 4
4	Low strength	< 50	< 50	<50	< 2

Table 4c: Classification of fine aggregate, mining potential & building stone and brick-making materials.

SUB CLASS	FINE AGGREGATE (SUB-CLASS DESCRIPTION)	MINING POTENTIAL AND BUILDING STONE (SUB-CLASS DESCRIPTION)	BRICK-MAKING MATERIALS (SUB-CLASS DESCRIPTION)
1	Clean, well-graded quartzite sand.	Area being mined: proven resources of building stone and minerals.	Clays composed of mixtures and clay minerals with 25-50% unsorted fine grained non clay minerals. Quartz ± 40%, Illite and Sericite 25%, Kaolinite 12%, Chlorite 4%, Montmorillonite 2%, Feldspar 10%.
2	Fairly clean, some silt, well-graded sand.	Area zoned for possible mining potential. Good quality building stone available.	Large percent quartz with minor or lesser amounts of clay. Low plasticity.
3	Moderately clean, fair % of fines, poorly graded.	Old diggings, mines, disused building stone quarries.	Sufficient amounts of non-clay minerals and clays but very high alkaline, iron and alkaline earth elements (reduce virtrification range temperature) and >2% montmorillonite.
4	Dirty, large % fines, requires washing, poorly graded.	Some minor amounts, but of poor quality, building stone (e.g. weathered slate).	Good clay/non clay matrix but very high proportion consists of montmorillonite.

Table 5: Engineering geological land-use classification (after Price & Bester, 1981).

TOTAL RATING	LAND-USE POTENTIAL	ENGINEERING GEOLOGICAL QUALIFICATION
91 - 100	VERY GOOD	GENERALLY ACCEPTABLE FOR DEVELOPMENT
71 - 90	GOOD	ACCEPTABLE WITH SOME MINOR INVESTIGATION OF CERTAIN INFLUENCE FACTORS.
41 - 70	FAIR	TERRAIN ECONOMICALLY VIABLE WITH FURTHER INVESTIGATION.
21 - 40	POOR	DEVELOPMENT UNECONOMICALLY VIABLE. ANALYSIS OF THE ECONOMIC IMPLICATIONS REQUIRED BEFORE ANY FURTHER INVESTIGATION.
< 21	VERY POOR	TOTALY UNACCEPTABLE FOR DEVELOPMENT. IF DEVELOPED THEN AT EXTREMELY HIGH COST.

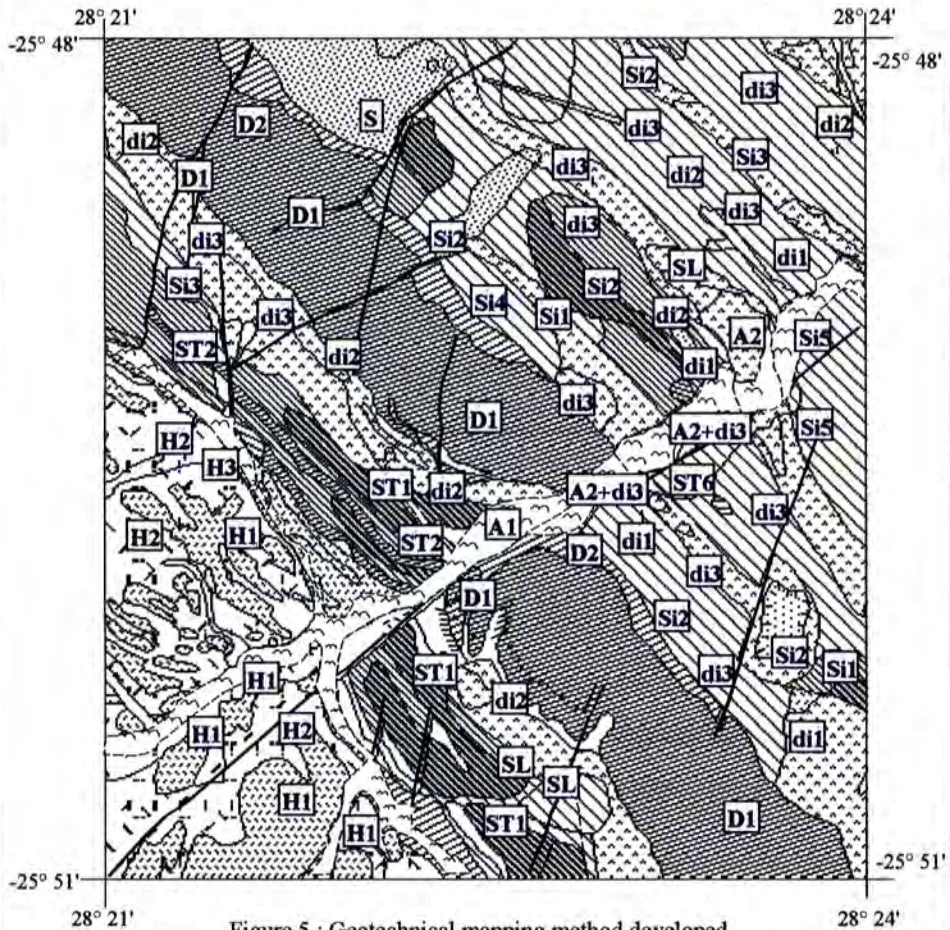
and those for roads.

- Distinction should be made between the suitability of foundations for light structures and roads, due to different financial implications.
- The Primary category "Roads" should be sub-divided into different road types. A difference in unit costs could cause that certain influencing factors plays a major role in one type of road during construction, whilst for another it will be of minor concern. Tables 4a-c represents the five types of construction materials, each sub-divided into four classes of quality according to certain minimum standard requirements. If these requirements aren't fulfilled, it can not be classed as a specific type of construction material. For this reason it was decided that the classification was not applicable and that a mapping unit can only be identified for one or the other source of construction material, with no sub-divided classes describing the quality of the construction material.

3.4.2.3 Presentation

The engineering geological maps produced by Price (Figure 5) and Bester (Figure 6) were compiled on a 1:50 000-scale, using the topographical sheet as base map to allow easy orientation. The geotechnical maps produced by Price and Bester consist of the following:

- Geological lithology, contacts, faults, joints, brecciated zones, strike and dip.
- Delineation of existing and potential construction material resources.
- Delineation of each facet group or mapping unit.
- Price gives a description of each facet group (mapping unit) with a map symbol allocated in Figure 5 in terms of: 1) Soil description & Unified classification, 2) Engineering geological land-use rating for township development and roads & railway, 3) Potential geotechnical problems, 4) Construction materials, 5) Engineering geological land-use potential, according to the rates in Table 5.
- Bester gives a description of each mapping unit with a map symbol allocated in Figure 6 in terms of: 1) Typical soil profile description, 2) typical land form, 3)



GROUP / SUBGROUP		FORMATION	FACET GROUP	MAP CODE	FACET GROUP DESCRIPTION & UNIFIED CLASSIFICATION	ENG. GEOL. LAND-USE RATING		POTENTIAL PROBLEMS	CONSTRUCTION MATERIALS	ENG. GEOL LAND-USE POTENT
RECENT DEPOSITS						TOWNSHIP	ROAD & R'WAY			
RECENT UNCONSOLIDATED DEPOSITS			A1		SILTY SAND, SANDY CLAY, SILT, GRAVEL, CLAY - VARIABLE	0	0	FLOODING		V POOR
			A2		ALLUVIAL CLAY (CH)	0	0	FLOODING EXPANSIVE		V POOR
			S1		COLLUVIAL SILTY SAND (SM) / VARIETY OF ROCK TYPES	75	74	COLLAPSIBLE GRAIN STRUCTURE	FINE AGGREGATE SUBGRADE	GOOD
TRANSVAAL SUPERGROUP										
PRETORIA GROUP		SILVERTON SHALE	Si1		CONTINUOUS OUTCROP OF FINE GRAINED SILTY & GRAPHIC SHALE	64	67	SLOPE UNSTABLE IN DEEP EXCAVATIONS	SUBBASE, S SUBGRADE	FAIR
			Si2		SCATTERED OUTCROP WITH INTERSTITIAL SILTY GRAVEL (GM)	66	71		SUBBASE, S SUBGRADE	FAIR - GOOD
			Si3		KHAKI COLLUVIAL SILTY GRAVELLY SAND (SM,SP) / SHALE	88	77		BRICKS, S SUBBASE	GOOD
			Si4		YELLOW / BROWN COLL - CLAYEY & SILTY GRAVEL (GC) / SHALE	75	73		BRICKS, FILL	GOOD
			Si5		RED / BROWN COLL - SANDY CLAY WITH FERRICRETE (CL) / RES SILTY GRAVEL (GM) / SHALE	54	50	ACTIVE CLAY		FAIR
			Si6		BLACK COLLUVIAL CLAY (MINOR CALCRETE) (CH) / RES SILTY GRAVEL (GM) / SHALE	16	17	EXPANSIVE		V POOR
		DASPOORT	D1		CONTINUOUS OUTCROP OF MEDIUM GRAINED ORTHO-QUARTZITE	30	40	EXCAVATION	FINE & COARSE AGGREGATE, BASE	FAIR
			D2		SCATTERED OUTCROP WITH INTERSTITIAL SILTY SAND (SM) & QUARTZITE BOULDERS / QUARTZITE	85	90			GOOD
		STRUBENKOP	ST1		CONTINUOUS OUTCROP OF FINE GRAINED HIGHLY JOINTED SHALE	64	67	SLIDING IN DEEP EXCAVATIONS		FAIR
			ST2		SCATTERED OUTCROP OF BROWN FERRUGINOUS SHALE INTERS SILTY GRAVEL	63	67			FAIR
			ST3		RED / YELLOW COLL SILTY GRAVEL (GM) / SHALE	73	73			GOOD
			ST1		CONTINUOUS OUTCROP OF FINE GRAINED IRON-RICH INTENSELY JOINTED QUARTZITE	75	70	EXCAVATION		GOOD
			ST2		SCATTERED OUTCROP OF QUARTZITE / INTERSTITIAL GRAVELLY SILTY SAND (SM) / QUARTZITE	83	80			GOOD
		HEKPOORT	H1		CONTINUOUS OUTCROP OF VERY HARD ANDESITE	71	63	EXCAVATION		FAIR - GOOD
			H2		SCATTERED OUTCROP OF AMYGDALOIDAL ANDESITE / INTERSTITIAL SANDY CLAY	51	36	EXCAVATION		FAIR
			H3		RESIDUAL RED SILTY CLAY (CH) / RED / OLIVE RES SILTY CLAY (CL) / ANDESITE	35	44	EXPANSIVE		POOR - FAIR
IGNEOUS INTRUSIVE										
SYENITE DYKES			s1		SYENITE ROCK (DYKES) WITH OR WITHOUT SILTY SANDY SOIL	31	32			FAIR
DIABASE DYKES & SILLS			d1		CONTINUOUS OUTCROP OF MEDIUM GRAINED, VERY HARD DIABASE	61	64	EXCAVATION		FAIR
			d2		SCATTERED OUTCROP WITH INTERSTITIAL RED SANDY CLAY	61	64	EXPANSIVE		FAIR
			d3		RED RESIDUAL SANDY CLAY (CL) / GREEN-GREY RES DIABASE (CL) / DIABASE	31	32	EXPANSIVE		POOR

Figure 5 : Geotechnical mapping method developed by Price (1981) with an overlay of the different site classes

1 : 50 000

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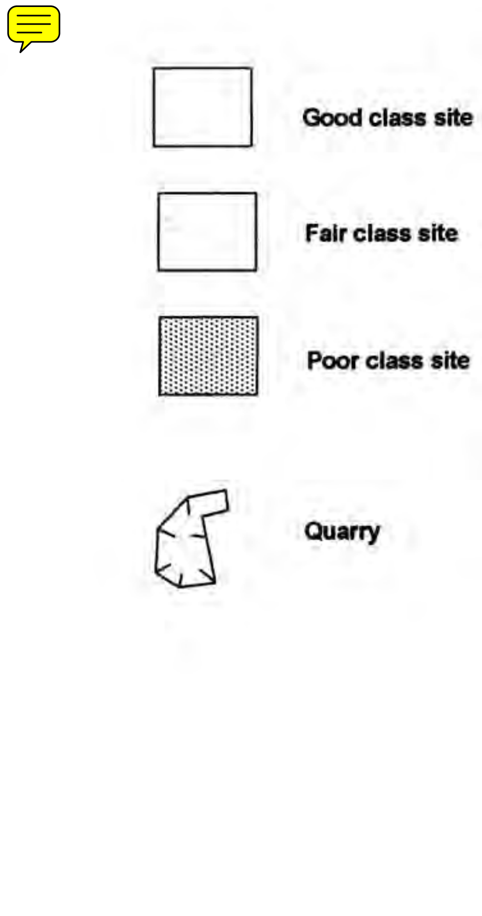

Figure 5 Overlay
1:50 000

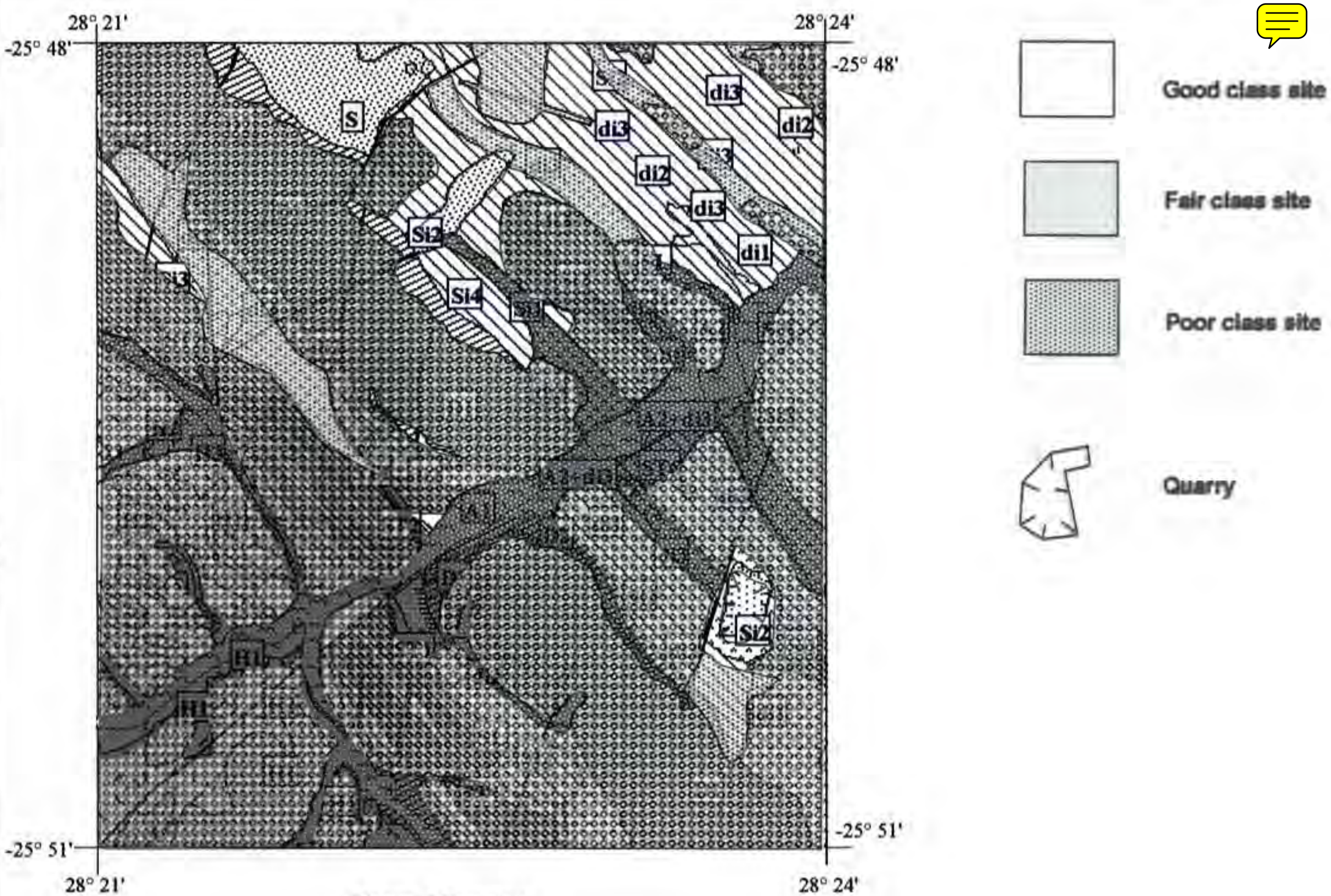

Figure 5 Overlay
1:50 000

1 : 50 000

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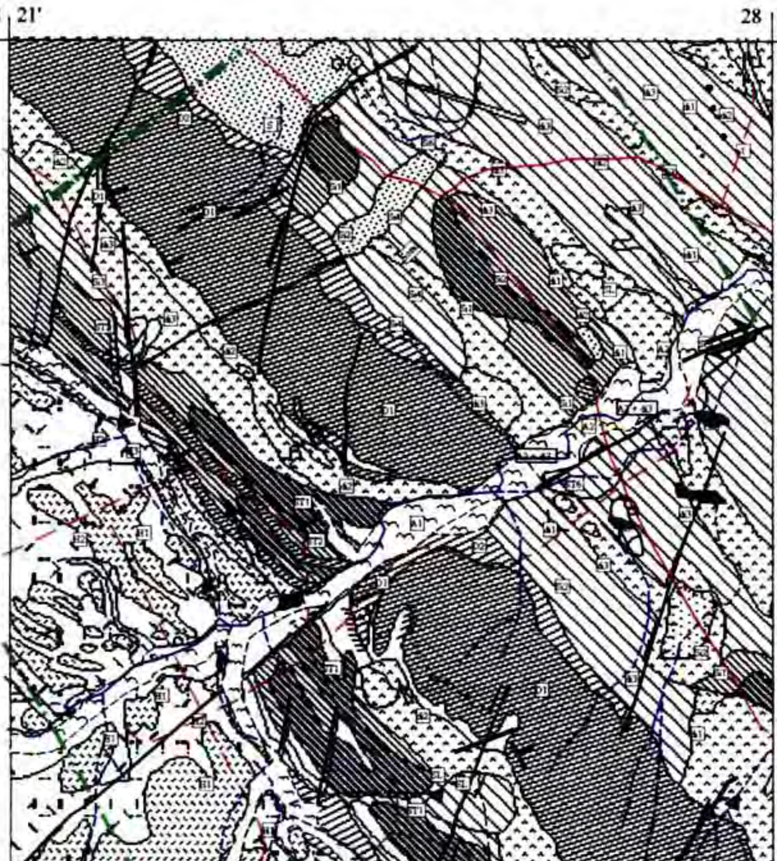
Date : October 2001

28 21' | 28 24'

-25 48' | -25 48'



-25 51' | -25 51'

28 21' | 28 24'

LEGEND:

LEGEND SYMBOLS

- Fault
- Main joint orientation
- Dip & Strike
- Geological Contact
- Borders between mapping units
- Farm boundaries and farm names
- Main roads
- Secondaryroads
- Geological boundaries
- DrainageFeatures(Non-perennial)
- DrainageFeatures(Perennial)
- Quarry
- Mapping unit / Geological formation (Si3)

UNCONSOLIDATED MATERIAL

ALLUVIUM	
SAND	(S)

CONSTRUCTION MATERIAL QUARRIES

- Sand
- Clay

SYMBOL: OUTCROP	SYMBOL: SCATTERED OUTCROP	SYMBOL: NO OUTCROP	ROCK TYPE	FORMATION	GROUP	SUPER GROUP
			Shale	SILVERTON (Si)	PRETORIA	TRANSVAAL
			Quartzite	DASPOORT (D)		
			Shale	STRUBENKOP (ST)		
			Quartzite			
			Andesite	HEKPOORT (H)		
			Diabase(dyke and/or sill)			
			Syenite(dyke)			

DEVELOPMENT CATEGORY		DEVELOPMENT POTENTIAL			MINING POTENTIAL
PRIMARY	SECONDARY	FAVOURABLE	UNFAVOURABLE	UNCERTAIN	
TOWNSHIP DEVELOPMENT	Light structures (foundation excavatability <1,0m).	Si2, Si3, Si4, D2, H2, H3, ST1, ST2, ST3 (shale), ST2 (quartzite).	D1, Si6, H1, ST1 (quartzite), di1, A1, A2	Si1, Si5, di2, di3, S.	
	Deep excavations (>1,0m).	Si3, Si4, H2, H3, di3, S.	D1, H1, ST1 (quartzite), di1.	Si2, D2, ST1, ST2, ST3 (shale), ST2 (quartzite), di2, A1, A2.	
	Roads (except bridges)	Same as for light structures, as well as Si5, di2, di3, S.	Same as for light structures.	Si1	
ROADS (except bridges)	National roads (highways)	All other	D1, H1, ST1 (quartzite).	Si6, A1, A2.	
	Provincial roads (tar)	All other.	Same as for national roads, as well as A1, A2.	Si6, di3	
	Other (gravel)	All other.	D1, H1, di1	-	
CONSTRUCTION MATERIAL	Coarse aggregate.	D1.	All other	di1	
	Fine aggregate.	D1	All other.	-	
	ROADS: Base.	D1.	All other	di1	
	ROADS: Sub-base.	Ferricrete over andesite.	All other	Si2, Si3, ST2, ST3 (shale)	
	ROADS: Selected Sub-grade.	-	All other	Si4, S.	
	ROADS: Fill	-	All other	Si4, Si5, S, di2, H3	
	Building sand.	-	All other.	s.	
	Brick clay.	-	All other	-	

General interpretation of the development potential for each development category

MAPPING UNIT: SYMBOL	TYPICAL PROFILE DESCRIPTION	GENERAL ENGINEERING GEOLOGICAL CHARACTERISTICS: TYPICAL LANDFORM	DRAINAGE (surface)	EXCAVATABILITY (after Weaver, 1975)	GENERAL FOUNDATION	GENERAL STABILITY	
Si 1	Continuous outcrop. Soft to hard rock, olive grey to yellowish brown, well layered, intensively jointed SHALE.	Hill crest	Good	Difficult rippability, although blasting may be required for deep excavations.	0 - 0,2m	Stable as foundation material and the side walls of deep excavations	Continuous outcrop, not good for light structures
Si 2	Scattered outcrop with a profile in between of loose to compact slightly moist, silty GRAVEL (GP) of 0,2m thickness, over soft shattered, highly to totally weathered SHALE, with a decrease in weathering with depth.	Straight slope	Good	Mainly difficult rippability, blasting required for excavations deeper than 1,0m.	0 - 0,2m	do	None
Si 3	No outcrop. Colluvial sandy, silty GRAVEL (GP) of 0,4m thickness, over soft intensively jointed highly to totally weathered SHALE, with a decrease in weathering with depth.	Straight to concave slope	Good	Difficult rippability with slight blasting in deep excavasions.	0,2 - 0,5m	Stable as foundation material and in deep excavations.	None
Si 4	No outcrop. Stiff, moist, dark brown, colluvium silty SAND (SM) to sandy CLAY (SC) of 0,4m thickness, over a 0,3m thick ferricrete concretion pebble marker, over stiff to very stiff, moist, residual, sandy CLAY (SC), over SHALE.	Flat straight slope	Poor (ground water level between 5m-10m).	Easy to difficult rippability. With no blasting required for excavations to a depth of 3,0m.	0,2 - 0,5m (due to ferricrete layer).	Ferricrete stable as foundation material, whilst the side walls of excavations may be unstable under the ground water level.	None
Si 5	No outcrop. Soft to stiff, moist, colluvium, sandy CLAY (CH) with gravel (shale fragments) to a depth of 1,0m over a 0,5m thick horizon of stiff, moist, residual silty CLAY (CL), over loose to medium dense residual clayey SAND (SC) with gravel over SHALE.	do	Poor	Easy rippability	>0,5m	Sandy CLAY with medium to high expansiveness, with 27% montmorillonite.	Medium to highly expansive clays, precaution should be taken against differential movement.
Si 6	No outcrop. Stiff to very stiff, highly plasticity CLAY (CH) of 0,3m thickness over stiff to very stiff, black, highly plasticity clay (CH).	Flood plain	Poor (marshy areas develope during rainy seasons).	Easy rippability, but elevated ground water levels could pose a problem.	>0,5m	Highly unstable due to expansive clays. Side walls of excavations unstable due to shallow ground water levels and pressure.	Clay highly expansive with a rise in the ground water table.
D 1	Continuous outcrop. Hard to very hard greyish white to light brown, medium grained, jointed to solid quartzite.	Hill crest	Good to the north east.	Extremely difficult rippability blasting required.	0-0,2m	Stable as foundation material and as side walls in deep excavations.	Continuous outcrop, not good for the development of light structure.
D 2	Scattered quartzite outcrop with a in between profile of dry, loose, colluvium silty SAND (SM) with weathered quartzite boulders to a depth of 0,35m over hard to very hard, mediumgrainedquartzite(slope40 N).	Straight slope	Good	Blasting required for excavation in rock & easy rippability in sand.	0-0,2m	Stable as foundation material and as side walls in deep excavations.	None
ST 1	Continuous outcrop. Soft to very hard, brown to purple, highly jointed, weathered to unweathered SHALE.	Concave slope	do	Blasting required for excavation in rock & easy rippability in sand.	0-0,2m	Stable as foundation material and as side walls in deep excavations	None
ST 2	Scattered shale outcrop with a profile in between of loose to medium dense, colluvium gravely (shale fragments) SILT (GM) with a thickness of 0,5m over soft shattered highly weathered, weathering decreases with increase in depth.	do	do	Easy rippability for shallow excavations, but difficult for deep excavations.	0,2-0,5m	do	None
ST 3	No outcrop, dry, loose to dense, colluvium silty GRAVEL (GP) with a thickness of between 0,2m to 0,5m over weathered to unweathered SHALE.	do	do	Easy rippability	do	do	None
ST 1	Continuous outcrop. Hard, red brown, fine grained iron-rich, intensely jointed QUARTZITE.	Hill crest	Good	Extensively difficult rippability, blasting required.	0-0,2m	No stability problems anticipated.	Continuous outcrop, not good for the development of light structures.
ST 2	Scattered quartzite outcrop with a profile in between of slightly moist, loose to dense, gravely, silty SAND (SM) to a depth of 0,3m over soft (harder with depth), stratified and shattered weathered to unweathered QUARTZITE.	Straight slope	Good	Extensively difficult rippability, blasting required.	0,2-0,5m	No stability problems anticipated.	None.
H 1	Continuous outcrop. Very hard, dark greyish green, massive ANDESITE.	Hill crest	do	Difficult to extensively difficult rippability, blasting required.	0,2-0,5m	Stable as foundation material & stable side walls of deep excavations	Spherical weathering under outcrop could be misleading, not good for the development of light structures.
H 2	Scattered andesite outcrop with a profile in between of dry, medium dense, colluvium sandy GRAVEL as the matrix with semi-rounded boulders of andesite to a depth of 0,35m over a PEBBLE MARKER, over slightly moist, stiff, residual silty CLAY (CL) to a depth of 2,0m.	Straight slope	do	Difficult rippability for excavation in between outcrop, with blasting required in rock.	0,2-0,5m (spherical weathering).	Differential movement may occur due to a big change in moisture condition of silty CLAY.	Silty CLAY (Residual andesite), with medium expansiveness & a free swell potential of 15-13mm.
H 3	No outcrop. Slightly moist, firm, colluvium silty CLAY (CL)) to a depth of 0,4m over a PEBBLE MARKER over slightly moist to moist, firm, residual silty CLAY (CL) to a depth of 2,0m.	Flat straight slope	Moderate to poor	Difficult to extensively rippability blasting required for deep excavation.	0,2-0,5m (reinforced foundation or split construction required)	Different movement may occur due to a big change in moisture condition of silty CLAY.	Colluvium CLAY & residual CLAY, with medium expansiveness & a free swell potential of 15-30mm.
s	Slightly moist, loose to dense, reddish brown to yellowish white, colluvium silty SAND (SM) with a thickness between 1,0 to 4,0m.	Straight slope	Poor (deep ground water level)	Easy rippability	0,2-0,5m (depended on the density of SAND).	In general stable. Side walls of deep excavations fairly stable due to free drainage.	SAND with a collapse potential may occur at the foot of the Magaliesberg and the Daspoort Ridge.
di 1	Continuous outcrop of hard, greyish green, DIABASE (stained joints).	Hill crest	Good	Mainly blasting with extensive difficult rippability where spheric weathering occurs under outcrop.	0-0,2m	No stability problems anticipated.	Continuous outcrop, good for the development of light structures.
di 2	Scattered outcrop with a profile in between of dry, stiff, microshattered, colluvium sandy CLAY (CL-CH) of 0,35m over slightly moist, microshattered, residual sandy CLAY (CH) to a depth of 1,0m over DIABASE.	Straight slope	do	Difficult to very difficult rippability, moderate blasting required.	0,2-0,5m (reinforced foundations or provision should be made for differential settlement	Differential movement could be anticipated if founded on rock & soil.	Medium to highly expansive CLAY, with a free swell potentail of >10mm.
di 3	No outcrop. Dry to slightly moist, firm, colluvium, silty CLAY (CL-CH) to a depth of 0,45m over a PEBBLE marker over dry to slightly moist, residual silty CLAY (CL-CH) to a depth of 1,0m over soft, sandy CLAY (highly weathered diabase).	Flat straight slope	Poor	Difficult to very difficult rippability,with slight blasting required for deep excavations.	do	Differential settlement could be anticipated, due to expansive CLAYS.	do
sl	Continuous outcrop, very hard, yellowish brown SYENITE.	Hill crest	Good	Extensively difficult rippability, blasting required	0-0,2m	No stability problems anticipated	Continuous outcrop, good for the development ofl ight structures
A 1	Alluvium deposits of sandy CLAY with lenses of Alluvium gravel.	River channel & terrace	Poor (fluctuating ground water level.	Easy rippability, but problems with ground water could be anticipated.	Unknown	Stability problems anticipated, due to fluctuating ground water table.	Development and stability could be influenced by floods.
A 2	Alluvium CLAY (poorly drained areas).	Flood plain	Very poor	Easy rippability, but problems can be anticipated with difficult workability & poor drainage.	Mostly >0,5m and provision should be made for differential movement.	Unstable foundation conditions. Side walls of excavations unstable due to shallow ground water levels & pressure.	Flood plain, extremely poor drainage conditions & highly expansive CLAYS.
SL	Gully development where a thin colluvium soil layer consisting of material transported from the immediate environment.	Gully	Generally good	Not applicable	Not applicable	Not applicable	None

Description of the general engineering geological characteristics for each mapping unit

Figure 6 : Geotechnical mapping method developed by Bester (1981)

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Drawn by : W.L.Buitendag
Date : October 2001

General description of engineering geological characteristics (e.g. drainage, excavatability, general foundation depth and general stability), 4) Critical influencing factors.

- After revision of the classification system, Bester divided the "Development category" into three Primary categories, namely "Township development, Transport systems and Construction material". Each Primary category were sub-divided in Secondary categories and each was then described in terms of it's Development Potential (favourable, unfavourable or uncertain). A separate column was also added to describe the mining potential of units (Figure 6).

3.4.3 Engineering Geological Mapping for Urban Planning in Developing Countries by Van Schalkwyk and Price (1990)

3.4.3.1 Purpose

The purpose was to develop a site classification system to distinguish between good, fair and poor site class areas for residential development. Such a sub-division, provided as an overlay to the engineering geological map, can readily be understood and used by planners.

3.4.3.2 Classification

For housing development, the most important geological influencing factors to take into account are the: 1) foundation, 2) slope stability and 3) drainage conditions. Each of these factors is classified in terms of their severity into three sub-classes and allocated a rating point. The three sub-classes are namely, favourable (rating point of 1), slightly unfavourable (rating point of 2) and unfavourable (rating point of 5).

Guidelines to identify the different conditions for each of the geological influencing factors, are represented in Tables 6 - 8. In order to classify foundation conditions, the term volumetric stability was used to describe the behaviour of swelling or shrinking clays, collapsible and compressible soils. The various terms are defined in Table 9.

Table 6: Guidelines for the identification of different foundation conditions (after Van Schalkwyk & Price, 1990).

CONDITION	RATING	DESCRIPTION
Favourable	1	1) No risk for sinkhole or doline formation, 2) > 500 mm of volumetric stable topsoil
Slightly unfavourable	2	1) Low risk for sinkhole or doline formation, 2) < 1 500 mm unfavourable layer of volumetrically very unstable topsoil, 3) > 1 500 mm layer of volumetrically moderately unstable topsoil, 4) Scattered or continuous rock outcrop
Unfavourable	5	1) Medium to high risk for sinkhole or doline formation, 2) > 1 500 mm layer of volumetrically very unstable topsoil

Table 7: Guidelines for the identification of different drainage conditions (after Van Schalkwyk & Price, 1990).

CONDITION	RATING	DESCRIPTION
Favourable	1	1) Good surface drainage - no ponding, 2) Deep groundwater table, 2) Highly to moderately permeable topsoil and bedrock.
Slightly unfavourable	2	1) Satisfactory surface drainage - occasional surface ponding, 2) Seasinal groundwater level fluctuations, 3) Poor draining topsoil on permeable bedrock
Unfavourable	5	1) Poor surface drainage - standing water, 2) Permanent shallow groundwater table - marshy areas, 3) Located in valley, below 1: 50 year flood line, 4) Poor draining topsoil on impermeable bedrock

Table 8: Guidelines for the identification of slope stability conditions (after Van Schalkwyk & Price, 1990).

CONDITION	RATING	DESCRIPTION
Favourable	1	1) Low surface gradient (<10°), 2) Deep groundwater level, 3) Good sub-surface drainage, 4) Dense granular topsoil, 5) Sound bedrock with favourable bedding dip
Slightly unfavourable	2	1) Moderate surface gradient (10 - 20°), 2) Fluctuating groundwater level, 3) Reasonably good subsurface drainage, 4) Unstable topsoil < 500 mm thick, 5) Evidence of soil creep, 6) Sound bedrock with favourable dip
Unfavourable	5	1) Steep surface gradient (>20°), 2) Shallow groundwater table, 3) Poor sub-surface drainage, 4) Unstable topsoil > 500 mm thick, 5) Evidence of hummocky ground or slip scars, 5) Discontinuous bedrock with unfavourable dip

Table 9: Definition of volumetrically unstable soils (after Van Schalkwyk & Price, 1990).

VOLUMETRIC STABILITY	SHEAR STRENGTH (Cu: kPa)	TOTAL MOVEMENT (mm)
Stable	> 200	< 6
Moderately unstable	50 -200	6 - 50
Very unstable	< 50	> 50

Table 10: Site classification in terms of total rating (after Van Schalkwyk & Price, 1990).

SITE CLASS	TOTAL RATING
Good	3
Fair	4 - 6
Poor	7 - 15

The three influencing factors are individually rated for each mapping unit and the total rating for each unit is obtained by adding the points for each factor. The site is then classified as Good, Fair or Poor according to Table 10. This classification implies that for a site to be good, all three geological factors must be favourable. One or more slightly unfavourable conditions place the site in the fair class, while one or more unfavourable conditions classify the site as poor.

3.4.3.3 Presentation

The site classification map developed by van Schalkwyk and Price (1990) is represented as an overlay for the regional engineering geological map (Figure 5). On this map, distinction is made between good site class areas (blank), fair site class areas (open dotted) and poor site class areas (dotted).

3.4.4 Geotechnical classification system for township development by Partridge, Wood & Brink (1993) and modified by the CSIR (1996)

3.4.4.1 Purpose

The classification system developed by Partridge *et. al.* (1993) was specifically for township development and use during urban planning. This classification system was approved by the South African Institute for Engineering Geologists (SAIEG) as the nomenclature for Regional Engineering Geological Mapping (SAIEG, 1997) and is also supported by the National Home Builders Registration Council (NHBRC, 1995) *Standards and Guidelines* for Urban Planning.

The Division of Building Technology of the CSIR in partnership with the consultants Partridge, Maud and Associates published a series of 1:50 000 scale maps in the year 1996, with the objective to rate the geotechnical suitability for housing development of vacant land in the greater Johannesburg, Gauteng province. The descriptors of relevant constraints and the severity thereof, was based on the classification system of Partridge *et. al.* (1993), with minimal modification by the CSIR, as indicated in the table "Geotechnical classification for urban development" shown in Figure 7.

3.4.4.2 Geotechnical Classification System for Urban Development

Land facets are classified into categories of constraints. The constraints that will have an influence on development can be grouped into three main categories; firstly, geological (dolomitic areas) and mining hazards, secondly physical and thirdly, geotechnical constraints and are described briefly in Table 11. Terrain types can be identified by allocating an alphanumeric code for each constraint present in the mapped unit. The categories of development suitability (most suitable/favourable, intermediate and least suitable/unfavourable) with respect to geotechnical constraints A to L are listed in the table "Geotechnical classification for urban development" presented in Figure 7.

The information and development suitability of map sheets produced by the CSIR, has been derived from the generalisation of data contained in a Geotechnical Information System (GeoIS) housed at the Division of Building Technology at the CSIR (Murphy and Stiff, 1994) as well as the assessment of geotechnical constraints within each terrain mapping unit. These maps therefore represents a generalisation of the occurrence and expected severity of a particular constraint within an area and are only to be used as a guide for the planning of housing projects.

3.4.4.3 Presentation

The terrain mapping units indicated on the maps have been coloured green, yellow and red, providing 'stop - go' colours with respect to the suitability for housing development.

Table 11: Geotechnical constraints for Urban Development (after CSIR, 1996).

CONSTRAINT	ASSOCIATED PROBLEMS
GEOLOGICAL & MINING HAZARDS	**Dolomitic areas:** Formation of sinkholes or dolines, which is a high cost factor in terms of potential loss of life and structural damage to buildings. Should be investigated on a site specific level according to the evaluation proposed by Buttrick and van Schalkwyk (1995). Dolomitic areas are denoted as 3H on the map.
	Undermined ground: Potential collapse of stopes in shallow undermined areas, which is a high cost factor in terms of potential loss of life and structural damage to buildings. Information on the location of mining activities should be obtained from the relevant local authority, before planning developments in areas of undermined land . Denoted as G on the map)
	Slimes dams and mine tailings: Footprints (reclaimed slimes dams) cannot be considered ideal for housing development, due to potentially high radon levels from decaying radioactive elements present in the soil and remnant materials. Denoted as 3S on the map.
	Seismicity: Natural seismic events, would occur in a very unstable geological environment (e.g. active fault zones). Induced seismicity could be caused by activities such as mining and is fairly common in the Central and far West Rand where deep level mining has taken place. SABS 0160-1989 provides design guidelines for the building design of structures in such areas. Denoted as K on the map.
PHYSICAL CONSTRAINTS	**Topographic features:** Areas that show a resilience to weathering and forms prominent physical features (e.g. ridges and hill crests), with poor soil development and high excavation costs to establish infrastructure. These areas are often also associated with excessively steep slopes. Denoted as I on the maps.
	Drainage features: Areas of river systems or seasonal drainage channels that are prone to flooding after heavy rainfalls, should not be developed, due to the potential loss of live and structural damage. It is therefore important that development adhere to the proclaimed 1:50 year flood line. Areas where a risk of inundation by flood waters exist are denoted L on the maps.
	Wetlands: Significant ecologically sensitive wetland systems, also denoted as L on the maps.
GEOTECHNICAL CONSTRAINTS	**Heaving clay:** The amount of expansion in millimetres (expressed as total soil heave) that can be expected when the moisture in the soil changes, causing vertical heave and differential movement that leads to structural damage. These areas are denoted as C on the maps.
	Collapsible soils: Associated with open structure soils, mainly silty and sandy soils. An increase in the moisture content of these soils under sufficient external load (such as a single-storey house) results in the collapse of their structure, expressed as % decrease in soil volume. Differential settlement occurs causing structural damage. Denoted as A on the maps.
	Compressible soils: Associated with thick, transported soils on side slopes adjacent to escarpments, or saturated soils with a low bearing capacity, causing differential settlement. Denoted as D on the maps.
	Poor excavation: The ease with which ground can be dug to a depth of 1,5 m. This is a high cost factor when installing foundations and underground services. Problematic areas are associated with prominent relief, shallow bedrock or the presence of pedocretes. Denoted as F on the maps.
	Slope instability: Natural slope instability, associated with areas comprising unstable geological materials that could move. The risk of movement is determined by the nature of the slope, slope gradient, role of water, vegetation cover, seismicity and impact of human activities such as undermining and excavations. Denoted J on the maps.
	Erodible soils: The extent to which a soil can be eroded by the action of water or wind. Erodibility needs otherwise only to be considered as a local occurrence, such as erosional channels, dongas or gulleys. Denoted as E on the maps.

Green represents areas that are most favourable for development (Class 1) and red represents areas least favourable for development (Class 3). Inside each coloured area is an alphanumeric code, which is a descriptor of the geotechnical constraint relevant to that particular area. The descriptors to relevant constraints and the severity thereof are given in the table "Geotechnical classification for urban development" represented in Figure 7. For example a code 2AB describes an area of intermediate suitability for housing development (coloured yellow on the maps) due to a potential for collapse (denoted A) and seepage condition (denoted B) in Class 2 for both of these constraints.

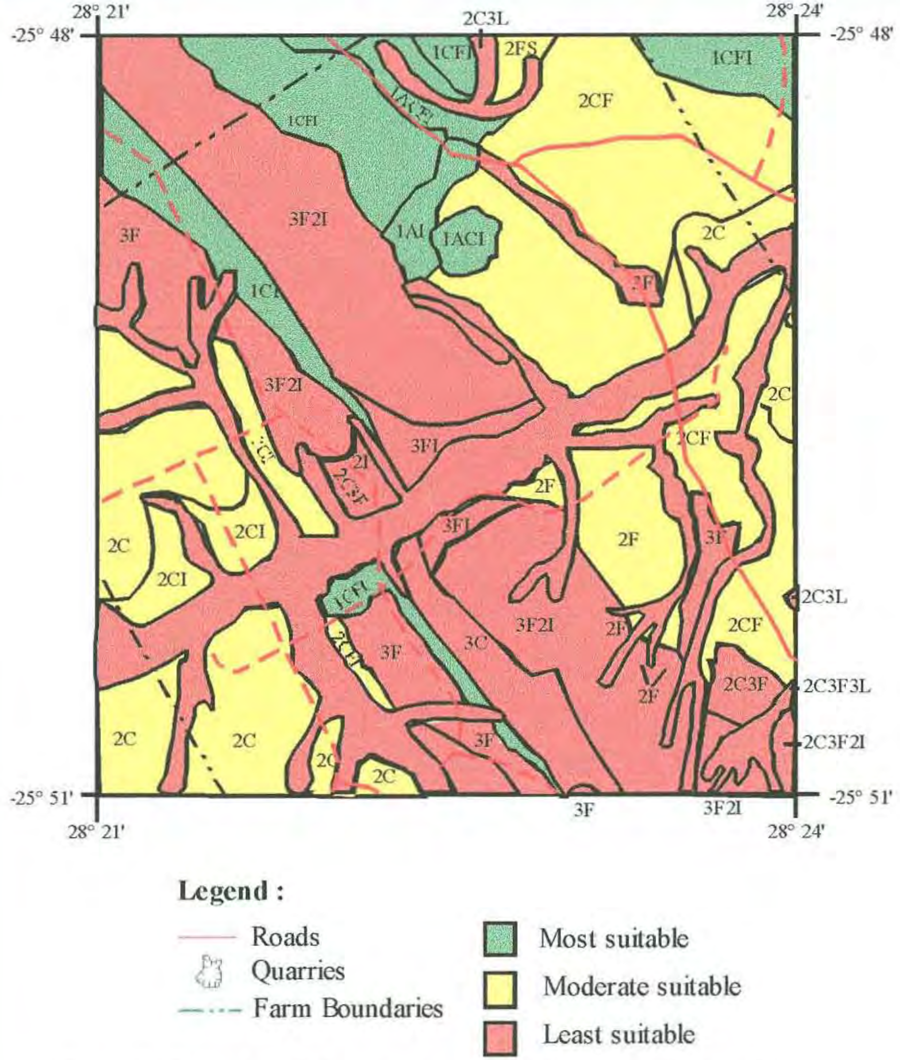

Figure 7 : Geotechnical classification method developed by Partridge, Wood & Brink (1993) and used by the Council for Scientific and Industrial Research (1996)

Scale : 1 : 50 000

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GEOTECHNICAL CLASSIFICATION FOR URBAN DEVELOPMENT (Partridge *et.al.*, 1993)

	PARAMETER	Class 1 (Most Favourable)	Class 2 (Intermediate)	Class 3 (Least Favourable)
A	Collapsible soil	Any collapsible horizon or consecutive horizons totalling a depth of less than 750mm thickness.	Any collapsible horizon or consecutive horizons with a depth of more than 750mm in thickness.	A least favourable situation for this constraint does not occur.
B	Seepage	Permanent or perched water table more than 1,5m below ground surface.	Permanent or perched water table less than 1,5m below ground surface.	Swamps and marshes
C	Active soil	Low soil-heave potential predicted*.	Moderate soil heave potential predicted.	High soil-heave potential predicted.
D	High compressible soil	Low soil compressibility expected.*	Moderate soil compressibility expected.	High soil compressibility expected.
E	Erodability of soil	Low	Intermediate	High
F	Difficulty of excavation to 1,5m depth.	Scattered or occasional boulders less than 10% of the total volume.*	Rock or hardpan pedocretes between 10 & 40% of the total volume.	Rock or hardpan pedocretes more than 40% ofthe total volume.
G#	Undermined ground	Undermining at a depth >100m below surface (except where total extraction mining has not occurred).	Old undermined areas to a depth of 100m below surface where stope closure has ceased.	Mining within less than 100m of surface or where total extraction mining has taken place.
H	Instability in areas of soluable rock.	Possibly unstable	Probably unstable	Known sinkholes and dolines
I	Steep slopes	Between 2 and 6° (all regions).	Slopes between 6 & 18° and less than 2° (Natal and Western Cape). Slopes between 6-12° and less than 2° (all other regions).	More than 18° (Natal and Western Cape). 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/s² within 50 years.	Mining-induced seismic activity more than 100 cm/s²	Natural seismic activity more than 100 cm/s²
L	Areas subject to flooding	A "most favourable" situation for this constraint does not occur.	Areas adjacent to a known drainage channel or flood plain with slope less than 1%	Areas within a known drainage channel or flood plain.

* These parameters are not considered by the CSIR geotechnical classification system.

These areas are designated as 1A, 1C, 1D or 1F where localised occurences of the constaint may arise

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Potential resources of construction materials, sites most suitable for cemeteries and waste-disposal can also be indicated on the map.

3.4.5 An Engineering Geological Geographic Information System (GIS) Model for Land-use Planning by Croukamp (Council for Geoscience, 1996)

3.4.5.1 Purpose

The purpose was to design a geographic information system with the primary objective to create an engineering geological development potential map. The map with classification criteria, will assist the engineering geologist in the determination of the development suitability of an area and the information provided is in a ready to use digital format.

3.4.5.2 GIS model & classisification criteria for a development potential map

A GIS can be regarded as a computer based system storing different spatial data sets (layers) or attribute data relevant to a certain locality for later retrieval and/or manipulation (Croukamp, 1996). It may be used for instance, to create a geotechnical or development potential map. Table 12 represents the different data layers with a brief description of each layer, that could be used for an engineering geological data model, as identified by Croukamp (1996). Each layer was assigned codes for ease of use during mapping and the codes are represented in Tables 13-19.

Other coverages (data sets) that could also be stored in the database include soil maps from the Institute of Soil, Climate & Water (ISCW), Weinert's climatic N-value map (1980), satellite imagery and hydrogeology.

The geotechnical map (Figure 8) was compiled by combining the coverages geology, land form and geotechnical properties. Each land facet was given an unique mapping number that represents the geotechnical properties and the severity thereof for that specific land facet. The codes of the different geotechnical properties were derived from Table 15.

The final product was a development potential map (overlay to Figure 8) based on the integration of a number of data sources (geology, land form, slopes, dolomite risk assessment, agricultural potential, construction material sources and geotechnical properties) intended to be used for land-use planning by town planners and / or developers. The classification criteria which were applied are presented in Table 20.

Table 12: Data layers and the type of data captured in each coverage for an engineering geological model (after Croukamp, 1996).

Data layer	Type of data
Geology (Lithology)	Lithological, stratigraphical and chrono-stratigraphical information of bedrock geology, including recent deposits (soil cover /regolith).
Structural Geology	Faults, shear zones and other linear features.
Landforms	Geomorphological features (e.g. river channels, fans, hillcrests) mapped from aerial photographic interpretation and coded as defined in TRH2 (1978) with some adaptions as shown in Table 1.
Slope grade	Height information is obtained either from digitizing the contours (1:10 000-scale) or from the Surveyor General's office and then changing the information into a gridded point data layer. These points are then stored in pre-defined slope classes (Table 13).
Instability features	Sinkholes, landslides and undermined areas.
Outcrop nature (Soil depth and rocky outcrop)	The occurrence and lateral extent of rock outcrops mapped from aerial photographic interpretation, subdivided into nine classes, as shown in Table 15.
Geotechnical properties	All geotechnical data, such as the presence of active clays, collapsing sands, erodibility, excavatibility, etc., for a given area. Where possible, an indication of the severity is also given. The information in this layer must be verified by laboratory testing (Table16).
Land-use	Existing land-use (e.g. farm, residential, informal or game reserve).
Construction materials	Information on road building material. The major classes defined are coarse aggregate (roads & concrete), fine aggregate, brick-making materials and dimension stone. Present or future utilization, as a material source, is also stored (Table17).
Soils	The soil depth, classified into four different classes, for use in determining the suitability of an area for the establishment of a cemetery site and/or the difficulty of surface excavations during the placement of services.
Cadastral data	Farm boundaries, names & ownership.
Infrastructure	Roads, railways and power lines.

Table 13: Codes used for the different slope grades (after Croukamp, 1996).

CODE	GRADE	GRADE DESCRIPTION	CODE	GRADE	GRADE DESCRIPTION
1	0° - 6°	Flat to gentle slopes	3	12° - 18°	Steep slopes
2	6° - 12°	Moderate slopes	4	> 18°	Very steep slopes

3.4.5.3 Presentation

The geotechnical properties (Table 15) which are represented by each geotechnical mapping number **with a distinctive colour** (Figure 8), are based on a coding system with an alphabetical part denoting the geotechnical property and a numerical part indicating the severity or magnitude of the property, for instance if the code is A3, A indicates the presence of swelling clay in a specific mapping unit and 3 indicates a moderate/medium activity (Croukamp, 1996).

Table 14: Codes used for instability features (after Croukamp, 1996).

CODE	FEATURE	CODE	FEATURE
1	None	18	Sinkhole -Tunneling -Recent
2	Piping	19	-Paleo
3	Slope instability	20	-Backfilled
4	Landslide	21	-Reactivated
5	Paleo	22	-Mining -Recent
6	Modern	23	-Paleo
7	Undercut slope	24	-Backfilled
8	Toppling failure	25	-Reactivated
9	Wedge failure	26	-Dewatering -Recent
10	Circular slip	27	-Paleo
11	Rockslides	28	-Backfilled
12	Mudflow	29	-Reactivated
13	Subsidence	30	Undermined area
14	Tunneling	31	- < 92m
15	Mining	32	- 92 - 244m
16	Dewatering -Dolines	33	- > 244m
17	-Surface cracks		

The development potential map is presented as an overlay to the geotechnical map (Figure 8). The development potential map depicting three classes of land, namely Category 1-land, showing High Development Potential, Category 2-land, being of

Moderate Development Potential and Category 3-land, depicting Low Development Potential (Croukamp, 1996). Category 1 could be considered as those areas most favourable for development and Category 3 as least favourable for development. This system relies on computer technology to produce maps fulfilling a certain set of criteria and each map produced will differ depending on the proposed land-use (Croukamp, 1996). It relies greatly on "produce and demand" rather than presenting a standard series of maps (Croukamp, 1996).

Table 15: Codes used for geotechnical properties (after Croukamp, 1996).

CODE	GEOTECHNICAL DEVELOPMENT CONSTRAINTS	CODE	GEOTECHNICAL DEVELOPMENT CONSTRAINTS
A/1	Active clay -No	H/1	Shallow water table -No
2	-Yes	2	-Yes
3	-High expansion (> 30 mm)	I/1	Permeability -Not tested
4	-Medium expansion (5 - 30mm)	2	-Low ($\leq 4 \times 10^{-6} - 9 \times 10^{-10}$cm/s)
5	-Low expansion (< 5mm)	3	-Medium ($\leq 4 \times 10^{-4} - 4 \times 10^{-6}$ cm/s)
B/1	Collapse potential -No	4	-High ($\geq 1 \times 10^{-1} - 4 \times 10^{-4}$ cm/s)
2	-Yes	J/1	Inundation -No
3	Slight trouble (1 - 5%)	2	-Yes
4	Moderate (5 - 10%)	K/1	Slope instability -No
5	Severe (10 - 20%)	2	-Yes
6	Very severe (> 20%)	L/1	Shifting sands -No
C/1	Erodible soil -Not tested	2	-Yes
2	-No	M/1	Sinkholes -No
3	-Yes	2	-Yes
D/1	Corrosive soil -Not tested	3	-Low risk
2	-No	4	-Medium risk
3	-Yes	5	-High risk
E/1	Dispersive soil -Not tested	N/1	Pseudokarst -No
2	-No	2	-Yes
3	-Yes	O/1	Excavatability problems -No
4	-Slight reaction	2	-Yes (> 1,5m)
5	-Moderate reaction	3	-Slight (1 - 1,5m)
6	-Strong reaction	4	-Moderate (< 1,0m)
F/1	Poorly consolidated soil -No	5	-Severe (< 0,5m)
2	-Yes	P/1	Slaking -Not tested
G/1	Induced subsidence -No	2	-No
2	-Yes	3	-Yes

Table 16: Codes used for outcrop/soil depth (after Croukamp, 1996).

CODE	OUTCROP	CODE	OUTCROP
d1	Solid rock outcrop (≥ 80% of area covered)	d3	No outcrop
d2	Scattered rock outcrop (> 0% & < 80% of area covered)	d3a	Sub-outcrop/thin soil cover (0m < soil cover ≤ 1m)
d2a	Sub-outcrp / thin soil cover (0m < soil cover ≤ 1m)	d3b	Medium soil cover (1m < soil cover ≤ 3m)
d2b	Medium soil cover (1m < soil cover ≤ 3m)	d3c	Deep soil cover (soil cover > 3m)
d2c	Deep soil cover (soil cover > 3m)		

Table 17: Codes used for construction materials (after Croukamp, 1996).

CODE	POTENTIAL CONSTRUCTION MATERIALS [included samples (yes/no), tests (yes/no), number of borholes or test pits]
1	Construction materials
2	-Clay
3	-Sand
4	-Stone (Dimension stone)
5	-Fill material (Landfill use)
6	-Aggregate
7	-Aggregate (concrete)
8	-Aggregate (road building)

Table 18: Codes used for the type of mining activity (after Croukamp, 1996).

CODE	TYPE OF MINING ACTIVITY
1	Mine
2	Opencast
3	Quarry
4	Sub-surface

Table 19: Codes used to define the sinkhole class (after Croukamp, 1996).

CODE	SINKHOLE (included event date, length, width, depth, shape)
1	Class I (0 - 5 m diameter)
2	Class II (5 - 10 m diameter)
3	Class III (10 - 20 m diameter)
4	Class IV (> 20 m diameter)

Table 20: Classification criteria applied for development potential map (after Croukamp, 1996).

CRITERION	CATEGORY 1 LAND	CATEGORY 2 LAND	CATEGORY 3 LAND
AGRICULTURAL POTENTIAL	Low potential	Medium potential	High potential
LANDFORMS	Convex slope, concave slope, plain.	Talus slope, pediment & disssected pediment, fan, rill erosion.	Crest (Hill, < ridge & mesa), sand bank, drainage features, excavation/mine dumps/landfills.
SLOPE CATEGORIES	< 6°	6° - 15°	> 15°
DOLOMITE RISK CHARACTERISATION		Risk classes I to IV	Risk classes V to VII
GEOTECHNICAL PROPERTIES	Collapsible soils, compressible soils.	Medium excavatability (1m < rock depth > 3m), heaving/active clays, shallow ground water level, poorly drained areas.	Shallow excavatability (outcrop/rock depth < 1m), steep/unstable slopes (>15° or highly erodible), drainage channels.
CONSTRUCTION MATERIALS			Identified potential resource areas.

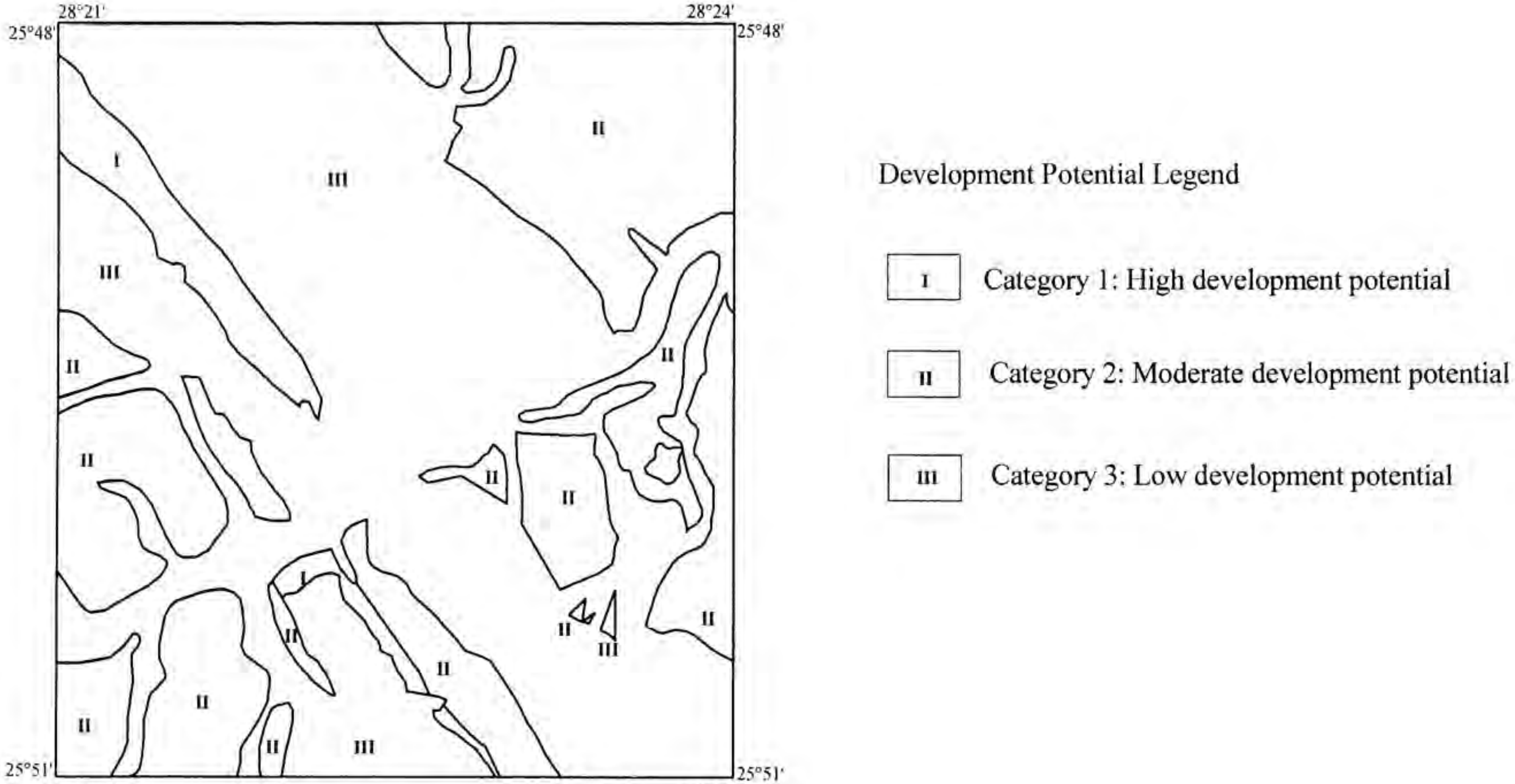

Figure 8: Development Potential

1:50 000

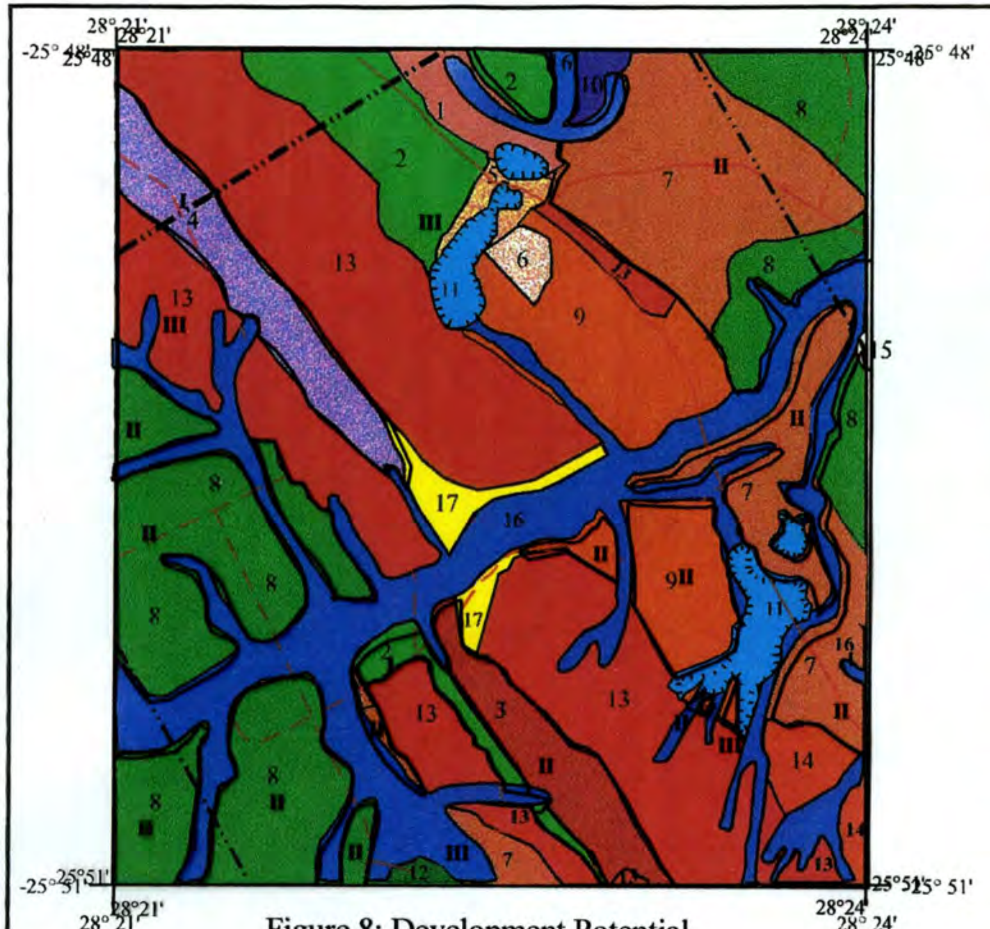

Figure 8: Development Potential

1:50 000

Figure 8 : Classification system developed by Croukamp (1996) to determine the Development Potential of an area (geotechnical map with an overlay of the different development potential classes)

Development Potential Legend

Category 1: High development potential

Category 2: Moderate development potential

Category 3: Low development potential

GEOTECHNICAL MAPPING NUMBER	GEOTECHNICAL PROPERTIES	DESCRIPTION
1	A5, B2, O3	Low activity clays, collapsible soils, slight excavatability problems
2	A5, O3	Low activity clays, slight excavatability problems
3	A3	Highly active clays
4	A5	Low activity clays
5 (I)	B4	Moderate collapsible soils
6	A5, B4	Low activity clays, moderate collapsible soils
7	A4, O4	Medium active clays, moderate excavatability problems
8 (II)	A4, O3	Medium active clays, slight excavatability problems
9	A5, O4	Low active clays, moderate excavatability problems
10 (III)	[illegible]	Low active clays, slope instability, moderate excavatability problems
11	H2, K2, O2	Shallow water table, slope instability, excavatability problems
12	A4, J2	Medium active clays, inundation
13	A5, O5	Low active clays, severe excavatability problems
14	A4, O5	Medium active clays, severe excavatability problems
15	A4, K2, O3	Medium active clays, slope instability, slight excavatability problems
16	A4, J2, O3	Medium active clays, inundation, slight excavatability problems
17	A4, K2	Medium active clays, slope instability

Legend :

- Farm boundaries
- Roads
- Quarries

1 : 50 000

Council for Geoscience

Compiled by : I.Kleinhans
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Date : October 2001

3.5 CONCLUSION

Methods to present regional engineering geological information and/or data in South Africa, based on the land facet approach, started as early as the 1950's. The main objective was then to define the best location for a route of a planned road, with no or little consideration towards land-use planning.

The scope of regional engineering geological mapping changed after the need for road construction slowed down at the end of the 1970's and it was realised that engineering geological mapping could make an effective contribution to the planning of developing areas, such as urban expansion.

Evaluation of classification systems used for regional engineering geological mapping since the 1970's, revealed that most of these systems are based on work previously done in the field of engineering geological mapping, with little or no modification. There was a decrease in interest in the development of/or research in engineering geological classification mapping systems, from 1981 to 1993. Up until 1993, no standardised engineering geological classification system existed and the TRH2 system, although not designed for this purpose, was the standard nomenclature used for urban development planning. Partridge, Wood and Brink (1993) developed a standardised method to conduct urban engineering geological investigations, which is still regarded as the accepted standard of practice by the engineering geological fraternity used in south Africa, including SAICE, SAIEG and the NHBRC.

Each classification system was evaluated in terms of, the objective, method of classification and map presentation. The following conclusions could be made for each system:

- The TRH2 system is a very simplified method and the map is easy to compile. The map presents, geology, structural geology, topography, physiography, potential soil problem areas and potential construction materials, with the geology used as the base map. The shortcomings of the system is that, although it could be used for regional land-use planning purposes it does not give any indication of the severity of potential problem areas and the potential for land-use of these areas.

- The method proposed by Price (1981) and Bester (1981) are both very complex systems. During the compilation of these maps, difficulty was experienced with the application of the proposed engineering geological land-use ratings for each influencing factor of each mapping unit. All the information is displayed as an overlay on the published 1:50 000 topographical map. Each mapping unit on the map, was indicated by a symbol and hatching code. Both these maps are very difficult to read, due to the format and amount of information displayed.

The associated table for the map developed by Price, gives a description of each facet group in terms of the Unified Soil Classification, engineering geological land-use rating for township and road & railways, potential geotechnical problems, construction materials and their engineering geological land-use potential. Van Schalkwyk and Price (1990) refined the method proposed by Price and developed a site classification system to distinguish between good, fair and poor site class areas for residential development, based on the rating of the following geological influencing factors: 1) foundation, 2) slope stability and 3) drainage conditions. This was provided as an overlay to the geotechnical map of Price (1981) that could easily be understood and used by planners.

The associated explanation table for the map developed by Bester, gives a description of each mapping unit in terms of, the typical soil profile description, land form, engineering geological characteristics (drainage, excavatability, foundation conditions and stability) and critical influencing factors. Furthermore, Bester developed a general interpretation for each development category, which he divided into Primary categories (township development, transport systems and construction materials), each Primary category was sub-divided into Secondary categories and each was then described in terms of its development potential (favourable, unfavourable or uncertain).

Although both systems provide a significant amount of information, the presentation of all this information on a 1:50 000-scale map is complex. The readability of and distinction between mapping units/facet groups are reduced by the use of only one colour (black) for the drawing of lines, hatching of mapping units/facet groups and text. Information is displayed as an overlay to the topographic map, making it very difficult to pinpoint a specific area and the associated geotechnical factors for that area.

The advantage of displaying so much information on one map, is that it is useable by the engineer and/or engineering geologist to recognise potential geotechnical factors and their associated problems, as well for the town planner and/or developer to recognise potential poor or good areas for development purposes, from the accompanied tables. The disadvantage is that a magnifying-glass is necessary to read the text on the map and in the accompanied tables, which makes the information and map unpractical. If the information was displayed on a map scale of 1:10 000, it would have been very clear and more useful.

- Based on all available information and the comparison of the different geotechnical classification methods proposed in this chapter, it seems that the system developed by Partridge et. al. (1993) and modified by the CSIR (1996), can be regarded as one of the best and most practical systems in use to classify terrain for planning and development purposes. The system developed by Partridge et. al. (1993) is presently still regarded as the accepted standard of practice in South Africa, by the engineering geological fraternity, including the SAICE, SAIEG and NHBRC.

Geotechnical constraints that are taken into account during the evaluation of a terrain for development purposes include collapsible soils, seepage, active soils, compressible soils, erodibility of soil, difficulty of excavation, undermining, instability associated with soluable rock, steep slopes, areas of unstable natural slopes, areas subjected to seismic activities and areas subjected to flooding. The parameters undermined ground and areas subjected to seismic activity are not considered by the CSIR geotechnical classification system.

The simplicity of the map and the information displayed is such that it could be utilised by engineers/engineering geologists and town planners/developers. The category of development suitability (most, moderate, least) for each terrain mapping unit has been coloured green, yellow and red, respectively, with an alphanumeric code, which gives a description of the relevant geotechnical constraints and the severity thereof. The use of three basic colours makes it possible for the developer/town planner to easily distinguish between the different categories of development suitability (most, moderate, least) and to select the area with the least geotechnical constrains to avoid high financial costs. The alphanumeric code and the indication of the severity of each constraint in each terrain mapping unit, makes it possible for the engineer/engineering geologist to interpret the different geotechnical constraints present in each mapping unit in order to determine the potential foundation requirements and design necessary for that specific area.

- The engineering geological geographical information system (GIS) model for land-use planning developed by Croukamp (Council for Geoscience,1996) includes different data layers, that could be stored, retrieved or manipulated to create different types of thematic maps (e.g. geotechnical or development potential). Advanced computer technology will steer future mapping technology for efficient land-use planning, towards the electronic environment.

The geotechnical map was compiled with ease. Each land facet was given an unique mapping number with a destinctive colour that represents the geotechnical properties and the severity thereof for that specific land facet. The geotechnical properties are presented in a coding system with an alphabetical part denoting the geotechnical property and a numerical part indicating the severity or significance of the property.

Problems that did occur during the compilation of the geotechnical map, was the confusion of the severity classes for the geotechnical factor active clays, because they are not ordered from low to high as the rest of the geotechnical factors with severity class sub-divisions. The use of different colours for different land facets makes it possible to easily distinguish between them on the map and increase the readability.

The development potential map, presented as an overlay and based on the integration of the data layers, geology, land form, slopes, dolomite risk assessment, agricultural potential, construction materials and geotechnical properties, provides a good overall land-use potential, taking into account financial and environmental implications. Each of the layers was assigned codes for ease of use during mapping and was sub-divided into three classes of land, namely Category 1-land (High Development Potential), Category 2-land (Moderate Development Potential) and Category 3-land (Low Development Potential) (Croukamp, 1996), which makes it possible to distinguish between areas that are safe for development purposes and environmental friendly versus those that are not. Category 1 could be considered as those areas most favourable for development and Category 3 as least favourable for development.

The advantages of a system like this is that different data layers could be incorporated, stored in a digital format and manipulated to produce different thematic geotechnical maps, based on the requirements of the client. The advantage of data stored in a digital format, is that information is immediately available and accessible, without any time constraints. The disadvantages of a system like this is the time and cost involved to develop a database that are user friendly where information could be stored, retrieved and manipulated. Other obstacles according to Croukamp (1996) is the lack of skilled personnel, inappropriate and ineffective hardware and/or software and inaccurate or insufficient original data.

CHAPTER 4

REGIONAL GEOTECHNICAL MAPPING PROCEDURES PROPOSED BY THE COUNCIL FOR GEOSCIENCE

4.1 INTRODUCTION

Regional geotechnical mapping is based on the land facet approach. A land facet can be classified as an area of ground with a simple surface form, a specific succession of soil profile horizons (each with reasonably uniform properties, but can vary in thickness) and a characteristic groundwater regime (Stiff, 1994). The assumption is made that an area of terrain with the same host lithology and land form will provide similar soil profiles and therefore similar geotechnical properties.

A systematic approach is proposed and the process can be divided into six phases (Swanepoel, 2001), namely: 1) Data gathering or desk study, 2) reconnaissance survey, 3) field mapping, 4) laboratory analysis, 5) compilation of the geotechnical map and 6) report writing. The different stages are discussed in detail in the following paragraphs.

4.2 DATA GATHERING OR DESK STUDY

This phase involves the accumulation and interpretation of existing data.

4.2.1. Data accumulation

Data from the following sources could be useful and should be accumulated if available:

- Maps: Topographic, geology, orthophotographs, geophysical, agricultural, soil, etc.

- Aerial photographs and satellite imagery: Most recent and older sets, in order to delineate landforms that have become obscured by new development and to observe temporal changes such as donga formation and new infrastructure.
- Reports: Geological, site specific geotechnical, hydrogeological and geophysical.
- Existing databases: Council for Geoscience, CSIR, etc.
- Other information: Economic geology (minerals and mining), climatic data (Weinert's climatic N-value, temperature, rainfall & wind direction), etc.
- Published relevant literature: Engineering Geology of South Africa (Brink, 1979 - 1985), etc.

4.2.2 Data processing

The preliminary interpretation of existing data is now possible in order to assist planning of the fieldwork phase. This will include:

- Compilation of a landform map from aerial photographs and orthophoto interpretation, where the boundaries of the different landforms are identified and delineated on a transparent aerial photo overlay. These overlays are captured digitally and GIS software is used to compile a landform map on a 1:50 000 scale or the boundaries can be transferred manually onto a transparent overlay using the 1:50 000 topographical map as a base.
- Adding all the other available information to the base map (1:10 000 or 50 000).
- The four volumes by Brink (1979 - 1985) on the engineering geology of South Africa, gives a broad overview of conditions to be expect on different rock types in South Africa and should be consulted prior to any regional geotechnical mapping project, carried out in South Africa.

4.3 RECONNAISSANCE SURVEY

During this stage the accuracy of the information gathered and interpolated during the desk study is checked by a walk-over site survey. Test pit positions are provisionally identified by overlaying the landform and geology maps to ensure that all mapping units delineated from the land facets will be profiled during the fieldwork stage. Information regarding possible undermining, occurrence of construction materials, current land-use and accessibility are evaluated. Fieldwork can now be planned in a more effective way.

4.4 FIELD MAPPING

The field mapping can be subdivided into geological and geotechnical mapping.

4.4.1 Geological mapping

Geological mapping is only necessary if no regional geological map on a scale of 1:50 000 (sometimes available on a 1:10 000 scale, with outcrop information) exists for the area. Geotechnical mapping can only commence after the geological map is compiled by a geologist, due to the fact that the geotechnical properties are derived directly from the underlying bedrock geology and land form. The published geology map should be checked during the geotechnical mapping phase.

4.4.2 Geotechnical mapping

Geotechnical mapping comprises the excavation of and description of soil profiles in test pits or soil profile description of exposed road cuttings and quarries, in order to determine the succession of soil layers present in a specific land facet. This information can then be extrapolated to other similar land facet types. A minimum number of three test pits per land facet type for regional geotechnical mapping is suggested by SAIEG (1997) for correlation purposes.

Representative soil samples (disturbed and undisturbed) are collected from the possible problem soil horizons for laboratory analysis.

The individual soil layers in each profile are described according to the MCCSSO method (Jennings *et al*, 1973). This method allows for the systematic description of surficial soil horizons in terms of moisture condition, colour, consistency, structure, soil type and origin. Soil profiling provides the basis for the first assessment of the engineering properties of the soil. The bedrock, if present in profile, is described in terms of colour, the degree of weathering, fabric & discontinuity spacing, rock hardness, rock type and a description of the discontinuity surface (SAIEG, 1996).

In addition, each soil profile should include notes on the position of the test pit, method of excavation, if the water table has been encountered or not, a description of the type of water table (perched or permanent) if encountered, at what depth and the reason why the test pit was stopped, stability of the test pit side-walls, the depth at which soil samples were taken, date of recording and the name of the profiler. Geotechnical problems identified during the field work stage should be noted to aid in the compilation of the final geotechnical map.

4.5 LABORATORY ANALYSIS

Laboratory analysis are carried out on disturbed and/or undisturbed soil samples to determine material and engineering properties of the various soil horizons present in the area of investigation.

Laboratory analysis on undisturbed soil samples are not considered as part of the normal sampling and testing procedure for regional geotechnical mapping, due to the scope of such a mapping exercise and the high costs involved with these tests. A number of undisturbed soil samples may be collected for analysis to determine a quantitative value for a specific problem that may occur in the area of investigation. These tests may include consolidation, tri-axial, shear-box, permeability and moisture-density tests/compaction (modified AASHO).

Disturbed samples are used to conduct foundation indicator tests, included grading analysis, determination of the Atterberg limits and Emerson crumb test.

Grading (particle size distribution) of the soils are determined by means of sieve analysis and hydrometer tests (to determine the clay percentage), resulting in cumulative grading curves. Samples are classified according to the A.S.T.M. standard, using the Unified Soil Classification System (Craig, 1997). This system is used to classify the material in each land facet, as well as determining its suitability as a construction material resource.

The mechanical or physical properties of a soil are described in terms of the liquid limit and plasticity index (determined by means of the Atterberg Limit test) and the linear shrinkage. The expected maximum probable heave and expansiveness can be evaluated according to the method of Van der Merwe (1964). This method is a development of the unit heave approach, which allows for the heave of profiles with layers exhibiting different potential expansiveness with a depth factor to be calculated. However, the use of unit heave under no load for the various classes of potential expansiveness does not take into account the influences of either initial moisture content or density and therefore gives a partial estimation of expansiveness. The degree of saturation would influence the potential expansiveness of the soil. For example, a partially saturated soil could show moderate expansiveness, whereas the same soil in a saturated condition will show little or no expansiveness. The method of van der Merwe is an empirical method and should be used with care. It is however a good indication of expected heave conditions on a regional scale.

The permeability of the material is classified in centimetres per second and can be calculated with Hazen's permeability equation, which uses the grading of the material (Hazen, 1982):

$$k = 100.\ D_{10}^2$$

where k - Coefficient of permeability in centimetres per second

D_{10} - Effective size (10% of particles are smaller than the size denoted by D)

It should be noted that this method is only applicable for clean sandy soils and not very reliable for permeabilities of clay and silty soils, which normally have permeabilities below 10^{-4}cm/s. Although not applicable for silty and clay soils, it could be useful as a first indicator at an early stage of the investigation.

The potential erodibility of soils could be determined by means of the Emerson Crumb test. According to Elges (1985), the test involves the submerging of a 15 mm cubical moist soil sample in 250 ml distilled water. As the soil crumb begins to hydrate the tendency for colloidal-sized particles to deflocculate and go into suspension is observed, in terms of different reaction grades.

XRD analyses could be conducted on disturbed soil samples to determine the mineral composition of the soil. This can be useful to establish the presence of a 1:1 lattice clay like kaolinite, to confirm the presence of a potential clay resource for construction purposes or to determine the presence of montmorillonite clays with a 2:1 lattice structure, that will be potentially expansive.

A method that is commonly used during regional geotechnical investigations to determine the potential collapse of undisturbed soil samples is the Collapse Potential test (Jennings and Knight, 1975). The percentage of collapse will depend on the initial dry density (mass of solids per unit volume of soil) and the initial moisture content (ratio of the mass of water to the mass of solids) of an undisturbed soil sample (Craig, 1997).

In the Collapse Potential test an undisturbed sample is cut to fit into an oedometer ring, followed by a consolidation test with the sample at natural moisture content. Loads are applied, incrementally, until 200kPa. When no further change in volume occurs at 200kPa the specimen is inundated with water and allowed to stand for 24 hours. Thereafter the consolidation test is continued to its normal final load. A pronounced reduction in void ratio will be experienced by collapsible material upon inundation (Jennings and Knight, 1975). The Collapse Potential (CP) is then defined as:

$$CP = \frac{\Delta e_c}{1 + e_0} \times 100$$

where Δe_c change in void ratio, at 200kPa, upon wetting.

e_0 original void ratio

This is only a first indication of collapse and no value for the amount of collapse can be obtained. A double oedometer test is necessary to quantify the collapse of a soil.

4.6 COMPILATION OF THE GEOTECHNICAL MAP

The soil profiles obtained in the field, the laboratory results, the land form map and the geology are used to compile a geotechnical map of the area. The following procedure is followed:

- If the primary mapping and data collation has been done at a 1:10 000-scale, the relevant information should be compiled at a 1:50 000-scale, either through means of a scanning and vectorising process or digitizing by hand.
- Test pit positions are plotted on an overlay and captured digitally or could be recorded and stored by using a GPS.
- Laboratory results and observations during the fieldwork stage are analysed to assess the geotechnical properties of an area.
- The corresponding geotechnical factors are then written down next to each plotted test pit.
- This overlay is then placed over the transparent land form overlay and both are placed on top of the geology map. It is then possible to identify areas with the same geology, landform and geotechnical properties and to extrapolate geotechnical properties to other areas with similar geology and landform where test pits may not have been sited.
- Geotechnically distinct areas are then identified and boundaries drawn dividing the area into mapping units with their specific geotechnical properties.

- Coding of mapping units follows. A table is then drawn, where each unique code represents a specific combination of geotechnical properties.
- The geotechnical map is then traced onto a chrona (topographical map printed on transparent polyester) and captured digitally for GIS processing. The final map printed with the codes and colours is then submitted to the drawing office.
- This mapping process could lead to the formation of a stack of layers of information or data sets, which could be stored in a data base. The data from these coverages can in turn be manipulated and integrated by computer software to create different types of maps, for instance a development potential map or a land-use map, by combining the geology, landform and geotechnical coverages.
- Other data coverages (apart from geology, land form and geotechnical properties) that will be useful for an engineering geological GIS data model include (Croukamp, 1996): Instability features, slope-grade, land-use, outcrop-nature (soil depth and outcrop), construction materials, cadastral data and infrastructure.

4.7 REPORT WRITING

A report or explanation should accompany the produced geotechnical map, outlining the methodology and reasoning behind the production of such a geotechnical map, as well as an explanation and discussion of the conditions found during the study. The following should be portrayed:

- **Introduction:** Should explain the purpose and scope of the mapping project and discuss previous investigations conducted in the study area, as well as information available in databases that could be used.
- **Methodology:** Describe the way information has been gathered and interpolated and how the geotechnical map has been compiled.
- **Physiography:** Define the study area in terms of locality, scale and size. Description of the geomorphology including drainage, relief and landform that can influence new developments.

- **Climate and vegetation:** The climate of the region is described by means of the average annual rainfall, minimum and maximum temperatures, prevailing wind direction and speed (Weather Bureau). These aspects are important during the selection of potential waste disposal and cemetery sites. Weinert's climatic N-value for the area is indicative of weathering predominance (mechanical breakdown or chemical decomposition), therefore expected depth to bedrock can be estimated (Weinert, 1980). The description of the area's vegetation is an important environmental consideration, this is to assure that endangered species are protected if new development should take place. It is also a good indication of the underlying geology, because certain vegetation species are associated with certain geology (Acocks, 1988; Low and Rebelo, 1998).
- **Geology:** A description of the geological Supergroups, Groups, Formations and lithologies, obtainable from an existing 1:50 000-scale geological map and explanation or published 1:250 000-scale geology maps.
- **Geohydrology:** Information regarding ground water movement and direction, compartments, quantity and quality should be discussed.
- **General engineering geological properties based on geology and land form:** The four volumes of Brink (1979-1985), as well as existing studies conducted in the area, should be used to discuss the kind of conditions to expect on transported and residual soils derived from different rock types in the study area.
- **Terrain evaluation:** Each geotechnical property should be described in detail in terms of physical parameters, classification (severity class), area covered, associated problems that could have an effect on development as well as recommended construction methods.
- **Potential construction materials:** Potential natural resources should be defined in terms of suitability, quality and available reserves. All existing quarries (non-operational and operational), as well as potential resources should be indicated and described in the report to reduce the risk of sterilisation of these resources.
- **Environmental considerations:** This include developments such as cemetery sites, waste disposal sites and ground based sanitation systems (pit latrines and septic tanks), that will have a negative impact on the environment. The

requirements should be listed and potential areas should be defined and described.

CHAPTER 5

GEOTECHNICAL CLASSIFICATION SYSTEM DEVELOPED BY ZAWADA (2000) WITH SPECIAL REFERENCE TO THE RIETVLEI DAM 2528CD MAP SHEET

5.1 INTRODUCTION

The Council for Geoscience has embarked on a 1:50 000-scale geotechnical mapping programme aimed at producing engineering geological maps of key development areas delineating the distribution and severity of key geotechnical parameters (Zawada, 2000). The primary objective was to provide a series of geotechnical maps that support a variety of regional planning policy and strategy initiatives.

The findings of an evaluation of the geotechnical aspects of an area south-east of Pretoria, based on the classification system proposed by Zawada (2000) is discussed. The shortcomings of the system is discussed and recommendations are provided to improve the end product (geotechnical map) and the use thereof.

5.2 GEOTECHNICAL CLASSIFICATION SYSTEM (ZAWADA, 2000)

5.2.1 Purpose

Zawada (2000) developed a classification system in which the geotechnical parameters are not generalised into zones for development to ensure that the map could be of value in a variety of land-use and development applications and not only for a specific type of development.

5.2.2 Classification

A total of 13 geotechnical factors were identified and evaluated in terms of their severity (Table 21). Each geotechnical factor was ranked in terms of overall significance to land use issues and the ranked list was then classified into groups having a critical and subcritical status (Table 22) (Zawada, 2000). The ranking of geotechnical factors is not meant to be definitive in the sense that a quantifiable difference exists between an expansive or swelling soil and an area exhibiting slope instability. Its purpose is to enable the identification of the highest ranked factor out of several geotechnical factors present in an area and therefore characterise the area with a dominant geotechnical factor (indicated by a colour type corresponding to the geotechnical factor) and to inform the user that additional critical and subcritical factors may also be present for the same area, which is denoted by a shade of colour corresponding to the dominant geotechnical factor colour (Zawada, 2000).

There are two major factors which are also considered when planning the development of an area, namely: financial cost and/or the environmental implications of the development. The geotechnical factors are therefore classed into these two categories (Table 23) using the following criteria:

Financial costs:

These are geotechnical factors or conditions which require significant financial input to remediate the condition prior to development. For example, an area exhibiting active or swelling soil represents a significant increase in cost for the development of low-cost housing due to the extra cost of specialised foundations to ensure the integrity of the buildings. A cost factor weighting has been assigned to each geotechnical factor. Although the cost weightings are qualitative, they give an indication of the cost factor associated with the geotechnical properties found in designated areas on the map.

Table21: Alphabetical listing of geotechnical factors mapped for the Rietvlei Dam map sheet with definitions, implications for development and classes of severity (after Zawada, 2000).

Active, expansive or swelling soil (Act) — *High cost factor* — *Severity: Act2, Act3, Act4 or Act5*

Explanation - The amount of expansion in millimetres (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 ground water due to abstraction, drainage changes or river modification.

Implications for development - The degree to which a soil expands or contracts is a critical cost factor in the foundation design, especially of single-storey residential buildings. Expansive clays, which can result in significant damage to buildings and pipelines, are probably one of the most widespread problem soils in South Africa.

Severity class -
- **Act2** Active or expansive soil is present (amount of expected heave is unknown)
- **Act3** Low expansion (heave is expected to be 0–5 mm)
- **Act4** Moderate expansion (heave is expected to be 5–30 mm)
- **Act5** High expansion (heave is expected to be greater than 30 mm).

Acidic soil (Aci) — *Subcritical environmental factor and low cost factor* — *Severity: Aci2*

Explanation - 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.

Implications for development - Adverse soil acidity affects metal- and concrete-pipe networks and concrete. It is also a serious yield-limiting factor in agriculture. It is not uncommon to have pH values of 2,5–4 close to slimes dams. This can have negative environmental impacts on the soil and the ground-water quality.

Severity class - **Aci2** Acidic soil is present.

Collapsing or settling of soil (Col) — *Moderate cost factor* — *Severity: Col2, Col3, Col4, Col5 or Col6*

Explanation - 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.

Implications for development - The degree of soil settlement is a moderate cost factor that must be considered, particularly in the foundation design of single-storey residential buildings.

Severity class -
- **Col2** Settlement potential is present (amount of decrease in soil volume is unknown)
- **Col3** Low settling potential (1–5 % expected decrease in soil volume)
- **Col4** Moderate settling potential (5–10 % expected decrease in soil volume)
- **Col5** Severe settling potential (10–20 % expected decrease in soil volume)
- **Col6** Very severe settling potential (greater than 20 % expected decrease in soil volume).

Poorly consolidated soil (Con) — *Moderate cost factor* — *Severity: Con2*

Explanation - Poorly consolidated or highly compressible soils are expected to have low bearing capacities and are therefore liable to differential settlement. Examples of highly compressible materials are areas of fill 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.

Implications for development - Risk of differential settlement and therefore damage to structures. A moderate to high cost factor requiring compaction techniques to reduce compressibility.

Severity class - **Con2** Area has poorly consolidated soil.

Dispersive soil (Dis) — *Subcritical environmental factor and low cost factor* — *Severity: Dis2, Dis3, Dis4 or Dis5*

Explanation - 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 and 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.

Implications for development - High dispersivity values indicate the soil's susceptibility to piping, the formation of erosional gulleys and internal cavities in the soil mass. Dispersivity can lead to stability problems of earth embankments, and increased sediment loads entering river bodies and channels.

Severity class -
- **Dis2** Soil is dispersive (based on field observation)
- **Dis3** Slight dispersive reaction (on addition of soil to water)
- **Dis4** Moderate dispersive reaction (on addition of soil to water)
- **Dis5** Strong reaction (on addition of soil to water).

Erodible soil (Ero) — *Critical environmental factor and low cost factor* — *Severity: Ero2*

Explanation - 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 effects or it may be of a more regional extent.

Implications for development - A critical environmental factor where erosion of soil represents a negative environmental factor. Certain types of development on erosion-prone soil can result in dramatic increases in sediment load entering water bodies and courses. This would have negative impacts on the biotic and abiotic elements of wetland and riverine environments.

Severity class - **Ero2** Erodible soil is present (erosional features were observed).

Excavatibility of ground (Exc) — *High cost factor* — *Severity: Exc2, Exc3, Exc4 or Exc5*

Explanation - The ease with which ground can be dug to a depth of 1,5 m.

Implications for development - A high cost factor in development when installing foundations and underground services such as water pipes and sewers.

Severity class -
- **Exc2** Excavatibility problems are anticipated (unspecified)
- **Exc3** Slight excavatibility problems (can be hand dug)
- **Exc4** Moderate excavatibility problems (backactor is required)
- **Exc5** Severe excavatibility problems (blasting and/or power tools are required).

Inundation (flooding): (Inu) — *Critical environmental factor* — *Severity: Inu2*

Explanation - Area that experiences flooding by either: (1) flood-water volumes that exceed the channel-carrying capacity of the channel, 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.

Implications for development - Inundation or flooding is primarily a critical environmental factor because floods are natural events that have to be taken into account where development encroaches on or is close to stream channels. Therefore most residential developments, such as houses, cannot be erected in areas below the 1:50-year flood line. Note should be taken, however, that certain developments may have significant effects on the flood behaviour of the river. Factors such as changed hydrology, sediment loads and river diversions can have significant impacts, to the extent that areas with a low risk of flooding before development can become high-risk areas after development. Development planning also needs to be aware of the significant abiotic and biotic effects on sensitive environments such as wetlands, that altered flow and flood patterns of rivers may have.

Severity class - **Inu2** Area at risk from inundation.

Permeability of soil (Per) — *Critical environmental factor* — *Severity: Per2, Per3 or Per4*

Explanation - The permeability of a soil is a measure of how easily fluids (usually water) pass through the soil and is related to the degree to 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 shape of the mineral grains in the soil, the grain size and the manner in which the grains are held together.

Implications for development - The permeability of a soil is a critical factor that affects the rate at which water and dissolved contaminants can pass through, and into, the ground water. This information is critical to the siting of certain developments such as cemetries and certain types of waste-disposal sites.

Severity class -
- **Per2** Low permeability ($< 4\times10^{-6}$–9×10^{-10} cm/s)
- **Per3** Medium permeability (4×10^{-4}–4×10^{-6} cm/s)
- **Per4** High permeability ($>4\times10^{-4}$ cm/s).

Shallow water table (Sha) — *Critical environmental factor* — *Severity: Sha2*

Explanation - 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.

Implications for development - A shallow water table is liable to contamination by incorrectly sited developments, such as waste sites, pit latrines and cemeteries. Knowledge of a shallow water table can be critical when planning certain developments.

Severity class - **Sha2** Shallow water table is present.

Sinkhole formation (Sin) — *High cost factor* — *Severity: Sin2*

Explanation - 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 are dependent on factors such as the type of carbonate, the presence of underground receptacles, the rate of solution caused by leaking water pipes and the lowering of water levels in underground caves by excessive pumping.

Implications for development - A high cost factor in terms of potential loss of life and structural damage to buildings. Dolomite and sinkhole formations are potentially critical geological constraints that must be incorporated during land-use evaluation and planning.

Severity class - **Sin2** Area is susceptible to sinkhole formation.

Slope instability (Slo) — *High to moderate cost factor* — *Severity: Slo2*

Explanation - 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.

Implications for development - Can be a significant cost factor for certain types of development. Detailed slope-stability analysis may be required.

Severity class - **Slo2** Unstable slope.

Subsidence (Sub) — *High cost factor* — *Severity: Sub2*

Explanation - Area is likely to or has experienced collapse or subsidence due to either ongoing or abandoned underground mining activities. Where underground mining is deeper than approximately 250 m, induced subsidence at the surface is not considered to be a problem.

Implications for development - A potentially high cost factor in terms of potential loss of life and infrastructural damage. Could be a highly significant or critical consideration for certain types of development.

Severity class - **Sub2** Induced subsidence problems are anticipated.

Table 22: Ranking of geotechnical factors and classification as critical or subcritical factors, in order of decreasing rank (after Zawada, 2000).

Rank	Mapped Geotechnical Factor	Status
1	Inundation (flooding)	Critical factors
2	Sinkhole formation	
3	Slope instability	
4	Active, expansive or swelling soil	
5	Excavatability of ground	
6	Collapsing or settling of soil	
7	Subsidence	
8	Erodible soil	Subcritical factors
9	Dispersive soil	
10	Acidic soil	
11	Poorly consolidated soil	
12	Shallow water table	
13	Permeability of soil	

Environmental implications:

These are geotechnical factors where development may significantly impact on the environment. For example, development in an area with a shallow water table should take place with care to prevent the infiltration of contaminants into the ground water.

Although the cost weightings are qualitative, they give an indication of the cost factor associated with geotechnical properties found in designated areas on the map. Applying the classification given in Table 23 to each geotechnical factor occuring in designated numbered geotechnical areas on the Geotechnical Map and listed in the accompanying Geotechnical Table enables a qualitative assessment of the area into one of 5 financial-environmental categories (Table 24).

The category into which the area has been grouped gives the reader an immediate indication of the financial cost or environmental implications of development in the area (Figure 9, Table of geotechnical factors and cost and environmental category for each geotechnical area on the map). Although the distinction between the financial and environmental implications of a particular geotechnical factor is partially subjective, it gives planners a broad indication of the cost and/or environmental factors affecting future development in these areas.

Table 23: Classification of geotechnical factors into cost and environmental categories (after Zawada, 2000).

Geotechnical Factor	Financial Cost	Environmental implication
Inundation (flooding)	-	High
Sinkhole formation	High	-
Slope instability	Moderate-high	-
Active, expansive or swelling soil	High	-
Excavatability of ground	High	-
Collapsing or settling of soil	Moderate	-
Subsidence	High	-
Erodible soil	Low	High
Dispersive soil	Low	Low
Acidic soil	Low	High
Poorly consolidated soil	Moderate-high	-
Shallow water table	-	High
Permeability of soil	-	High

Table 24: Financial cost and environmental categories ordered in increasing influence of environmental implications (after Zawada, 2000).

Financial - Environmental category	
1	Financially related geotechnical factors.
2	Mainly financially related geotechnical factors with some environmental factors.
3	Combination of financial and environmental - related geotechnical factors.
4	Mainly environmentally-related geotechnical factors and a small number of factors with a low financial cost.
5	Predominantly environmentally related geotechnical factors.

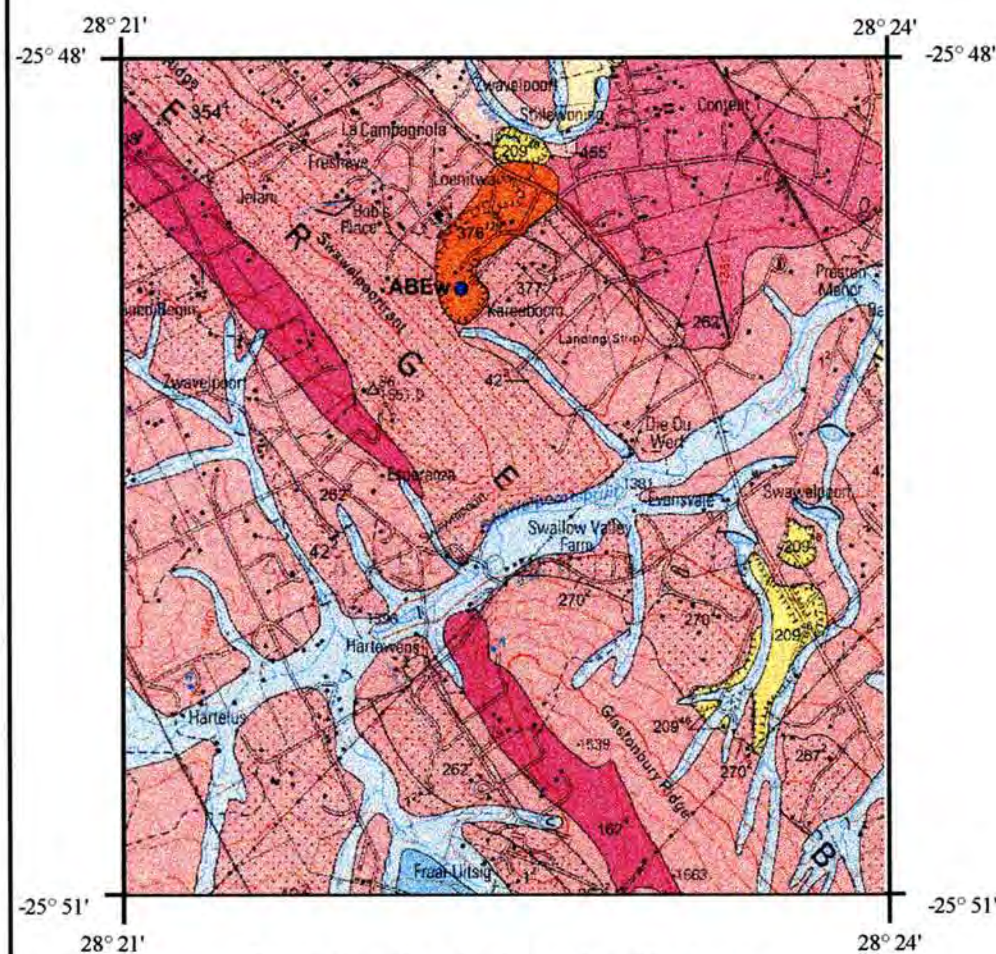
5.2.3 Presentation

This chapter outlines the findings of an assessment of the geotechnical aspects of an 1:50 000-scale map area south-east of Pretoria, based on the classification system proposed by Zawada (2000), with the 1:50 000-scale geotechnical map presented in Appendix 2. It was decided to use the 2528CD08 1:10 000-scale orthophoto map area once again as a basis to represent this system in order to compare this system with the other engineering geological classification systems previously and currently used in South Africa and which are all presented on the orthophotograph 2528CD08 in Chapter 3.

Each geotechnical unit or area was given an unique geotechnical mapping number that represents a sequence of geotechnical factors and the severity thereof for that specific geotechnical area. The different geotechnical properties and their severity classes are presented in Table 21. Any unique combination of geotechnical factors as given an unique number to be used on all subsequent and adjoining maps.

Each geotechnically distinct area was numbered on the 1:50 000-scale map and listed in the accompanying table, the "Table of geotechnical factors and cost and environmental category for each area on the geotechnical map", from which the reader can identify all the critical and subcritical geotechnical factors identified and mapped in the area, with its financial and/or environmental category (Figure 9).

Realising that an area can exhibit several geotechnical properties, a legend (Figure 9, Table named "Geotechnical Legend") was developed by Zawada (2000) to inform the reader of the dominant geotechnical factors (indicated by a colour type corresponding to the geotechnical factor) and the presence of one or more additional geotechnical factors (denoted by shade of colour corresponding to dominant geotechnical colour) present in any particular area of the map sheet applied. Hatching was used to distinguish between an area with minor differences in geotechnical factors compared to an adjacent area of the same colour (Figure 9, Table of geotechnical factors and cost and environmental category for each numbered area on the geotechnical map).



Superscript number refers to the colour of the dominant geotechnical factor shown in the **Geotechnical Legend**

Number of area is used to identify the geotechnical area in the **Table of Geotechnical Factors** from which a listing of the geotechnical factors present in the area can be read.

OPERATIONAL QUARRIES

AGGREGATE QUARRIES		
QUARRY CODE	QUARRY NAME	COMMODITIES
ABEw	Willow Quarries	Aggregate, building sand, river sand and plaster sand

Reference :

- Road
- Track & Hiking Trail
- Power Line
- Buildings
- Excavation
- Original Farms
- Perennial River
- Perennial Water
- Non-perennial River
- Non-perennial Water

Table of geotechnical factors and cost and environmental category for each numbered area on the geotechnical map

Number of geotechnical area	GEOTECHNICAL FACTORS (see 'Geotechnical Factors : Definition, Implications and Severity' for an explanation of abbreviations)						Cost and environmental category				
							1	2	3	4	5
1	Act4	Exc4			Per2		■				
42	Act4	Exc3			Per2		■				
81	Act4	Exc4					■				
155	Act3	Exc3	Col2		Per2		■				
157	Act3	Exc3			Per2		■				
162	Act5				Per3		■				
209	Slo2	Exc2			Sha2				■		
233	Inu2	Act4			Per2				■		
262	Act3	Exc5			Per2		■				
267	Act4	Exc5			Per2		■				
270	Act3	Exc4			Per2		■				
290	Slo2	Act3	Exc4		Per2		■				
302	Act3	Exc3			Per3				■		
308	Act3				Per2		■				
354	Act3	Exc5			Per3				■		
361	Slo2	Act4	Exc3		Per2		■				
365	Act4	Exc3			Per3			■			
376	Col4				Per4				■		
377	Act3	Col4			Per2		■				
392	Inu2	Act4	Exc3		Per2				■		

GEOTECHNICAL LEGEND

Additional Geotechnical Factors				Dominant Geotechnical Factor	
Dominant geotechnical factor plus either no additional factors or one or more subcritical factors	Dominant geotechnical factor plus one critical factor	Dominant geotechnical factor plus one critical and one or more sub-critical factors	Dominant geotechnical factor plus more than one critical factor	Abbreviation	Factor
4	3	2	1	Act	Active, expansive or swelling soil
8	7*	6*	5*	Aci	Acidic soil
12	11*	10*	9*	Col	Collapsing or settling of soil
16	15*	14*	13*	Con	Poorly consolidated soil
20	19*	18*	17*	Dis	Dispersive soil
24	23*	22*	21*	Ero	Erodible soil
28	27	26	25*	Exc	Excavatibility of ground
32	31	30	29	Inu	Inundation (flooding)
36*	35*	34*	33*	Per	Permeability of soil
40	39*	38*	37*	Sha	Shallow water table
44	43	42	41	Sin	Sinkhole formation
48	47	46*	45	Slo	Slope instability
52	51*	50*	49*	Sub	Subsidence

Area shows minor differences in geotechnical factors compared to adjacent area of the same colour (see Table of Geotechnical Factors)

5* Combination of dominant geotechnical factor with additional factor(s) is not present in map area

Figure 9 : Geotechnical classification system developed by Zawada (2000) for the Council of Geoscience

Scale : 1 : 50 000

Council for Geoscience

Compiled by : I.Kleinhans
Drawn by : W.L.Buitendag
Date : November 2001

Other information represented on the geotechnical map and the accompanied explanation include the following:

- All operating clay and aggregate quarries were indicated on the map, with information regarding the name and commodities exploited for each quarry. Areas containing potential reserves of construction materials such as brick making clay, building sand and aggregate are identified and discussed in the explanation to ensure that these resources are not sterilized by unplanned development.
- A 1:100 000-scale map of available test-pit and borehole positions to give the user an indication of the information available in the CGS GEODE database.
- The presentation of each geotechnical factor on an A4 size map in the accompanied explanation, depicting the different severity classes for that specific geotechnical factor and the distribution of the severity classes.

5.3 GEOTECHNICAL EXPLANATION OF THE RIETVLEI DAM 2528CD MAP SHEET

5.3.1 Locality

The Rietvlei Dam 2528CD 1:50 000-scale map sheet covers approximately 625 km^2 and is situated south-east of Pretoria, between latitudes 25°45'S and 26°00'S and longitudes 28°15'E and 28°30'E (Fig. 10).

5.3.2 Previous investigations

Apart from site specific geotechnical investigations, two regional geotechnical investigations were conducted within the map sheet area. The first was done by Bester (1981) covering orthophotographs: 2528CD 1 - 10 and the second by Carr (1995) covering orthophotographs: 2528CD 11 - 13, 16 - 18 and 21 - 23. This information was reviewed and incorporated in the compilation of the Rietvlei Dam geotechnical map with explanation booklet.

Existing borehole and test-pit information from several databases of the Council for Geoscience's (CGS) GEODE was consulted and incorporated during the geotechnical mapping process. Information from 1253 test pits and boreholes for the Rietvlei Dam map sheet have been plotted on a 1:100 000-scale base map with the 1:10 000-scale orthophotograph grid (Fig. 11). A summary of the data type, amount and source of information is presented in Table 25.

Table 25: Summary of data in the CGS database (GEODE) for 1253 borehole and test pit positions occurring on the Rietvlei Dam map sheet.

Data type *(DATABASE)*	Number of data points	Data captured
Boreholes:		
Gold exploration *(COREDATA)*	4	Header (longitude, latitude, depth etc), lithologies
Dolomite related *(ENGEODE)*	27	Header, lithologies
Test Pits/Auger/Percussion Data:		
Sampled and tested *(ENGEODE)*	492	Header, moisture, colour, soil type, texture, lithology, origin, water table depth, grading analysis, liquid limit, plasticity index(s) linear shrinkage, total clay, grading modulus, permeability.
Unsampled *(ENGEODE)*	730	Header, moisture, colour, soil type, texture, lithology, origin, water table depth.

5.3.3 Geotechnical method of investigation

The investigation involved a desk study, field work and the compilation of the geotechnical map based on the land facet approach. An integral part of the mapping process was therefore to obtain representative samples on any given geological and landform type. The geotechnical properties were then extrapolated to other areas exhibiting similar geology and land form. A total of 13 geotechnical factors were evaluated in terms of their severity (Table 21).

The first stage of the investigation involved aerial photograph interpretation, using 1:10

000-scale orthophotographs and 1:50 000-scale aerial photographs from which the landforms were identified and compiled on a 1:50 000 scale. A literature study to obtain previously collected geotechnical information from the engineering geological database (ENGEODE) of the Council for Geoscience was done to assess the potential geotechnical problems that occur in the map sheet area and to assist with the siting of trial pits.

The density of test pits during the fieldwork stage depended on the number of land form types, geological variation, access to property and the availability of existing information. An average of eight test pits were excavated for every 1:10 000-scale orthophotograph sheet (approximately 1 test pit per 3 km^2). A total of 103 test pits were excavated using a Case 580K backactor. The soil profiles were described using the MCCSSO (moisture, colour, consistency, structure, soil type and origin) method proposed by Jennings *et al.* (1973). Seventy-five disturbed and three undisturbed soil samples were submitted for geotechnical laboratory testing. Particle size distribution was obtained by sieve analysis and hydrometer tests and the soils were classified according to the Unified Soil Classification system (Howard, 1984). Atterberg limits were determined along with the expected maximum probable heave and expansiveness according to the method of Van der Merwe (1964). Hazen's formula was used to determinate the soil's permeability. Emerson Crumb tests were performed on fifty disturbed samples. This test gives a good indication of the potential erodibility of soils.

The soil profiles, laboratory results, land form analysis and geology were integrated, from which the 1:50 000-scale geotechnical map, covering the Rietvlei Dam map sheet was compiled.

A qualitative assessment has been made of each numbered area on the 1:50 000-scale geotechnical map of the Rietvlei Dam area to classify each area into one of the 5 financial-environmental categories. The category into which the area has been grouped gives the user an immediate indication of the financial cost or environmental implications of development for each particular area (Table 26).

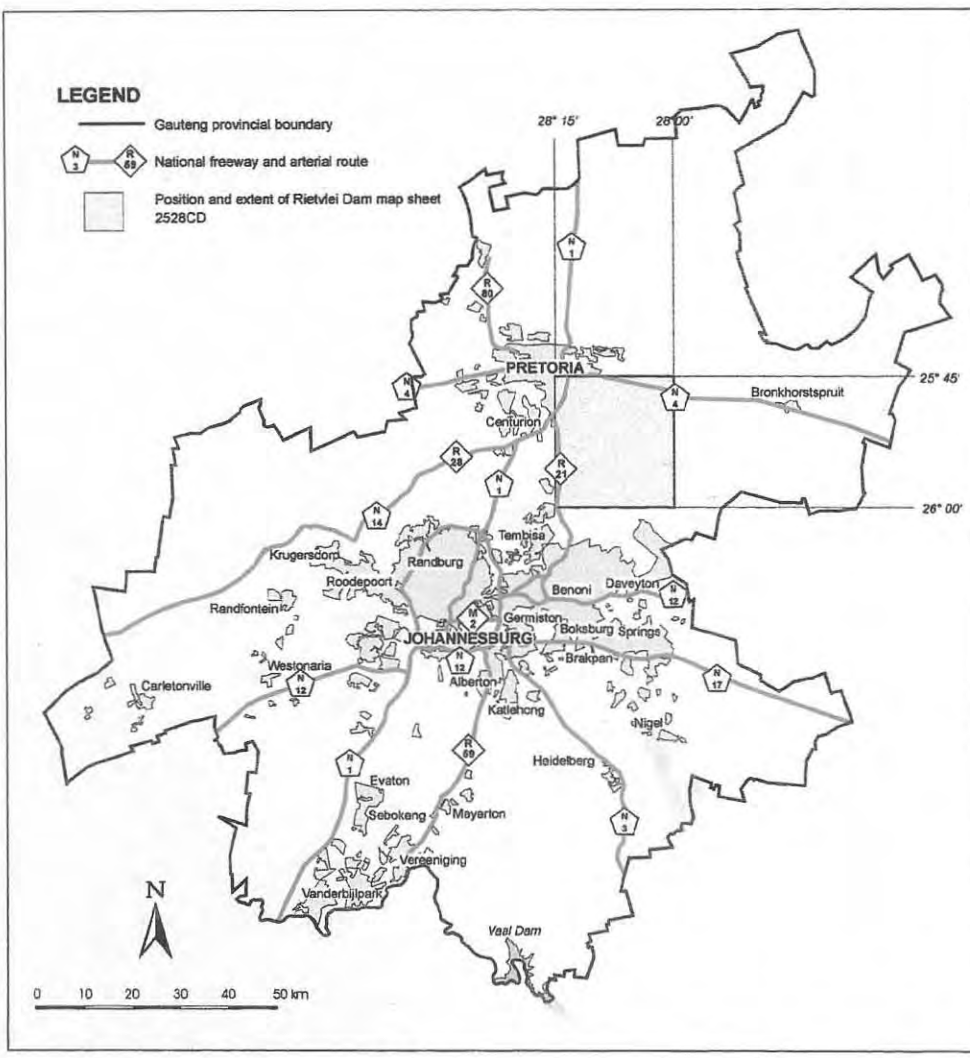


Figure 10: Position and extent of the 1:50 000 scale Rietvlei Dam map sheet 2528 CC.

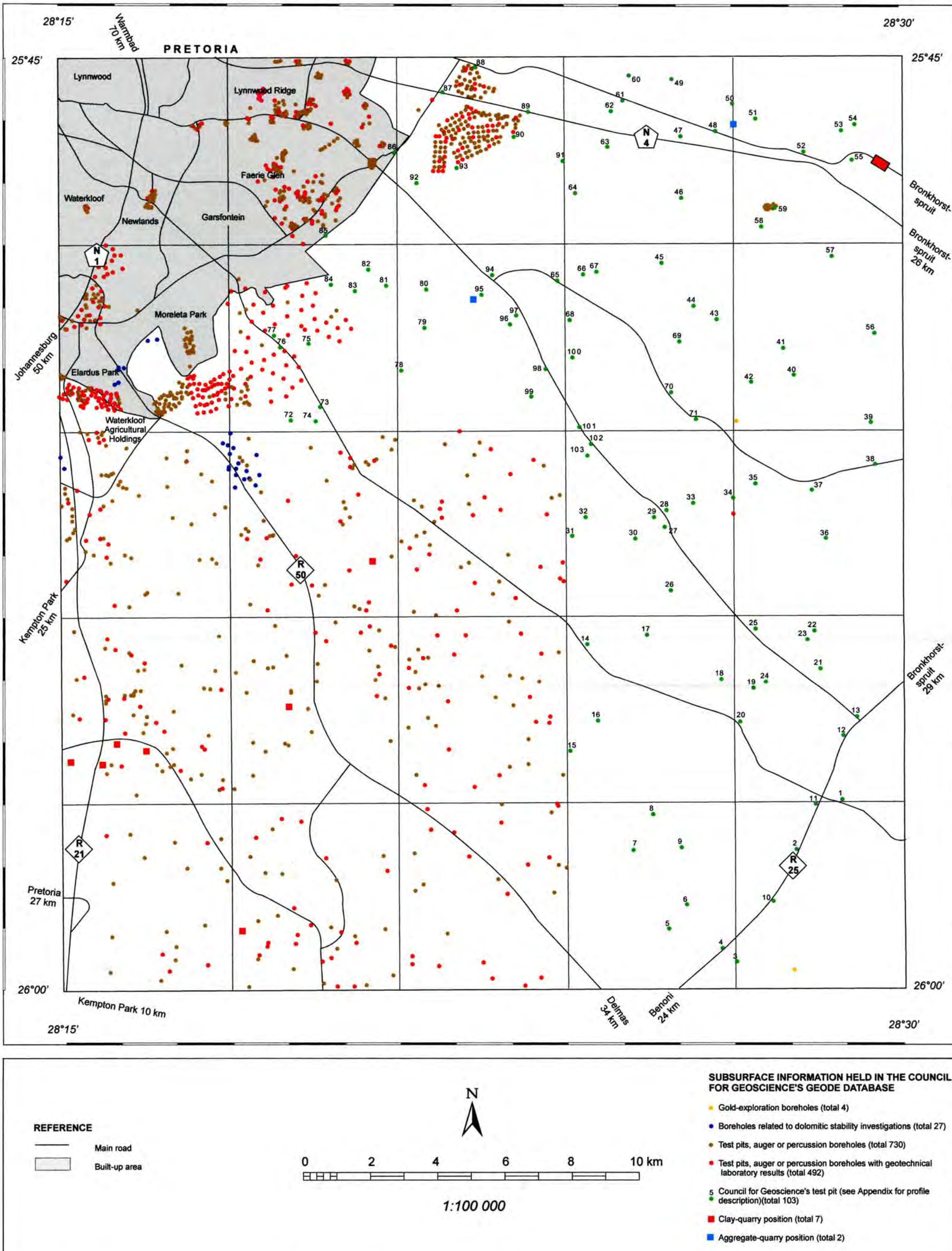


Figure 11: Physoigraphy of the Rietvlei Dam map sheet with an orthophotograph grid showing the positions of boreholes and test pits for wich information is held (Table 25) in the Council for Geoscience's database (GEODE)

Table 26: Listing of geotechnical factors and cost and environmental category for each area numbered shown on the 1:50 000-scale geotechnical map

Number of geotechnical area	GEOTECHNICAL FACTORS (see 'Geotechnical Factors: Definition, Implications and Severity' for an explanation of abbreviations)						Cost and environmental category				
	Critical factors				Subcritical factors		1	2	3	4	5
1	Act4	Exc4			Per2		■				
3	Exc5						■				
8	Col2						■				
9	Exc3	Col2			Per3			■			
17	Act3	Col2			Per2		■				
24	Inu2										■
30	Exc4	Col2			Per3			■			
34	Sin2	Col4			Per3			■			
42	Act4	Exc3			Per2		■				
44	Act4	Exc3					■				
73	Act3	Exc3					■				
74	Sin2	Exc3					■				
76	Sin2	Exc5					■				
81	Act4	Exc4					■				
82	Sin2	Exc4					■				
141	Exc3	Col2			Sha2					■	
146	Sin2	Act4			Con2	Sha2			■		
147	Inu2	Sin2	Act4		Sha2	Per2				■	
148	Sin2	Act3			Per3				■		
149	Inu2	Sin2	Act4		Sha2					■	
153	Sin2	Act2	Exc3				■				
155	Act3	Exc3	Col2		Per2		■				
156	Act5	Col2			Per3			■			
157	Act3	Exc3			Per2		■				
162	Act5				Per3		■				
163	Inu2	Sin2	Act3		Sha2				■		
164	Act2	Exc4	Col2				■				
165	Inu2	Act2			Sha2	Per2					■
167	Slo2	Act2	Exc2	Col2			■				
168	Act2	Exc2	Col2				■				
169	Act2	Col2			Sha2				■		
171	Inu2	Sin2	Act2						■		
180	Act2	Col2			Per2		■				
209	Slo2	Exc2			Sha2				■		
227	Inu2	Sin2	Act5		Per2				■		
233	Inu2	Act4			Per2				■		
241	Act3	Exc4	Col2		Per2		■				
262	Act3	Exc5			Per2		■				
267	Act4	Exc5			Per2		■				
268	Sin2	Act3	Exc4		Per3			■			
270	Act3	Exc4			Per2		■				
271	Act3	Exc5	Col2		Per2		■				
273	Inu2	Act5			Per2					■	
276	Sin2	Act3	Exc4		Per2			■			
278	Slo2	Act3	Exc3		Per2		■				
289	Act3	Exc3			Per4				■		
290	Slo2	Act3	Exc4		Per2		■				
302	Act3	Exc3			Per3				■		
306	Act4				Per2		■				
307	Act3	Exc5			Per4				■		
308	Act3				Per2		■				
321	Act3	Exc5					■				
331	Slo2	Act3	Exc5		Per2		■				
339	Sin2	Act3	Exc5		Per3			■			
340	Sin2	Act3	Exc3		Per3			■			
341	Slo2	Act4	Exc4		Per2		■				
342	Sin2	Act3			Per4				■		
345	Sin2	Act3	Exc3	Col2	Per3			■			
346	Act3	Exc4			Per3			■			
347	Exc5	Col2			Per3			■			
348	Exc5	Col2			Per4			■			
349	Exc4	Col2			Per4			■			
350	Act3	Ero2			Per2			■			
353	Slo2	Act3	Exc3		Per3			■			
354	Act3	Exc5			Per3				■		
356	Act3				Per4				■		
357	Slo2	Act3	Exc5		Per3				■		
358	Act4	Exc4			Per3				■		
359	Act4	Exc5			Per3			■			
360	Act4				Per3			■			
361	Slo2	Act4	Exc3		Per2		■				
362	Act2	Exc4			Per3			■			
363	Slo2	Act4			Per2		■				
364	Act5				Per2		■				
365	Act4	Exc3			Per3			■			
367	Col4				Per2		■				
368	Inu2	Sin2	Act4		Per4				■		
369	Act3	Col4			Per3			■			
370	Act3	Col5					■				
371	Act3	Col2			Per4				■		
372	Act3	Col2	Ero2		Per2				■		
373	Inu2	Sin2	Act4		Per2				■		
374	Inu2	Act3	Exc3		Per2					■	
375	Act3	Col3			Per3				■		
376	Col4				Per4				■		
377	Act3	Col4			Per2		■				
378	Act3	Exc4			Per4				■		
379	Sin2	Act3	Col3		Per3			■			
380	Sin2	Act3	Exc3		Sha2	Per2			■		
381	Inu2	Act3	Exc3		Per3					■	
382	Inu2	Act3			Per3					■	
383	Sin2	Act3	Col4		Per3				■		
384	Inu2	Act3	Exc4		Per3				■		
385	Inu2	Act4	Exc3		Sha2	Per2			■		
386	Inu2	Act3	Exc4		Per2				■		
387	Inu2	Sin2	Act3	Exc3	Per2				■		
388	Inu2	Sin2	Act3		Per4				■		
389	Inu2	Sin2	Act3	Exc4	Sha2	Per2			■		
390	Inu2	Act5	Exc3		Per2						■
391	Inu2	Act2			Per2						■
392	Inu2	Act4	Exc3		Per2				■		
393	Sin2	Act3	Exc5		Per2		■				
394	Sin2	Act3	Sub2		Per3			■			
395	Act4	Exc4	Ero2		Per2			■			
397	Slo2	Act3			Per2		■				
398	Act3	Col2			Per3			■			

Financial-Environmental category

1	Financially related geotechnical factors
2	Mainly financially related geotechnical factors with some environmental factors
3	Combination of financial and environmentally related geotechnical factors
4	Mainly environmentally related geotechnical factors and a small number of factors with a low financial cost
5	Predominantly environmentally related geotechnical factors

5.3.4 Terrain description

5.3.4.1 Physiography

The area covered by the Rietvlei Dam map sheet is relatively flat to gently undulating, with three prominent quartzite and chert ridges striking north-west to south-east across the map area. The first ridge is situated north of the N4 (Magaliesberg), the second (Bronberg Ridge) is situated between the N4 and the R50, with the third situated south of the R50. Slope profiles vary from concave or convex to straight slopes. The majority of slopes exhibit a 1° - 6° gradient, with slope angles greater than 12° in the vicinity of the ridges and some of the hill crests. The highest point in the map sheet area, is situated south of the R25 road at 1668,6 metres above mean sea level (m.a.m.s.l.). The lowest point is situated in the flood plain of the Pienaars River, situated north of the 104 road at 1298 m.a.m.s.l.. Other landforms present in the map sheet area, are plains, drainage channels, river channels, dams, excavations, and marshy areas.

5.3.4.2 Climate

Climatic data was obtained from the Johannesburg International Airport weather station, which is situated approximately 20 km south of the map sheet. The climate of the area is sub-humid, with an average annual rainfall of 760 mm falling predominantly between September and March. Annual temperatures vary from an average summer maximum of 25,8°C to an average winter minimum of 3°C. The prevailing wind direction is north-east and averages 6,5 knots (personal comment Weather Bureau, 1999). Weinert's climatic N-value for this area is N=2.4, which indicates that decomposition is the dominant form of weathering resulting in the formation of thick soils (Weinert, 1980).

5.3.4.3 Drainage

A few perennial rivers (Rietvlei and Pienaars), streams (Sesmylspruit, Moreletaspruit) and several non-perennial streams drain the map area, in a northly direction. Numerous perennial (Rietvlei Dam, Groot Dam, Witfontein Dam, Pan Dam) and non-perennial dams and pans, are scattered throughout the area.

5.3.4.4 Vegetation

Much of the area is occupied by farms and agricultural holdings, with grazing and maize as the predominant crop. Uncultivated areas are described as Moist Cool Highveld Grassland and Rocky Highveld Grassland (Bredenkamp and van Rooyen, 1998). The Moist Cool Highveld Grassland comprises *Cymbopogon-Themeda* Veld (sparse, tufted veld) and *Themeda triandra-Eragrostis curvula* Grassland. The area covered by Rocky Highveld Grassland comprises Giant Speargrass (*Trachypogon spicatus*), Broadleaf Bluestem (*Diheteropogon amplectens*), Red Autumngrass (*Schizachyrium sanguineum*), *Andropogon schirensis*, Loudetia simplex (*Tristachya leucothrix*), *Panicum natalense*, *Bewsia biflora*, *Digitaria tricholaenoides*, *Digitaria monodactyla* and *Sporobolus pectinatus* grassveld types.

5.3.4.5 Geology

The following is an overview of the major rock types that occur in the Rietvlei Dam map area as described by Minnaar and Britz (1997) that accompanies the 1:50 000-scale geological map of the Rietvlei Dam 2528CD map sheet (Council for Geoscience, in prep.) and the geological explanation by Visser *et al.* (1984) for the 1:1 000 000-scale geological map (Table 27).

The map sheet is underlain by three major sequences, namely the Transvaal Supergroup, followed by the Karoo Supergroup, with the youngest geological deposits represented by unconsolidated alluvium and colluvium of Quaternary age. A large number of faults intersects the Pretoria Group rocks, across the map sheet in a general north-east to south-west direction (strike).

Table 27: Summary of the geological units present on the Rietvlei Dam 1: 50 000 map sheet (after Minnaar and Britz, 1997).

GEOLOGICAL ERA	AGE (Ma)		GROUP	SUBGROUP	FORMATION	LITHOLOGY	INTRUSIVE ROCS
Quaternary	0 - 1,6	Surficial Deposit				Alluvium (clays, silts, gravels and conglomerate); colluvium (sands, silts, clays and gravels)	
Permian	250 - 355	Karoo Supergroup	Ecca Group		Vryheid	Sandstone, grit, conglomerate, shale, clay and subordinate coal beds	
Carboniferous			Dwyka Group			Tillite, sandstone and grit	
Mokolian	900 - 2050						Syenite
Vaalian	2050 - 2650	Transvaal Supergroup	Pretoria Group		Rayton	Quartzite	Diabase
					Magaliesberg	Quartzite	
					Silverton	Shale and chert	
					Daspoort	Quartzite	
					Strubenkop	Shale and quartzite	
					Dwaalheuwel	Quartzite and shale	
					Hekpoort	Andesite	
					Boshoek	Quartzite	
					Timeball Hill	Shale and diamictite	
					Klapperkop Member	Quartzite	
					Timeball Hill	Shale and diamictite	
					Rooihoogte	Conglomerate	
			Chuniespoort Group	Malmani Subgroup	Eccles	Chert-rich dolomite and chert breccia	
					Lyttleton	Dark, chert-free dolomite with large, elongated stromatolitic mounds	

Outcrop is good with the resistant lithologies such as quartzite and chert forming hill crests and ridge crests. Alluvium is present in drainage channels, marshy areas and in flood plains, across the map sheet. Much of the area is covered with colluvium, except in areas where alluvium or outcrop occur. Intrusive dykes and sills of diabase (Transvaal related) and syenite (Mokolian age) occur across the map sheet, striking north-west to south-east.

The Transvaal Supergroup consists of clastic and chemical sediments and volcanic rocks, of the Chuniespoort Group and Pretoria Group. The Malmani Subgroup (Chuniespoort Group) comprises alternating bands of chert-bearing and chert-free dolomite, with local occurences of carbonaceous shale and quartz. The Malmani subgroup is subdivided into five formations, of which only the Lyttleton and Eccles Formations occur on the map sheet. The Lyttleton Formation is situated west of the R21 road (on orthophotograph 16) and east of the R50 road (on orthophotograph 17) and the overlying Eccles Formation occurs in the vicinity of the R21 and R50 roads (on orthophotographs 11, 12, 16 - 18 and 21 - 24). The overlying Pretoria Group covers more then 95% of the map sheet area and comprises mainly clastic rocks of quartzite, shale and a prominent volcanic unit with locally occurring carbonates. The Pretoria Group is subdivided into the Rooihoogte, Timeball Hill, Boshoek, Hekpoort, Dwaalheuwel, Strubenkop, Daspoort, Silverton, Magaliesberg and Rayton Formations.

The overlying Karoo Supergroup occurs in the southern portion of the map sheet (on orthophotograph 16 - 18 and 22 - 25) and is subdivided into the Dwyka and Ecca Groups. Remnants of Karoo Supergroup occur as pockets or outliers in dolomite of the Chuniespoort Group. The Dwyka Group is composed mainly of diamictite with subordinate shale and mudstone, containing pebbles, gravel and conglomerate. The overlying Ecca Group is represented by the Vryheid Formation, which comprises sandstone, alternating with beds of soft sandy shale and some coal seams.

5.3.4.6 Hydrogeology

Most of the information in this section was obtained from research done by Kuhn (1989), based on the hydrogeology of the Midrand - Kempton Park dolomite area.

The hydrogeological properties of the dolomite in the Rietvlei Dam map sheet area are controlled by structure, stratigraphy and geomorphology. Water bearing properties of the dolomite stem from preferential development of carbonate dissolution along fault and fracture zones, joints and bedding planes. Chert-rich dolomite formations constitute better aquifers, since the chert layering supports the strata and keeps the leached void system open. The dolomite is traversed by low permeable or impermeable dykes that act as hydrogeological barriers (Kuhn, 1989). The overlying Pretoria Group exhibits very low primary permeabilities and weakly developed secondary permeabilities along faults and fractures (Kuhn, 1989).

Outflow of groundwater from dolomite compartments occurs as discharge into surface drainage systems, underground flow through weathered and fractured dykes or as leakage over impermeable dykes to adjacent compartments. Perched water levels are usually associated with Karoo outliers (Kuhn, 1989).

The positions of Figure 13, 14 and 15 are indicated on Figure 12.

5.3.4.6.1 Water levels

Piezometric water levels in metres above mean sea level (m.a.m.s.l), depth to water level from surface and groundwater contours are shown in Figure 13. The contour map revealed low groundwater gradients (less than 0,006 or 6 m/km) along strike and moderate gradients (up to 0,012 or 12 m/km) normal to strike (Kuhn, 1989). Water levels in the Pretoria Group follow the general topography (Kuhn, 1989).

5.3.4.6.2 Groundwater flow

Groundwater flow in the dolomite rocks occurring in the study area occurs generally from south to north in the highly transmissive Eccles Formation parallel to geological strike, with the Pretoria Group in the east supplying groundwater to the dolomite (Kuhn, 1989).

Piezometric levels in the Sterkfontein compartment (Fig. 14), reveals that the direction of groundwater flow in this compartment is from south-southeast to north-northwest (Fig. 13). Piezometric levels in the Rietvlei compartment (Fig. 14), revealed that the direction of groundwater flow in this compartment is in a south-western direction, whilst the groundwater flow direction in the Witkoppies compartment (Fig. 14) is also from south to north (Fig. 13).

5.3.4.6.3 Hydrogeological Compartments

Dykes can act as linear groundwater barriers, depending on their depth of weathering/fracturing and on the water levels in the adjacent compartments. Dykes which initially do not act as barriers may form groundwater barriers once large scale abstraction results in excessive lowering of watertables. On the other hand, leakage occurring through dykes which form barriers in the present state, might increase due to the increased hydraulic pressure differences caused by abstraction on one side of the dyke (Kuhn, 1989). Figure 12, delineate the different dolomite compartments, created by dykes and other geohydrological barriers, for the south-western portion of the map.

Rietvlei Compartment

This compartment is confined by the Pretoria Group in the north, south and west and the Sterkfontein dyke in the south. Numerous dolerite and syenite intrusions that occur in this area subdivided this compartment into subcompartments (Fig. 15). Dyke A, represents the Sterkfontein dyke that forms the southern boundary of the Rietvlei compartment, with dykes B and C subdividing the compartment into three

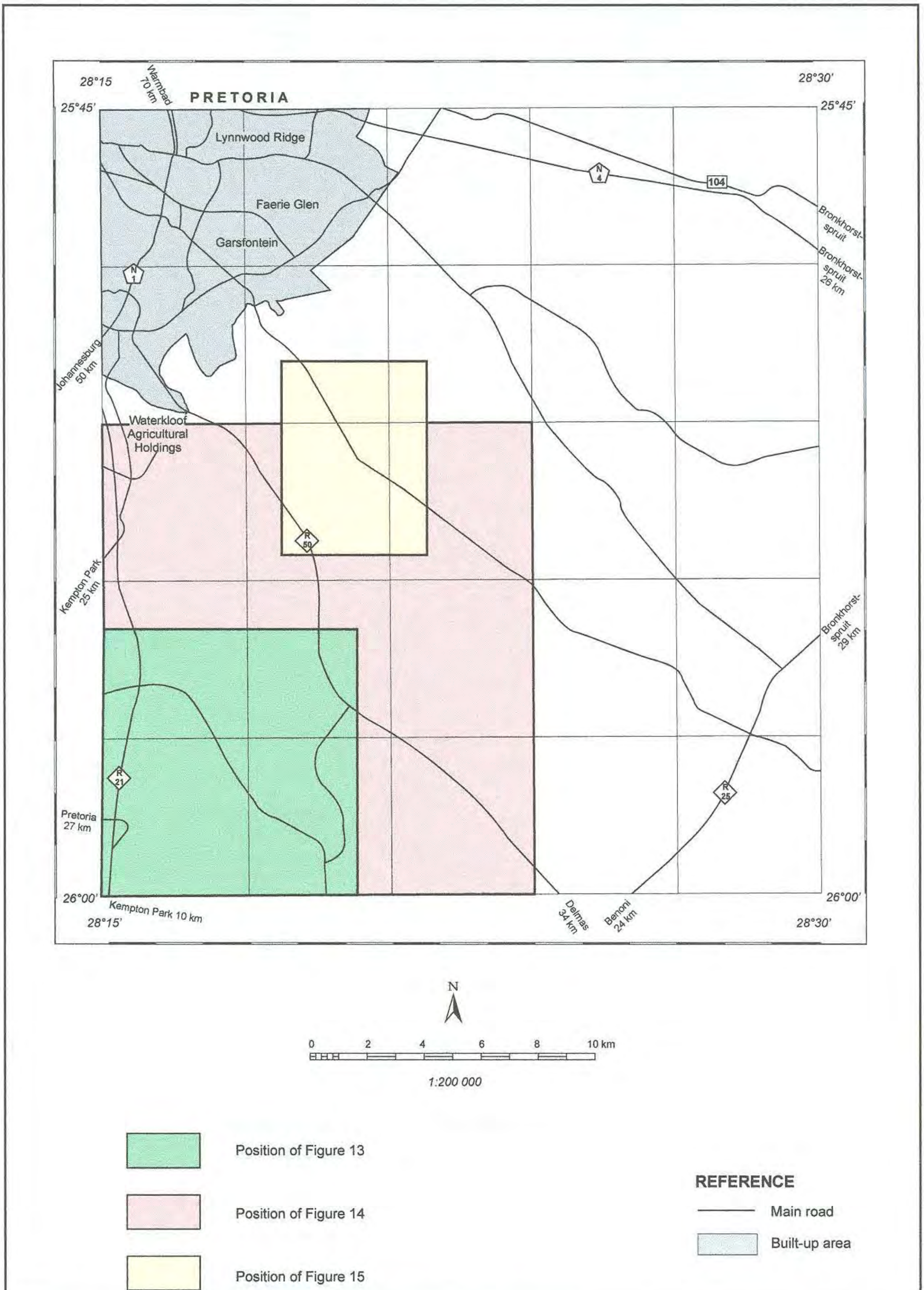


Figure 12: Position of Figures 13, 14 and 15 for the 1:50 000-scale Rietvlei Dam map sheet (after Carr,1995).

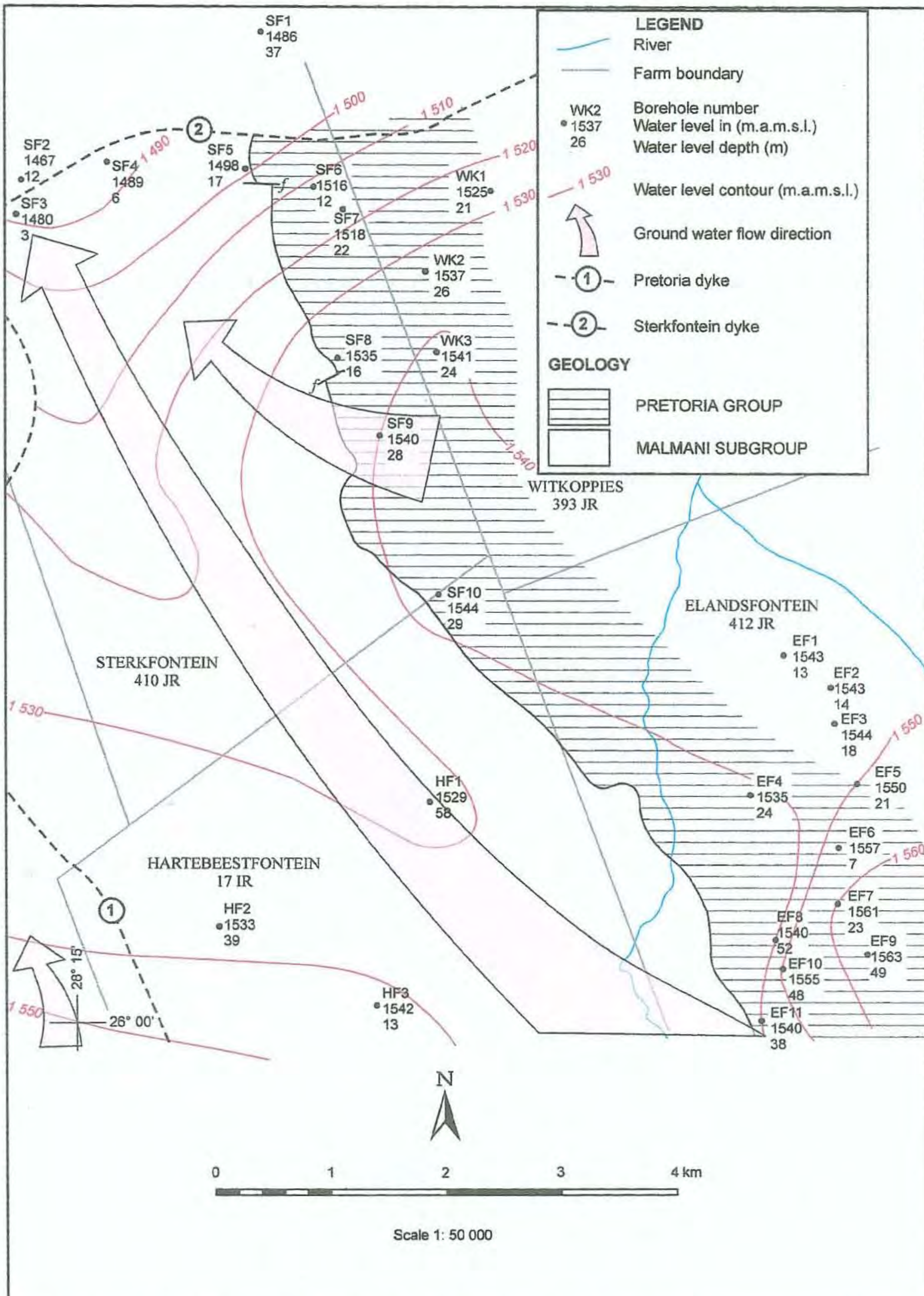


Figure 13: Movements and levels of ground water in the dolomite compartments for the southwestern portion of the Rietvlei Dam map sheet (after Kuhn, 1989).

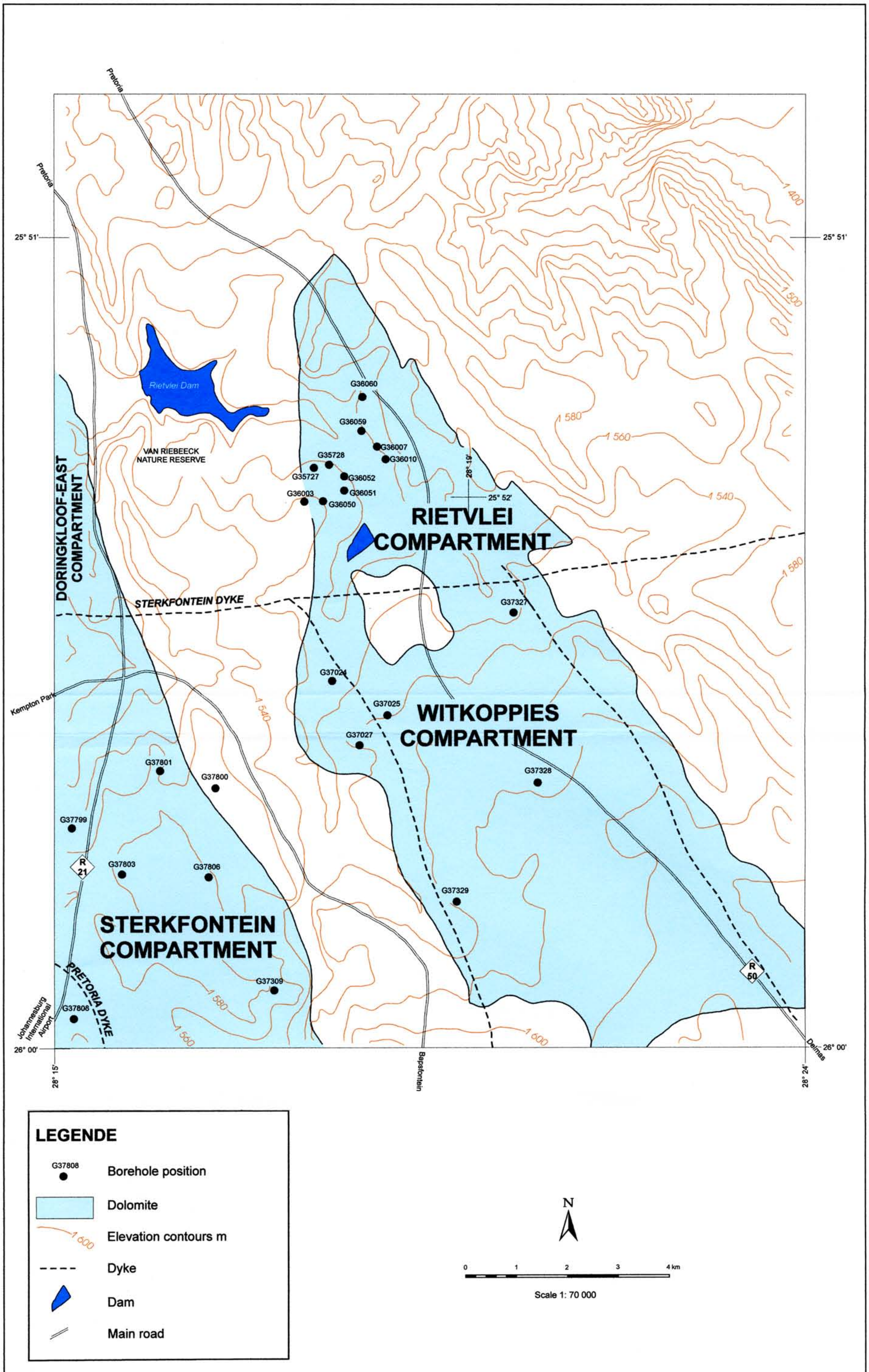


Figure 14 Dolomite compartments and Department of Water Affairs and Forestry (DWAF) boreholes for the Rietvlei Dam map sheet (after Kuhn, 1989)

subcompartments, X, Y and Z (Kuhn,1989). Loss of groundwater occurs through the discharge of springs and is recharged by rainfall. Compartment X is also recharged by surface inflow from a nearby stream. A purification plant situated at the Rietvlei Dam, purifies effluent discharged from the Kempton Park sewage works that flow into the drainage system of the Rietvlei compartment. Large-scale pumping of groundwater from the compartment has resulted in the lowering of the groundwater table and consequently drying-up of springs. This practice could lead to the formation of sinkholes and dolines in the area (Kuhn, 1989).

Witkoppies Compartment

This compartment is confined by the Pretoria Group in the east and west, the Sterkfontein dyke in the north and the Tweefontein dyke (outside map sheet area) in the south (Fig. 14). An average groundwater depth could not be estimated, due to fluctuating groundwater levels (Kuhn, 1989).

Sterkfontein Compartment

The Sterkfontein compartment is confined by rocks of the Pretoria Group in the east, the Sterkfontein dyke in the north, the Tweefontein dyke (outside map sheet area) in the south and the Pretoria dyke (outside map sheet area) in the west (Fig. 14). The groundwater level for this compartment is less variable than those in the Rietvlei and Witkoppies compartments (Kuhn, 1989). Groundwater is discharged from this compartment mainly for agricultural purposes and municipal water supply (Kuhn, 1989).

Doornkloof-east Compartment

This compartment covers a small area of the map sheet being confined by the Irene dyke (outside map sheet area) in the north, Pretoria Group in the east, Sterkfontein dyke in the south and Pretoria dyke (outside map sheet area) in the west (Fig. 14). No groundwater levels or borehole information is available for this compartment (Kuhn, 1989).

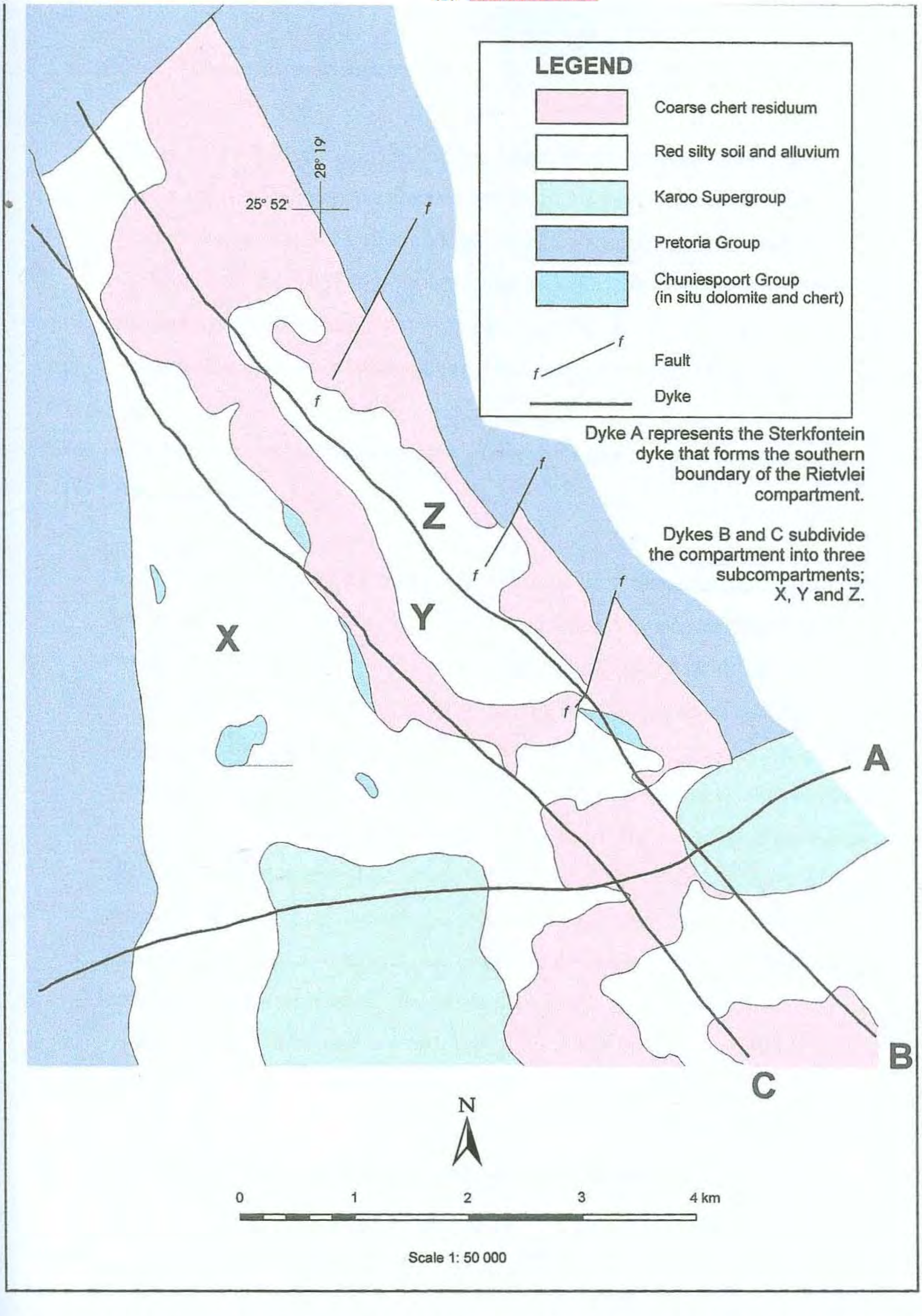


Figure15: Rietvlei dolomite compartment and subcompartments for the Rietvlei Dam map sheet (after Kuhn, 1989).

5.3.4.6.4 Groundwater quality

The groundwater contained within the dolomite and surrounding aquifers is of excellent quality for both human consumption and irrigation purposes, except in the vicinity of the Rietvlei drainage feature, where effluent from the Kempton Park sewage works infiltrates the aquifer (Kuhn, 1989). It was found that groundwater samples obtained from quartzite and shale of the Pretoria Group with pH-values less than 6.5, could be slightly corrosive towards steel structures, although the pH normally changes to 7 on aeration (Kuhn, 1989).

5.3.5 Engineering geological properties of residual and transported soils in the Rietvlei Dam map sheet area

Soil is formed when the parent rock is broken down by chemical and physical weathering processes. Physical weathering (disintegration caused by alternate freezing and thawing) or erosional processes, results in soil particles which retain the same mineralogical composition as that of the parent rock. In contrast, chemical weathering results in changes in the mineral form of the parent rock due to the action of water, oxygen and carbon dioxide and the formation of new minerals (clays and salts). Many of the physical properties of soils are dictated by the size, shape and chemical composition of the individual particles and their origin (parent material). If the products of weathering remain at their original location (in-situ weathering) they constitute a residual soil, but when the products of weathering are transported and deposited in a different location they constitute a transported soil. Below an overview of the general geotechnical properties of soils formed from various rock types that occur on the Rietvlei Dam map sheet is given.

5.3.5.1 Residual soil derived from the Transvaal Supergroup

5.3.5.1.1 Chuniespoort Group (Malmani Subgroup)

The Malmani Subgroup comprises dolomite and chert (Table 27). Ancient carbonate rocks are predominantly composed of the minerals calcite ($CaCO_3$) or dolomite ($CaMg(CO_3)_2$) . If a carbonate rock is dominated by calcite (more than 95%) it is called limestone, when it is dominated by dolomite (the mineral) it is called dolomite (the rock) (Warren, 2000). Dolomite, as a rock contains more than 90% dolomite and less than 10% calcite as well as detrital minerals and secondary silica (chert). Very few, if any sedimentary dolomites are realy stoichiometric (($CaMg(CO_3)_2$) and are better represented as: $Ca_{(1+x)}Mg_{(1-x)}(CO_3)_2$, encompassing the spectrum from calcian to magnesian dolomites (Warren, 2000).

Acidic rainwater and groundwater that percolates through the network of joints, fractures and faults in the vadoze and phreatic zones dissolves the dolomite in the form of bicarbonate and giving rise to karst features such as cave systems and voids (Buttrick, 1992). This karst landscape (irregular bedrock of dolomite pinnacles) is buried beneath younger deposits which may collapse or be transported into the voids and cave systems due to the infiltration of surface water, water level draw-down by the lowering of the water table, or ground vibrations, resulting in catastrophic ground movement at the surface, to form sinkholes or where subsidence is gradual to form dolines (Buttrick, 1992).

The occurrence of dolomite floaters that represents former dolomite pinnacles could cause excavatability problems and/or can lead to a misleading interpretation of the bedrock depth and geotechnical conditions (Brink, 1979). Consolidation problems can also be expected where wad (highly compressible manganiferous earth derived from the weathering of dolomite) is present close to the surface (Brink, 1979).

5.3.5.1.2 Pretoria Group

The Pretoria Group comprises mainly quartzite and shale (Table 27). Brink (1979) reported that collapsible sands can be derived from the weathering of quartzite of the Pretoria Group, especially if it has a high feldspathic content. However, foundation problems at shallow depth are usually not encountered on residual shale or quartzite of the Pretoria Group, due to their high bearing capacities (Brink, 1979). The Silverton and Strubenkop shale Formations exhibit smooth and even bedding planes, which can result in sliding of the rockmass along the direction of dip into excavations (Brink, 1979). Differential settlement can occur at the contact between residual soft shale and hard rock quartzite, due to differential weathering (Brink, 1979). Although residual shale of the Pretoria Group exhibits a generally low potential for expansiveness, portions of the Silverton Formation shale contain a high percentage of montmorillonite to give highly expansive residual soils (Brink, 1979). Similarly, residual soil on andesite of the Hekpoort Formation may also be moderately to highly expansive (Brink, 1979). An important feature of the andesite is the extreme variability in depth of weathering and soil profile thickness within several metres of an outcrop (Brink, 1979). This irregular bedrock profile, gives rise to differential settlement problems requiring shallow footings on outcrop and piling in deep residual soils when placing foundations (Brink, 1979). Attention should be given to the occurrence of andesite core-stones and 'floaters', which can lead to a misleading interpretation of the bedrock depth and geotechnical conditions (Brink, 1979).

5.3.5.2 Residual soil derived from the Karoo Supergroup

Tillite, shale and sandstone of the Dwyka Group weathers to form, brown or red brown, clayey to gravelly residual soils that are potentially collapsible and expansive (Brink, 1983). The Vryheid Formation of the Ecca Group, comprises mainly sandstone, shale and coal seams (Table 27). The sandstone weathers to brown or red, medium to fine-grained sand or silt, which may exhibit a collapsible fabric (Brink, 1983). The shale weathers to grey, yellow or black clays, that contain a high percentage of kaolinite and subordinate illite, which implies a low potential for expansiveness. The depth of weathering of the shale varies from 1 m to more than 2 m. According to Brink (1983), dispersive clays are also associated with soils derived from the Dwyka and Ecca Groups.

5.3.5.3 Pebble Marker

The pebble marker is a band of gravel that demarcates the boundary between transported soils and the underlying residual soils or bedrock (Jennings *et al.*, 1973). The pebble marker is not a regular stratigraphic unit but differs in age and mode of origin from place to place. From an engineering geotechnical perspective the pebble marker represents a stratum of free drainage, which must be sealed for certain constructions such as dams. Conversely, where drainage is required it may be retained and be usefully employed to provide free flow of water especially in areas susceptible to inundation (Jennings *et al.*, 1973). The pebble marker may pose excavatability problems where the unit comprise gravel and boulders of fresh quartzite, shale, andesite, chert, dolerite or diabase. Pebble markers were found in more than 40% of the trial pits, at different depths, varying in thickness from 0,1 to 0,4 metres, comprising gravel and boulders of quartzite, chert, shale and andesite, ferricrete concretions and occasionally diabase gravel and boulders.

5.3.5.4 Ferricrete deposits (Pedogenic material)

A colloquial name for ferricrete is 'ouklip'. It forms by the percolation of water through a soil profile in which a fluctuating water table occurs. In areas with a N-value of less than 5, percolating water mobilises soluble, ferrous iron (Fe^{2+}), which is derived predominantly from the partial solution of mafic minerals. This iron is conveyed downward to the base of the perched water table where it is oxidised to less soluble ferric iron (Fe^{3+}) and precipitates to form ferricrete. According to Brink (1985), ferricrete can develop in any soil type where the hydrological conditions are favourable. Geomorphologically, these include gully heads, hillslope-pediment junctions and on pan and vlei side slopes (Partridge, 1975). Ferricrete was encountered in more than 60% of the test pits, at depths of 0,1 to 2,0 metres varying between 0,2 and 1,0 metres thickness. The type of ferricrete varies from concretionary, honeycomb to hardpan ferricrete with the concretionary type being dominant. A ferricrete layer of adequate thickness can also provide stable founding conditions at a shallow depth for structures (Brink, 1985). Severe excavatability problems are also associated with hardpan ferricrete.

5.3.5.5 Colluvium

Colluvium is defined as unconsolidated material on hill or mountain slopes, which has moved downslope principally by the action of gravity and aided by non-channelled running water (Brink, 1985). The engineering characteristics of colluvium are controlled by the nature of the parent rock type and the processes of transportation to which it has been subjected to (Brink, 1985). Colluvial soils vary in exhibiting an intact to open structure with high void ratios and low in-situ densities. The main engineering geological problem associated with these soils is the presence of a collapsible soil fabric. Colluvial material derived from weathered sandstone and quartzite in the map area is potentially collapsible, as was observed in test-pits on Magaliesberg quartzite (on orthophotograph 5). The clays that occur in colluvial soils may also have dispersive properties (Brink, 1985). The good compaction characteristics of these soils render them suitable for use in the lower layers of road pavements.

5.3.5.6 Alluvium

Alluvium includes the most recent deposits and is confined to drainage channels, flood plains and marshy areas. The behaviour of alluvial soils depends largely on the rock type from which it was derived (Haskins, 1994). For example, where quartzite or sandstone is the source, the transported soils will exhibit a collapse potential, whereas transported soils from shale, dolerite or Hekpoort Formation andesite will exhibit a potential for heave (Brink, 1985). The collapsible soils or soft alluvial clays may also exhibit a low shear strength and is therefore highly compressible (Brink, 1985).

5.3.6 Geotechnical laboratory analysis of soils

The 236 disturbed samples obtained during the fieldwork phase and those from an investigation previously conducted by Carr (1995) for the Council for Geoscience, were analysed for key indicator tests and other parameters to determine the geotechnical properties to be expected for unconsolidated materials in the map area.

The following laboratory tests were conducted on disturbed soil samples:

- Particle size distribution
- Atterberg limits
- Emerson crumb test

Particle size distribution was obtained by sieve analysis and hydrometer tests and the soils were classified according to the Unified Soil Classification System (Howard, 1984). Atterberg limits were determined along with the expected maximum probable heave and expansiveness according to the method of Van der Merwe (1964). Hazen's formula was used to determine the soil permeability. Emerson Crumb tests were performed to determine the potential erodibility of the soils.

Nineteen undisturbed samples were submitted for collapse potential tests to determine their potential for collapse and possible problems with settlement.

5.3.7 Geotechnical characteristics of soils in the area and implications for development

A number of geotechnical problems were identified from the fieldwork and laboratory results. An indication of the surface area covered by each of the specific geotechnical entities is given in Table 28. The distribution of severity classes for each geotechnical factor present on the Rietvlei Dam map sheet, are presented in Appendix 1. The more important geotechnical parameters are discussed below.

5.3.7.1 Inundation

Inundation or flooding affects the use of low, flat lying alluvial lands for agricultural, construction and development purposes. Incorrect site development could lead to the loss of life and financial loss through infrastructure damage.

Table 28: Spatial analysis showing the total area (km^2) and severity class (Table 21) for each geotechnical factor identified on the Rietvlei Dam map sheet.

Geotechnical Factor	Total area (km^2) and % of Map sheet	Area (km^2) and % of each Severity Class
Inundation (flooding)	101 (15%)	-
Sinkhole formation	113 (16%)	-
Slope instability	39 (6%)	-
Active, expansive or swelling soil	665 (96%)	Act2: 5 (<1%) Act3: 398 (58%) Act4: 246 (36%) Act5: 16 (2%)
Excavatability of ground	516 (75%)	Exc2: 2 (<1%) Exc3: 324 (47%) Exc4: 123 (18%) Exc5: 67 (10%)
Collapsing or settling of soil	55 (8%)	Col2: 51 (7%) Col3: 0,2 (<1%) Col4: 3 (<1%) Col5: 0,1 (<1%)
Subsidence	0,1 (<1%)	-
Erodible soil	3 (<1%)	-
Poorly consolidated soil	0,2 (<1%)	-
Shallow water table	8 (1%)	-
Permeability of soil	665 (96%)	Per2: 438 (63%) Per3: 215 (31%) Per4: 12 (2%)

Approximately 101 km^2 (15%) of the map sheet is susceptible to inundation (Table 28, Fig. 16). This includes the areas confined to drainage channels and the flood plains of the Rietvlei River situated west of the R50, the Pienaars River situated east of the R50 road, the Sesmyl Spruit and Moreleta Spruit (Fig. 16). Inundation can also occur at Rietvlei Dam (othophoto 11), Groot Dam (orthophoto 18), Witfontein Dam (orthophoto 13) and Pan Dam (orthophoto 18) (Fig. 16).

5.3.7.2 Sinkhole formation and subsidence

All areas underlain by dolomite exhibit a potential for sinkhole or doline formation. Approximately 113 km^2 (16%) of the map sheet is susceptible to sinkhole formation (Table 28, Fig. 17). According to Carr (1995), more than 30 sinkholes exist in the area underlain by dolomite, due to abstraction of groundwater for municipal water supply. The sinkholes occurred mainly in the Rietvlei (orthophotograph 12) and Witkoppies (orthophotographs 17, 18, 22, 23 and 24) hydrogeological compartments (Fig. 17). Preferential groundwater movement along faults in the dolomite increases the risk of sinkhole development along these zones.

The regional nature of the geotechnical mapping did not allow the determination of sinkhole formation severity classes for any particular area. Borehole information reveals that the extent of the area underlain by dolomite is much greater than that indicated on the geology map where large areas are shown to be covered by shale and quartzite of the Pretoria Group. Precautionary measures, site specific investigations and specified founding methods should be employed in areas that are underlain by dolomite. According to Buttrick (1992), these may include:

- No accumulation of surface water to be permitted with the entire development being properly drained.
- Conventional foundations (strip or spot footings) for light structures where the risk of settlement is found to be acceptable.
- Split construction where differential settlement is greater than 5 mm.
- Construction of a mattress of improved material below the foundations.
- Inserting reinforcing strips in the underlying mattress.
- Founding on pinnacles.
- Compaction of material overlying dolomite bedrock.
- Grouting of the soil beneath the foundations.

5.3.7.3 Slope instability

Residential development is favoured on slopes with a gradient of less than 12°. The Rietvlei Dam area is relatively flat to undulating with three prominent ridges that trend north-west to south-east across the map sheet and which are capped with resistant quartzite, chert and shale.

Approximately 39 km^2 (6 %) of the Rietvlei Dam map sheet exhibits potential slope instability problems (Table 28, Fig. 18). Natural slope instability (steep slope gradients and the occurrence of faults) comprises ridges and isolated hills, consisting of quartzite, shale or chert breccia of the Transvaal Supergroup (orthophotographs 1, 2, 6, 7, 18 and 19) (Fig. 18). The Pretoria Group rocks of the Transvaal Supergroup dip in a north-easterly direction. The south-western side of hill slopes and ridges may therefore exhibit slope instability in excavations. This was noted in some test-pit profiles, that showed unstable sidewalls in the north-eastern and south-eastern portion of the map sheet, including the farms Zwartkoppies 364 IR, Zwavelpoort 373 JR, Tiegerpoort 371 JR, Mooiplaats 367 JR, Donkerhoek 365 JR, Kleinfontein 368 JR, Klipkoppie 396 JR and Kameel Zynkraal 547 IR. Induced slope instability into excavations can also occur in shale of the Silverton Formation, due to its smooth and even bedding planes along which the rock mass can slide along the direction of dip (Fig. 18).

Existing quarries were classified as exhibiting potentially unstable slopes and occur north of the N4 (orthophotograph 4 and 5), south of the N4 in the northern to central portion of the map sheet, on Zwartkoppies 364 IR, Tweefontein 372 JR, Mooiplaats 367 JR, Tiegerpoort 371 JR and Zwavelpoort 373 JR (orthophotographs 3, 8, 9, 14) and in the south-eastern portion of the map sheet on the farm Onbekend 398 JR (orthophotographs 12, 13, 16, 17, 21 and 22) (Fig. 18).

5.3.7.4 Active, expansive or swelling soils

The method of Van der Merwe (1964) was used to determine the potential heave of soil samples. Although this method is widely used in South Africa, it may under estimate the potential expansiveness. This is ascribed to it's reliance on the plasticity index and clay percentage (fraction of soil passing the 2 micron sieve) of the soil, where the clay fraction could also contain a significant amount of non-swelling minerals such as quartz and calcite. In addition to Van der Merwe's method, the plasticity index and linear shrinkage of soil samples were used to indicate the soils potential expansiveness.

Large areas of the Rietvlei Dam map sheet, approximately 665 km^2 (96%) exhibit swelling or expansive properties ranging from low to high (Table 28, Fig. 19). Areas with high expansive potential are expected to have a heave of greater than 30mm and can be grouped into two geomorphic/geological areas. The first area is confined to parts of the Rietvlei River flood plain situated west of the R50 and the Swawelpoort Spruit flood plain situated east of the R50. The second area is associated with colluvial and residual soils developed on the Hekpoort andesite Formation and the Transvaal Supergroup related diabase situated on the farms Tiegerpoort 371 JR and Zwavelpoort 373 JR (orthophoto 8, 13 and 14). The same applies to the Dwyka Group tillite and shale on the farm Grootfontein 394 JR (orthophoto 18) in the central and south-western portion of the map sheet (Fig. 19). Areas with a medium expansive potential have an expected heave of 5-30mm and are grouped into two north-west to south-east striking geomorphic/geological areas. The first area is associated with colluvial and residual soils developed on the Hekpoort andesite Formation (orthophotos 1, 2, 7, 8, 11, 13, 14, 16, 19, 20, 22 and 25) and Transvaal related diabase (orthophotos 2-5, 8-10, 14, 15 and 20) (Fig. 19). The second area is associated with alluvial soils present in drainage systems, situated on most of the orthophotos except numbers 1, 6, 7, 11-13, 19, 20, 23 and 25 (Fig. 19). Areas with low expansive potential have an expected heave of less than 5mm and are associated with colluvium and residual dolomite, shale and quartzite of the Transvaal Supergroup, that occur across the whole map sheet except in areas of outcrop and some of the drainage features (Fig. 19).

Areas with a potential for expansion but with an unknown severity rating were recognized in profile by the soil colour and structure often being black, dark grey, red or mottled yellow-grey, showing slickensiding or shattering. These areas are associated with pans, flood plains and drainage channels in the southern portion of the map sheet on the farms Elandsfontein 412 JR, Tweefontein 413 JR, Elandsvlei 414 JR and Knoppiesfontein 549 JR (orthophoto 22, 23, 24 and 25) (Fig. 19).

Where development is anticipated in areas with potential expansive soils, one or more of the following modified construction methods proposed by Williams *et al.* (1985), may be employed:

- Pre-wetting of expansive soil horizons.
- Removal of the active layer.
- Construction of moisture barriers and paving around the structures.
- Stiffened raft foundations, sandwich raft foundations (two overlying raft foundations with a mattress of gravel or sand between the rafts) or piled foundations.
- Split construction.

5.3.7.5 Excavatability problems

Excavatability is a high cost factor for development when installing underground services and foundations. Approximately 516 km^2 (75%) of the map sheet exhibits some form of excavatability problem, ranging from slight to severe (Table 28, Fig. 20).

Severe excavatability problems are present over 67 km^2 (10%) of the map sheet (Table 28), where solid rock outcrop or shallow bedrock is present and refusal of the backactor occurred within the first 0,5m from surface. These areas comprise outcrop or sub-outcrop of quartzite, shale, andesite, dolomite, chert and diabase of the Transvaal Supergroup occurring as north-west to south-east striking hill crests and ridge crests and occur in the following areas (Fig. 20): 1) Quartzite of the Magaliesberg Formation in the north-eastern portion of the map sheet (orthophotograph 5); 2) Shale with interbedded chert of the Silverton Formation and diabase dykes, situated between the R104 road and the road south of the N4 highway; 3) Quartzite of the Daspoort Formation situated between the road south of the N4 highway and the road north of the R50; 4) Andesite of the Hekpoort Formation situated in the vicinity of the road north of the R50; 5) Shale and quartzite of the Timeball Hill Formation situated east of the R21 road and in the vicinity of the R50 road; 6) Dolomite and chert situated directly south of the R50 road.

Moderate excavatability problems are present over 123 km^2 (18%) of the map sheet and are associated where ferricrete, shale bedrock, quartzite bedrock, chert bedrock, dolomite bedrock or with andesite boulders occurring at depths of 0,5 - 0,1 m (Table 28, Figure

20). The development of ferricrete is favoured in soils overlying andesite (situated in the vicinity of the road north of the R50 road) and shale of the Pretoria Group (Figure 20). The occurrence and depth of ferricrete development is variable. It is therefore difficult to predict where ferricrete will be encountered in relation to the surface, unless detailed investigations are conducted. Moderate excavatability is anticipated in sub-outcropping shale of the Silverton Formation (between the 104 road and the road south of the N4 highway), shale and quartzite of the Timeball Hill Formation (north of the R50 road and east of the R21 road), quartzite of the Rayton and Magaliesberg Formations situated in the north-eastern portion of the map sheet (orthophotograph 4 and 5) and with quartzite of the Daspoort Formation (in the area between the road south of the N4 highway and the road north of the R50). Moderate excavatability is also expected on chert and dolomite of the Eccles and Lyttelton Formations, situated south of the R50 road (Fig. 20).

Slight excavatability problems are present for 324 km^2 (47%) of the map sheet where refusal of the backactor occurred at a depth of 1,0 - 1,5 m (Table 28, Fig. 20). These are areas associated with ferricrete overlying andesite and shale of the Pretoria Group. Slight excavatability problems are also associated with sub-outcrop quartzite of the Strubenskop Formation in the area between the road south of the N4 highway and the road north of the R50, sub-outcrop of dolomite and chert occurred on the farm Hartebeestfontein 171 IR and Witkoppies 393 JR (orthophoto 17 and 21) and of sandstone and shale of the Vryheid Formation in the southern portion of the map sheet on the farms Sterkfontein 401 JR, Elandsfontein 412 JR, Witkoppies 393 JR and Grootfontein 394 JR (orthophoto 16, 17, 23) (Fig. 20).

Unspecified excavatability problems are present for 2 km^2 (less than 1%) of the map sheet (Table 28, Fig. 20). These are areas where ferricrete concretions, gravels of quartzite, shale and andesite were encountered in the first 1,5 m of the excavation without refusal of the back-actor.

Excavatability associated with chert and dolomite of the Chunniespoort Group is variable due to the highly irregular bedrock topography of the dolomite. Dolomite boulders found in residual soil may also pose an excavatability problem and differential settlements. Soil thicknesses overlying dolomite and dolomite boulders can be between 0 - 100 m (Buttrick, 1992). A detailed investigation is therefore required to determine the severity of these problems in areas underlain by dolomite. Andesite of the Hekpoort Formation weathers irregularly resulting in solid outcrop occurring within metres of a deep soil profile, which also results in variable excavatability conditions.

5.3.7.6 Collapsible soil

Colluvial sediments situated on straight slopes, plains and residual soils on well-drained hill slopes, that were derived from weathered dolomite, sandstone and quartzite of the Transvaal and Karoo Supergroups exhibit a collapsible and open structured fabric. Collapsible soils are dark red, dark red brown, yellow brown or orange brown, loose to very loose in consistency, open structured, silty sands or sands with minor silt.

Approximately 55 km^2 (8%) of the map sheet exhibits soils with a collapse potential ranging from low to severe (Table 28, Fig. 21). Areas with severe collapse have an expected collapse potential of 10% - 20% and are associated with colluvial soil derived from quartzite of the Strubenkop Formation situated in the south-eastern portion of the map sheet on the farm Rietfontein 395 JR (orthophoto 19 and 20) (Fig. 21).

Areas with moderate collapse potential have an expected collapse potential of 5% - 10% and cover 3 km^2 (less than 1%) of the map sheet (Table 28, Fig. 21). They are associated with colluvial soils derived from, quartzite of the Daspoort Formation situated in the northern portion of the map sheet on the farm Zwavelpoort 373 JR (orthophoto 8), dolomite and chert situated directly west of the R50 road (orthophotographs 12 and 17), shale of the Silverton Formation situated on orthophotographs 9 and 14 and with shale of the Timeball Hill Formation situated on orthophotographs 7, 12 and 16 (Fig. 21).

Areas with a low collapse potential have an expected collapse potential of 1% - 5% and are associated with colluvial and residual soils derived from sandstone and shale of the

Vryheid Formation in the south-western portion of the map sheet west of the R21 and with colluvial soils overlying dolomite and chert in the southern portion of the map sheet, east of the R50 road (Fig. 21).

Areas exhibiting a potential for collapse, but where the expected decrease in soil volume is unknown, cover 51 km^2 (7%) of the map sheet. These areas were classified according to their sandy matrix, open structure and a comparison of disturbed soil samples with Knight (1961) and Errera (1977) grading curves. These soils are associated with: colluvial and residual material derived from quartzite of the Magaliesberg Formation in the north-eastern portion of the map sheet next to the N4 highway, colluvium on orthophotograph 2, 3 and 7, shale of the Silverton Formation on orthophotograph 10, quartzite of the Daspoort Formation on orthophotograph 20, sandstone and shale of the Karoo Supergroup in the southern portion of the map sheet (orthophotograph 22-25), quartzite of the Timeball Hill Formation in the south-western portion of the map sheet (orthophotograph 22), and with dolomite and chert in the southern portion of the map sheet on orthophotograph 23 (Fig. 21).

According to Schwartz (1985), remedial measures to prevent or reduce the impact of collapsible soils include:

- Adequate drainage to prevent the ingress of water into collapsible horizons.
- The use of raft, stiffened raft or pile foundations
- Chemical stabilisation of the soil.
- Densification of the collapse horizons.
- Removal of the collapsible horizons and replacing these with compacted layers (where 0,5 metres is the general depth of excavation for foundations). This is often the most cost effective method, by excavating 1,5 times the width of foundation and recompacted in 150 mm layers at a moisture content of 98% from optimum (Mod. AASHTO) .

A well developed ferricrete layer overlying a collapsible profile will often provide a good founding platform.

5.3.7.7 Erodible soils

The erodibility of soils is a function of the resistance of slope materials to entrainment and transport, and the potential of slope processes that promotes erosion. A multitude of factors influence the erodibility of soils making it difficult to quantify or predict the rate of erosion on a particular slope (Summerfield, 1991). The resistance of the soil to rain splash and slope wash, the slope length and gradient and the proportion of the ground surface that is covered with vegetation are factors affecting erosion and erosion rates. The resistance of soil to erosion is also related to the mechanical strength, cohesion and particle size.

Less than 1% of the map sheet is likely to have erodible soils (Table 28, Fig. 22). Erodible soils can be grouped into two geomorphic areas. The first, is associated with the Pienaars River flood plain situated in the eastern portion of the map sheet on orthophotograph 14. The second, is associated with hillsides comprising quartzite and shale of the Timeball Hill Formation in the southern portion of the map sheet at Bashewa Agricultural holdings (orthophotograph 18, 23 and 24) and in the western portion of the map sheet at Rietfontein Small holdings (orthophotograph 12, Fig. 22).

5.3.7.8 Poorly consolidated soils

Poorly consolidated or compressible soils cause shear strength, compressibility and time related settlement problems. Less than 1% of the map sheet is covered by poorly consolidated soils (Table 28). Poorly consolidated soils occur in flood plain clays, situated in the south-western portion of the map sheet (orthophotograph 21). These soils give rise to settlement problems, unless adequately treated prior to construction.

5.3.7.9 Shallow groundwater

A shallow water table is vulnerable to contamination from incorrectly sited facilities, such as waste sites, ground based sanitation systems and cemeteries. Presence of a shallow water table can be critical when planning certain developments. A shallow groundwater table is expected to occur adjacent to drainage channels, vleis, pans and flood plains, covering approximately 8 km^2 (1%) of the map sheet (Table 28, Figure 23). Groundwater conditions may fluctuate seasonally. The occurrence of ferricrete indicates a present or historic fluctuating groundwater table during which iron is precipitated at the base of the perched groundwater table. Where a soil has a clay matrix, the shrink and swell characteristics will be influenced by a fluctuating watertable.

5.3.7.10 Permeability

Permeability is the ability of the soil to transmit water through voids. The size and interconnection of the voids, rather than the void ratio, governs the rate of seepage. The size of voids is related to the distribution of particle size, particle shape and soil structure. Where the soil is stratified, permeability is usually higher parallel to the stratification than perpendicular to it. High permeabilities are generally associated with sandy soils and low permeabilities with clayey soils (Brink *et al.*, 1982).

The permeability of soils is an important geotechnical property, depending on the type of development being considered. Permeability controls the rate at which a soil will consolidate under load and is also an important consideration in the treatment of subfoundation soils in dams and the prevention of seepage into excavations. Low permeability can result in the ponding of water during the rainy season which may be a problem for certain types of develoment and high permeabilities can lead to instant contamination of the groundwater (Brink *et al.*, 1982).

In this study the permeabilities of the soil samples were derived using Hazen's formula, which is more applicable to sandy soils. Other methods to determine the permeability of soil are the constant head permeability test for sandy soils and the falling head permeability test for clay-rich soils (Craig, 1974), neither of which were applied during this investigation. Approximately 12 km^2 (2%) of the map sheet exhibits high permeabilities (Table 28, Fig. 24) and is associated with sandy colluvial and residual soils derived from quartzite of the Magaliesberg Formation on orthophotograph 5; quartzite of the Daspoort Formation on orthophotographs 8 and 20; quartzite and shale of the Timeball Hill Formation on orthophotographs 13, 16 and 18; alluvial soils overlying dolomite in a drainage feature on orthophotograph 12 and colluvium and residual soils overlying dolomite and chert of the Eccles Formation on orthophotographs 18 and 23 (Fig. 24).

Areas with medium permeability covers 215 km^2 (31%) of the map sheet and are associated with colluvial or residual silty sand and sandy silt derived from quartzite of the Magaliesberg Formation on orthophotograph 5; shale of the Silverton Formation and diabase dykes on orthophotographs 4, 5, 9 and 10 and from quartzite of the Daspoort Formation on orthophotographs 1, 2, 8, 13, 14, 19, 20 and 25 (Fig. 24). Residual soils overlying andesite of the Hekpoort Formation (orthophotographs 7 and 12); quartzite or shale of the Timeball Hill Formation (orthophotographs 6, 7, 11-13, 16, 18, 21, 22 and 24), and dolomite or chert of the Eccles formation (orthophotographs 11, 12, 16-18, 21-24), also exhibit medium permeabilities (Fig. 24).

Areas with low permeability cover 438 km^2 (63%) of the map sheet and are associated with silty clay or clayey silt derived from shale of the Silverton Formation and diabase in the north-eastern portion of the map sheet; the Hekpoort Formation andesite in the central portion of the map sheet, and on quartzite or shale of the Timeball Hill Formation in the south-western portion of the map sheet (Table 28, Fig. 24).

5.3.8 Potential construction materials

The rapid growth of South Africa's urban areas and demand for new houses have put immense pressure on existing construction material resources such as brick-making clay, concrete and road aggregate and building sand.

5.3.8.1 Clay

Seven operating clay quarries exist in the Rietvlei Dam map sheet area (Table 29). These clay deposits are confined to the Vryheid Formation of the Karoo Supergroup and the Timeball Hill Formation of the Transvaal Supergroup.

Table 29: Location, type and end use of operating clay quarries for the Rietvlei Dam map sheet.

Quarry Name	Commodity	Host Rock Lithology	Latitude	Longitude	End Uses
Rietvlei Quarry	Brick clay	Vryheid Formation Shale and clay	25° 55' 24"	28° 19' 06"	Face Bricks, Semi-Face Bricks
Victoria Bricks	Brick clay	Timeball Hill Formation Shale / clay	25° 56' 18"	28° 16' 26"	Semi-Face Bricks
Sterkfontein Bricks	Brick clay	Vryheid Formation Shale / clay	25°56' 10"	28° 15' 28"	Face Bricks, Semi-Face Bricks
Olifantsfontein Quarry 1	Brick clay	Timeball Hill Formation Shale / clay	25° 56'03"	28° 16' 09"	Face Bricks, Semi-Face Bricks
Olifantsfontein Quarry 2	Brick clay	Vryheids Formation Shale / clay	25° 56' 12"	28° 15' 45"	Face Bricks, Semi-Face Bricks
Apollo Brick	Brick clay	Timeball Hill Formation Shale / clay	25° 59' 0"	28° 18' 15"	Stock bricks, Semi-Face Bricks
Berko Stock Bricks	Brick clay	Timeball Hill Formation Shale / clay	25° 53' 07"	28° 20' 33"	Stock Bricks

The Vryheid Formation comprises alternating layers of shale, sandstone, coal and conglomerate. The shale weathers to form quartz and kaolinite with impurities of oxides and other clay minerals such as illite and montmorillonite. The clays that are formed varies in colour from pink, cream, grey, brown and black. The Vryheid Formation occurs as patches on the Chuniespoort Group dolomite and chert in the south-eastern portion of the map sheet on the farms Witkoppies 393 JR, Grootfontein 394 JR, Tweefontein 413 JR, Elandsfontein 412 JR, Elandsvlei 414 JR, Sterkfontein 401 JR and Rietfontein 375 JR. The Timeball Hill Formation comprises shale and siltstone at the base, with shale, quartzite and graywacke at the top. In between is a thin layer of quartzite and ferruginous shale. The shale varies from pale-yellow to shades of red. The Timeball Hill Formation occurs in two north-western to south-eastern striking bands. The first band includes portions of the farms Elandsfontein 412 JR and Tweefontein 413 JR in the south and portions of the suburbs Elarduspark and Moreletapark in the north. The second band occurs on the farm Elandsfontein 412 JR in the south and the suburb Elarduspark and Erasmusrand in the north.

Although the Vryheid Formation represents a source of economically viable clay deposits in the map sheet area, its thickness varies, which is an important consideration when identifying future clay quarries.

5.3.8.2 Aggregate

Aggregate is defined as any hard, inert material such as sand, gravel, slag or crushed rock, which constitutes the bulk filler in concrete, mortar, plaster and tarmac, as well as railroad ballast or road metal when used alone. Only two operating aggregate quarries exist on the map sheet area (Table 30).

Table 30: Location, type and end use for operating aggregate quarries on the Rietvlei Dam map sheet.

Quarry Name	Commodity	Host Rock Lithology	Latitude	Longitude	End Uses
Donkerhoek Quarry	Sand, aggregate	Magaliesberg Formation Quartzite	25° 45' 51"	28° 27' 36"	Manufacturing industry
Willow Quarries	Building sand, river sand, plaster sand	Daspoort Formation and Quaternary Deposits Quartzite, aeolian / fluvial sand	25° 48' 54"	28° 22' 21"	Building industry

Quartzite of the Pretoria Group, especially those of the Magaliesberg, Daspoort, Strubenkop and Timeball Hill Formations provides potentially good sources of aggregate that are durable and strong. The Magaliesberg Formation occurs in the north-eastern portion of the map sheet (orthophotograph 5), the Daspoort and Strubenkop Formations in the area between the road south of the N4 and the road north of the R50. The Timeball Hill Formation is situated in the vicinity of the R50 and directly north of it and east of the R21. Other sources of potential aggregate include dolerite, andesite and shale. However, chemical decomposition is the dominant mode of weathering in the area resulting in the formation of secondary clay minerals that may have a deleterious effect on the durability and strength of aggregates obtained from these rocks (Weinert, 1980).

Care should be taken with the use of aggregate manufactured from sandstone of the Vryheid Formation as it has resulted in failure of concrete because of its abnormally high dimensional changes with a change in moisture content (Morrison, 1980). Dolomite is a good source of aggregate, providing that it does not contain more than 15% chert, which is not the case for dolomite of the Eccles Formations (Morrison, 1980).

The potential fine aggregate sources for the Rietvlei Dam map sheet are natural sands or manufactured sands. Natural fine aggregate or building sand is formed by the weathering of rocks and subsequent transport. The sands tend to be well-graded but contain an excessive amount of silt and clay which require the additional expense of washing to make them suitable for use. Areas in the northern portion of the map sheet, are potential sources for fine aggregate, comprising sandy deposits that were formed by weathering of quartzite of the Magaliesberg, Strubenkop and Daspoort Formations and subsequently reworked by wind and water activity. Manufactured or crusher sand is obtained mainly from the crushing of rock material such as quartzite of the Pretoria Group, especially those of the Magaliesberg, Daspoort and Timeball Hill Formations.

5.4 CONCLUSION

The geotechnical classification system proposed by Zawada (2000) for regional geotechnical mapping on a 1:50 000-scale, with the Rietvlei Dam 2528CD map sheet used as an example, was evaluated. The critical evaluation of this system is regarded as useful to guide the Council for Geoscience in the modification and improvement of this system for future implementation.

The following is a summary of the conditions which exist in the Rietvlei Dam 2528CD 1:50 000-scale map sheet area:

- The Rietvlei Dam 2528CD map sheet covers approximately 690 km² (25 km × 25 km) and is situated south-east of Pretoria which includes a portion of the Tshwane (Pretoria) municipal area.
- The area is relatively flat to gently undulating, with three prominent ridges striking north-west to south-east across the map sheet area. Other landforms on the map sheet include, hill crests, plains, dams, excavations, marshy areas, drainage and river channels.
- The climate of the area is sub-humid, with an average annual rainfall of 760 mm, an average summer maximum of 25,8°C and an average winter minimum of 3°C. The prevailing wind direction is north-east and averages at 6,5 knots (pers. comm. Weather Bureau, 1999). Weinert's climatic N-value for this area is 2.4, which indicates that decomposition is the dominant form of weathering resulting in the formation of thick soils (Weinert, 1980).
- The area is drained in a northerly direction by the Rietvlei and Pienaars Rivers, the Sesmyl Spruit, Moreleta Spruit and several non-perennial streams.
- Rapid development is taking place in the north-western portion of the map sheet area, whilst much of the remaining area is occupied by farms and agricultural holdings.
- The area is underlain by rock of the Transvaal and Karoo Supergroups, with the surficial deposits consisting of unconsolidated alluvium and colluvium of Quaternary age.
- The dolomite area on the map sheet is subdivided into the Rietvlei, Witkoppies, Sterkfontein and Doornkloof-east hydrogeological compartments. The groundwater within the dolomite area is of excellent quality for human consumption and irrigation purposes, except for the Rietvlei compartment which has been contaminated by effluent from the Kempton Park sewage works.

- Geotechnical factors and their associated severity classes (definitions are given in Table 21) anticipated for the area are represented on the geotechnical map (Appendix 2). These include: Inundation (Inu2), sinkhole formation (Sin2), slope instability (Slo2), swelling or expansive soils (Act2, Act3, Act4, Act5), excavatability problems (Exc2, Exc3, Exc4, Exc5), collapsible soils (Col2, Col3, Col4, Col5), subsidence (Sub2), erodible soils (Ero2), poorly consolidated soils (Con2), shallow water table (Sha2), permeability (Per2, Per3, Per4). Each geotechnical factor is presented on an A4 map, showing the different severity classes for that specific geotechnical factor.
- Existing construction materials extraction or mining include seven operational clay quarries and two aggregate quarries. The clay deposits are confined to shales of the Vryheid Formation of the Karoo Supergroup and the Timeball Hill Formation of the Transvaal Supergroup. The aggregate deposits are confined to quartzite of the Magaliesberg Formation and the Daspoort Formation. Quartzite of the Strubenkop and Timeball Hill Formations also provide potentially good sources of aggregate. The sandy deposits formed by the weathering of quartzite of the Magaliesberg, Strubenkop and Daspoort Formations and reworked by wind and water, provide potential sources of fine aggregate.

The results above show that the classification system proposed by Zawada (2000) can be applied to create a geotechnical map that is of value for a variety of land-uses and development issues. The method seeks to combine computer technology with hard copy map presentations by providing familiar looking printed maps of different geographical areas and yet allows for the generation of maps by computer for specific purposes.

The following shortcomings were identified during the course of this evaluation and should be addressed to improve the end product (geotechnical map).

- Browsing through the accompanying tables in order to understand the meaning of information and/or data presented on the map is too time consuming.
- The ranking of geotechnical factors and the classification of the ranked list into

groups having critical and subcritical status, to enable the identification of the highest ranked geotechnical factor present in an area, could be confusing to the non-geotechnical specialist. This confusion is associated with the fact that the reader may understand that the word 'dominant geotechnical factor' means that this factor will have the largest impact during regional planning and development stages, although it is only classed according to a ranking system developed by Zawada (2000) for general land use purposes, taking into account financial and environmental factors. This problem can be illustrated by looking at the 'number of geotechnical area' on the geotechnical map (Appendix 2), the number 321 represents the geotechnical properties Act3 (low expansiveness) and Exc5 (severe excavatability problems) or by looking at the number 377 which represents the geotechnical properties Act3 (low expansiveness) and Col4 (moderate collapse potential). In both cases the second listed geotechnical factor will pose a much bigger impact on development than the first one, namely Act3 (low expansiveness).

- The dominant geotechnical factor is indicated by a colour type and additional critical and subcritical factors present for the same area are denoted by a shade of colour corresponding to the colour of the dominant geotechnical factor. The consequences of this is that, although other factors listed lower down the ranking list, could impose a much bigger impact, they are not highlighted as the primary geotechnical factor for a specific area on the map, especially in terms of colour distinction. For this reason an important geotechnical factor or factors could be concealed. The example used under the previous point can once again be applied here, for the numbers 321 and 377 the colour codes are shades of red for active clays which is first on the ranking list, although severe excavatability problems represented by the code Exc5 (green is the denoted colour for excavatability) and moderate collapse represented by the code Col4 (peach is the denoted colour for collapse) have respectively higher impacts than low expansiveness (Act3), and for this reason are concealed.
- The above mentioned point not only reduces visibility in terms of contrast, but also could imply that only one or two geotechnical factors are present on the map

sheet. For example, if the domintant geotechnical factor ranked first on the list as developed by Zawada, is active soils, most of the map sheet area will be coloured in shades of red and only after careful scrutiny the user may realise that although the colours of different numbered areas are the same, the geotechnical factors differ.

- The use of only one hatching code to distinguish between adjacent areas of the same colour with minor differences in additional geotechnical factors, could also pose a problem, because the geotechnical factor for which it is applied could be different every time, for example it could be applied where a minor difference exists in excavatability (Exc4 and Exc5) between two adjacent areas, or permeability (Per2 and Per3) or any other geotechnical factor.
- According to Zawada (2000), the purpose of the map was not to generalise the geotechnical parameters into zones for development to ensure that the map would be of value to a variety of land-use and development issues. The outcome of this is a very complex legend which only an engineering geologist with the necessary background would find useful. This map will be of no meaning to the town planner and/or developer and will be regarded as a map full of data that provides no useful information, regarding poor and good areas for potential development (zonation map).

CHAPTER 6

PROPOSED MODIFICATION OF THE GEOTECHNICAL CLASSIFICATION SYSTEM DEVELOPED BY ZAWADA (2000)

6.1 INTRODUCTION

The reasoning behind this modification is to simplify the proposed system by Zawada (2000), in order to improve the utilization of the compiled geotechnical maps. A map was compiled to demonstrate the proposed modifications (Appendix 3). This was necessary for comparison with the existing geotechnical map (Appendix 2), to indicate the recommended modifications which were applied to the classification system.

6.1.1 Classification

The following modifications were recommended and applied:

- The ranking of geotechnical factors in order of decreasing rank (Table 22), in terms of overall significance to land use issues (financial and/or environmental), provides a systematic approach in which data is imported in the database. It is strongly recommended that no alteration needs to take place in the way that information is imported into the database, which was designed specifically for this classification system. Changes to the database could not be done due to cost and time related factors associated with the development of a new geotechnical database system.

  Although the classification of the ranked list into groups having critical and subcritical status should fall away to simplify the system. Geotechnical factors only need to be ranked in terms of their overall significance to land use issues, as presented in Table 31.

Table 31: Ranking of geotechnical factors, in order of decreasing rank.

Ranked	Mapped Geotechnical Factor
1	Inundation (flooding)
2	Sinkhole formation
3	Slope instability
4	Active, expansive or swelling soil
5	Excavatability of ground
6	Collapsible soil
7	Subsidence
8	Erodible soil
9	Dispersive soil
10	Acidic soil
11	Compressible soil
12	Shallow water table
13	Permeability of soil

- A classification system was developed to distinguish between areas potentially favourable, less favourable and unfavourable for the development of single storey houses. The different geotechnical factors and their severity classes are individually evaluated for each numbered geotechnical area in terms of these three development categories (Table 32). Those geotechnical factors that may pose an environmental constraint for developments such as cemetery sites, waste disposal sites and pit latrines, are indicated by hatching (Table 32).

- This classification implies that for a geotechnical area to be favourable, all the geotechnical factors must be favourable. One or more less favourable geotechnical factor place the geotechnical area in a less favourable class, while one or more unfavourable geotechnical factor classify the site as unfavourable for development.

Table 32: Alphabetical listing of geotechnical factors, their severity classes, development potential classification and those with environmental constraints for the Rietvlei Dam map sheet.

Geotechnical factor Severity class		Development potential	Environmental constraint
Act2	Expansive soil present (expected heave unknown)	Favourable	
Act3	Low Expansion (0-5mm)	Favourable	
Act4	Medium Expansion (5-30mm)	Less favourable	
Act5	High Expansion (>30mm)	Unfavourable	///
Col2	Collapse potential present (amount of decrease in soil unknown)	Favourable	
Col3	Low collapse potential (1-5%)	Favourable	
Col4	Medium collapse potential (5-10%)	Less Favourable	
Col5	Severe collapse potential (10-20%)	Unfavourable	///
Con2	Area has compressible soil	Favourable	
Ero2	Erodible soil is present	Favourable	///
Exc2	Excavatability problems anticipated (unspecified)	Favourable	
Exc3	Slight excavatability problems, refusal at >1,5m on boulders.	Favourable	
Exc4	Moderate excavatability problems, refusal between 0,5 - 1,0m.	Less favourable	
Exc5	Severe excavatability problems, refusal at <0,5m.	Unfavourable	///
Inu2	Area at risk for inundation/flooding	Unfavourable	///
Per2	Low permeability ($<4 \times 10^{-6} - 9 \times 10^{-10}$ cm/s)	Not described in terms of development potential.	
Per3	Medium permeability ($<4 \times 10^{-4} - 4 \times 10^{-6}$ cm/s)		
Per4	High permeability ($>4 \times 10^{-4}$)		///
Sha2	Shallow water table present	Unfavourable	///
Sin2	Area susceptible to sinkhole formation.	Unfavourable	///
Slo2	Unstable slope	Unfavourable	///
Sub2	Induced subsidence anticipated	Unfavourable	///

- Those geotechnical areas with one or more than one geotechnical factor classified as an environmental constraint (Table 32) are indicated in the Table of Geotechnical factors (Appendix 3). It was necessary to delineate those areas that can be negatively effected by developments such as cemetery sites, waste disposal sites and the facilitation of ground based sanitation systems (pit latrines or septic tanks). Geotechnical factors classified as an environmental constraint (Table 32) are based on criteria normally taken into consideration during site specific investigations for the above mentioned type of facilities.

6.1.2 Presentation

- The choice of colour assigned to each 'number of geotechnical area', presented in the 'table of geotechnical factors' (Appendix 3), should be decided on by the mapper. The colour of the most problematic geotechnical factor (primary factor) in terms of land-use for the specific 'number of geotechnical area' can be used. The other geotechnical factors (secondary factors) present for that area can be indicated by coloured hatching codes. Each geotechnical factor with severity classes, colour codes and hatching is presented in 'Geotechnical factors: Explanation and severity classes' (Appendix 3).

A distinctive colour was assigned to each geotechnical factor (presented in the table 'Geotechnical factors: Explanation and severity classes'(Appendix 3)). The shade of colour depends on the different severity classes of each geotechnical factor, with the darkest colour assigned to the most severe class (for example Exc5, is dark green) and the lightest colour assigned to the least severe class (for example Exc3, is light green). This is incorporated next to each severity class in the table 'Geotechnical factors: Explanation and severity classes'(Appendix 3), thus reducing the number of tables that need to be read and the complexity of the system. The colour and/or hatching assigned to each 'number of geotechnical area' is presented in the 'table of geotechnical factors'.
As for example the geotechnical area numbered 321 is coloured as a shade of red (as for active clays which is first on the ranking list), although severe excavatability problems represented by the code Exc5 (green is the denoted colour for excavatability) also exists for that specific number and could be regarded as a higher impact than low expansiveness (Act3), as represented in Appendix 2. For this reason, the number of geotechnical area', number 321 should rather be

coloured a dark green (severe excavatability problems) which will immediately highlight the severity of the primary (prominent) geotechnical factor present in a specific 'number of geotechnical area' (Appendix 3). The secondary geotechnical factor (Act3) can then be represented by a coloured hatching code (Appendix 3). The primary geotechnical factor in a specific numbered geotechnical area is shaded in the 'Table of geotechnical factors' (Appendix 3) for easy identification.

Geotechnical areas are classified as areas of different development potential. A distinction is made between areas which are favourable (yellow), less favourable (orange) and unfavourable (red) for development of single storey houses, as shown in the 'Table of Geotechnical Factors'. Those geotechnical areas that may pose an environmental constraint are indicated by hatching. The development potential and environmental constraint of geotechnical areas are presented on a 1:100 000-scale complimentary map. This will provide useful information to the town planner and/or developer and hereby improve the utilization of the map.

Each geotechnical area has a unique number listed in the Table of Geotechnical factors, as well as a superscript number linked to the specific colour code. Permeability was not taken into account with the colour coding, but can be read from the 'Table of Geotechnical Factors'.

CHAPTER 7

CONCLUSIONS

The following conclusions can be made from the literature survey and research:

- The amount and type of information required to produce a geotechnical map, will depend on the purpose, content and scale of the map. Regional scale geotechnical maps can be divided into special or general purpose maps. Special purpose maps are produced if information is evaluated for a specific purpose and usually only covers one component of engineering geology such as the grade of weathering, where general purpose maps are produced to provide information on many aspects of engineering geology for a variety of planning and engineering purposes. Most of these maps are comprehensive in content, depicting all the principal components of the engineering geological environment, where on one map sheet areas classified as units based on the uniformity of their engineering geological conditions are shown. In terms of scale, regional engineering geological information could be presented on a 1:10 000 or 1:50 000 scale, where a 1:10 000 scale can be regarded as a large and medium scale map, and the 1:50 000 scale is regarded as a medium scale map (Dearman, 1991).

- The accuracy of information gathered for a regional geotechnical map, based on the principle of the land facet approach (three test pits per area of similar geology and landform, SAIEG, 1997), will depend on the following factors: 1) the scale of the base map used (1:10 000 or 1:50 000), 2) the complexity of the terrain mapped, in terms of geology and landform (a complex terrain will require more test pits to cover all the different land facets), 3) the scale of the final map (a medium scale of 1:50 000 is recommended as most of South Africa is covered by 1:50 000 topocadastral and other theme maps, Price, 1981).

- A need for the provision of rapid and accurate engineering geological information will always exist for broad planning and development purposes. The identification of land to satisfy the growing demand for infrastructure and housing development on a regional scale is necessary. It is therefore important to identify land that is suitable for cost effective urban development, environmentally sustainable, with a relatively low natural hazard risk as well as to target reserves of construction materials to prevent sterilisation.

- Factors that should be taken into consideration during regional geotechnical mapping is defined and the identification in the field and from laboratory tests and the implications of these factors on development are described. The terrain evaluation criteria included geotechnical factors (expansive soils, collapsible soils, compressible soils, dispersive soils, excavatability problems, inundation, pseudokarst, shallow water table, sinkhole formation and slope instability), existing and potential construction material sources (clays, fine and coarse aggregate) and environmental considerations (siting of cemetery sites, waste disposal sites and ground based sanitation systems).

- The development of geotechnical maps and their associated classification systems, previously and currently being used in South Africa and the application of these different systems, was reviewed in terms of there purpose, classification and the presentation of data. Orthophotograph 2528CD08 was used to present all the different geotechnical classification systems, which aided with the comparison of the different system and the presentation of information on a map. The revision of each classification system and the compilation of maps based on the different systems, made it clear that these classifications systems range from simple to very complex. No one classification system can be regarded as being better than the other, due to the fact that each of these classifications systems was designed for a specific purpose. Although it was found during the application and comparison of the different systems, that the geotechnical classification system developed by Partridge *et. al.* (1993) was the most simplified and practical method to use for the classification of terrain for urban planning and development purposes.

- The standardised methodology and procedures used by the Council of Geoscience for regional geotechnical mapping follows a systematic approach and can be divided into the following phases: 1) Data gathering or desk study, including the accumulation and interpretation of existing data, such as the compilation of a landform map based on the land facet approach, 2) Reconnaissance survey, assuring that data gathered during the desk study is accurate by field checking and provisionally locating test pit positions based on accessibility considerations, 3) Field mapping, during which test pits are excavated and each individual soil layer in each profile are described according to the MCCSSO method proposed by Jennings *et al.* (1973), 4) Laboratory testing of disturbed soil samples to determine material and engineering properties of the various soil horizons by means of foundation indicator tests. Undisturbed soil samples may also be tested for specific problems, although this is not standard procedure for regional geotechnical mapping. 5) Compilation of the final geotechnical map showing areas with similar geotechnical properties, are based on the soil profiles, laboratory results, landforms and geology. The presentation of the engineering geological information is based on the specific geotechnical classification system used; 6) Reporting of the data in the form of a report or explanation accompany the geotechnical map. The report should explain the methodology used, reason for the map and include a discussion of the conditions found during the mapping exercise.

- Special reference is made to the geotechnical classification system developed by Zawada (2000) for the Council of Geoscience and this was also applied to the Rietvlei Dam 2528CD map sheet in order to determine the applicability of this system for regional geotechnical mapping on a 1:50 000-scale. This classification system could be applied to create a geotechnical map that is of value for a variety of land-uses. Certain shortcomings were identified during the application and evaluation of the system and recommendations are made to modify and eventually simplify the geotechnical classification system to be of more use. The following were applied:

- Geotechnical factors were only ranked in terms of overall significance to land use issues, excluding the classification of the ranked list into groups having critical and subcritical status, to simplify the system.

- Only those geotechnical factors (10) of the 13 geotechnical factors considered during geotechnical mapping were presented on the Rietvlei Dam 1:50 000-scale geotechnical map, to prevent confusion.

- A classification system was developed to distinguish between areas potentially favourable, less favourable and unfavourable for the development of single storey houses. The different geotechnical factors and their severity classes were individually evaluated for each numbered geotechnical area and placed in terms of these three development categories in the table of geotechnical factors. Those geotechnical factors that may pose an environmental constraint for developments are indicated by hatching in the Table of Geotechnical Factors. Geotechnical factors classified as an environmental constraint, are based on criteria normally taken into consideration during investigations for waste disposal sites, cemetery sites and ground based santitation systems.

- The choice of colour assigned to each 'number of geotechnical area', presented in the 'table of geotechnical factors', is decided on by the mapper. The colour of the most problematic geotechnical factor (primary factor) in terms of land-use for the specific 'number of geotechnical area' as specificly allocated to that geotechnical factor, is used and not according to the geotechnical factor first on the ranked list. Other geotechnical factors (secondary factors) present for that area are indicated by specific allocated coloured hatching codes. Each geotechnical factor with severity classes, specific allocated colour codes and hatching is presented in 'Geotechnical factors: Explanation and severity classes' on the map.

- The shade of colour depends on the severity class of the geotechnical factor, with the darkest colour assigned to the most severe class (for example Exc5, is dark green) and the lightest colour assigned to the least severe class (for example Exc3, is light green). This reduces the number of tables that need to be read and the complexity of the system. The specific colour and/or hatching assigned to each 'number of geotechnical area' is presented in the 'table of geotechnical factors'.

- The development potential and environmental constraint of geotechnical areas are presented on a 1:100 000-scale complimentary map. This will provide useful information to the town planner and/or developer and hereby improve the utilization of the map. Geotechnical areas are classified as areas of different development potential. A distinction is made between areas which are favourable (yellow), less favourable (orange) and unfavourable (red) for development of single storey houses, as shown in the 'Table of Geotechnical Factors'. Those geotechnical areas that may pose an environmental constraint are indicated by hatching.

- Each geotechnical area has a unique number listed in the Table of Geotechnical factors, as well as a superscript number linked to the specific colour code. Permeability was not taken into account with the colour coding, but can be read from the 'Table of Geotechnical Factors'.

After the above mentioned modifications to the geotechnical classification system of Zawada (2000) which is currently being used by the Council for Geoscience (CGS), it is clear that the system is much more simplified, understandable and provide more useful information. This map is now of use, not only to the engineering geologist but as well to the town planner and/or developer, regarding poor and good areas for potential development (zonation map) and areas not suitable for the facilitation of waste disposal sites, cemetery sites and ground based sanitation systems.

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APPENDIX 1

Figures 16 - 24

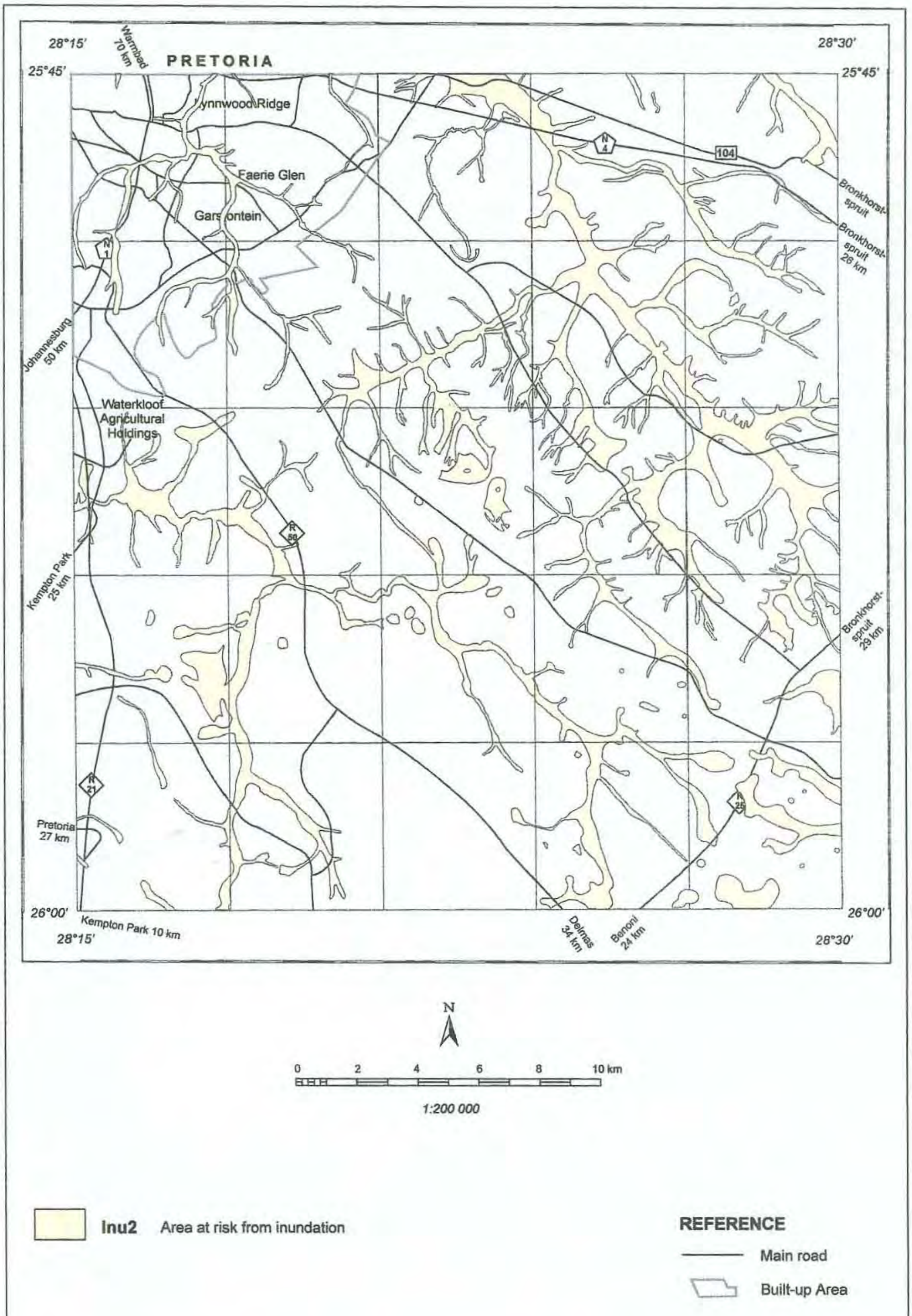


Figure 16: The area thath are susceptible to inundation in the Rietvleiam 2528 CD map sheet

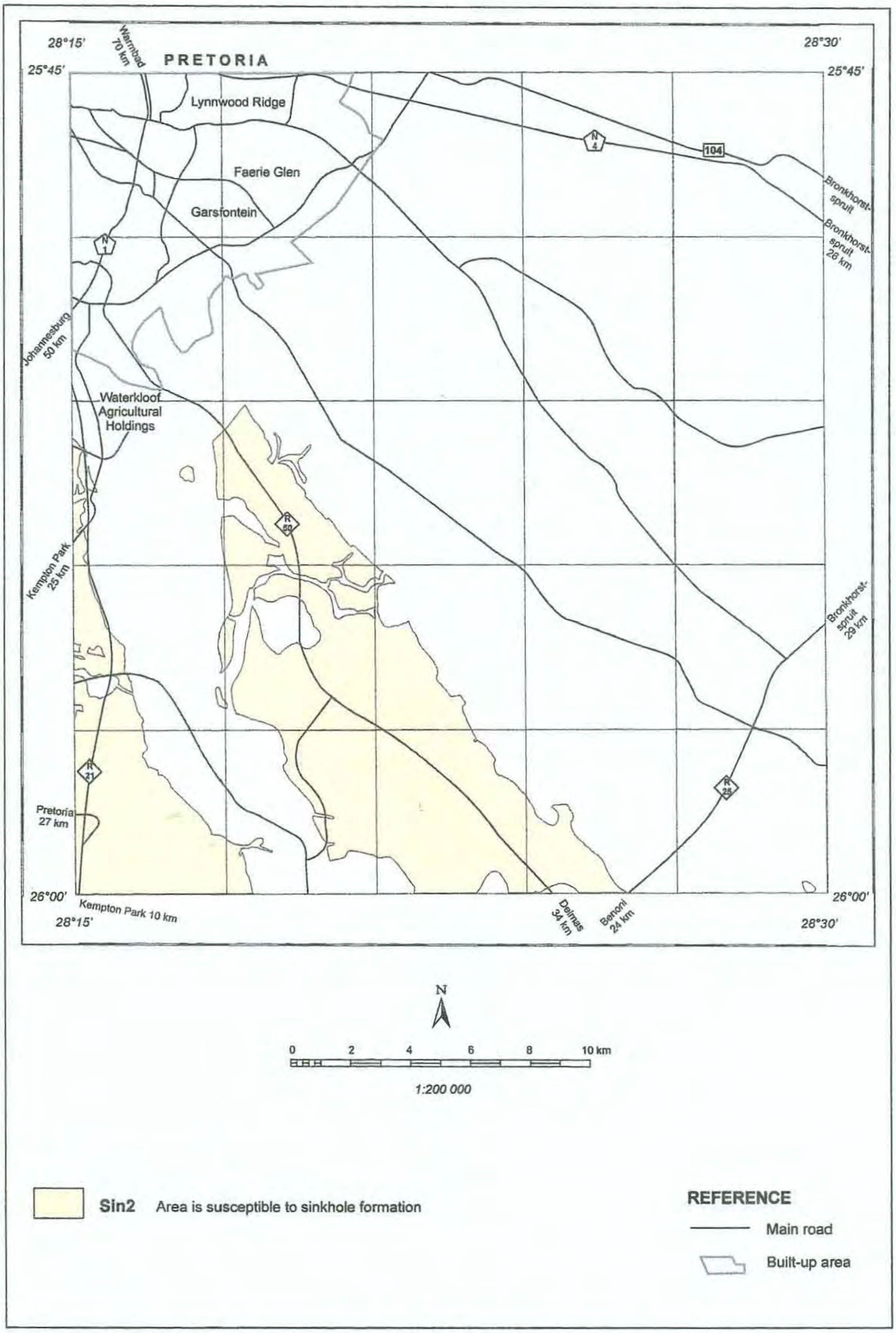


Figure 17: The area where potential exist of sinkhole formation in the Rietvleiam 2528 CD map sheet

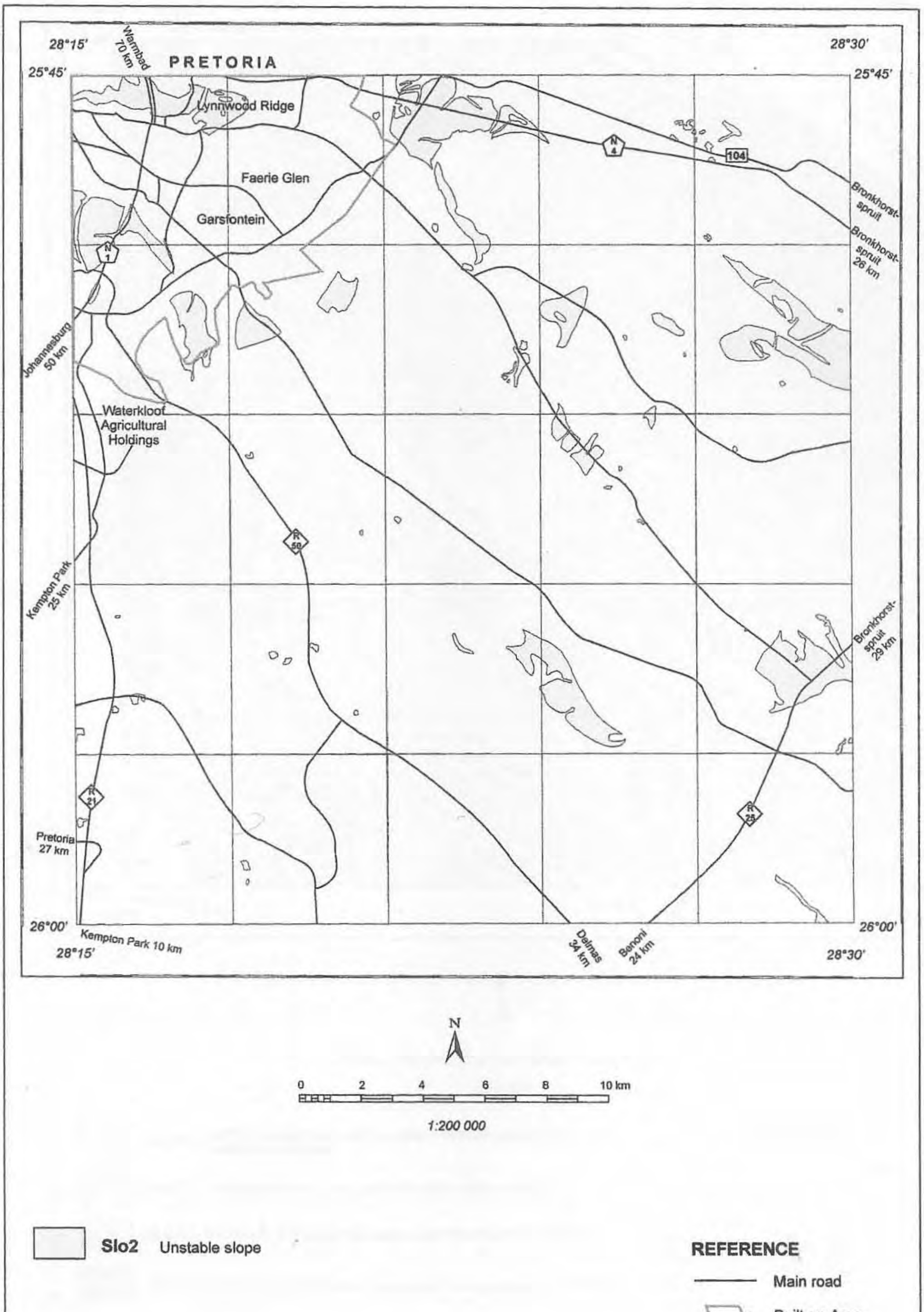


Figure 18: The area covered by slope instability characteristics in the Rietvleiam 2528 CD map sheet

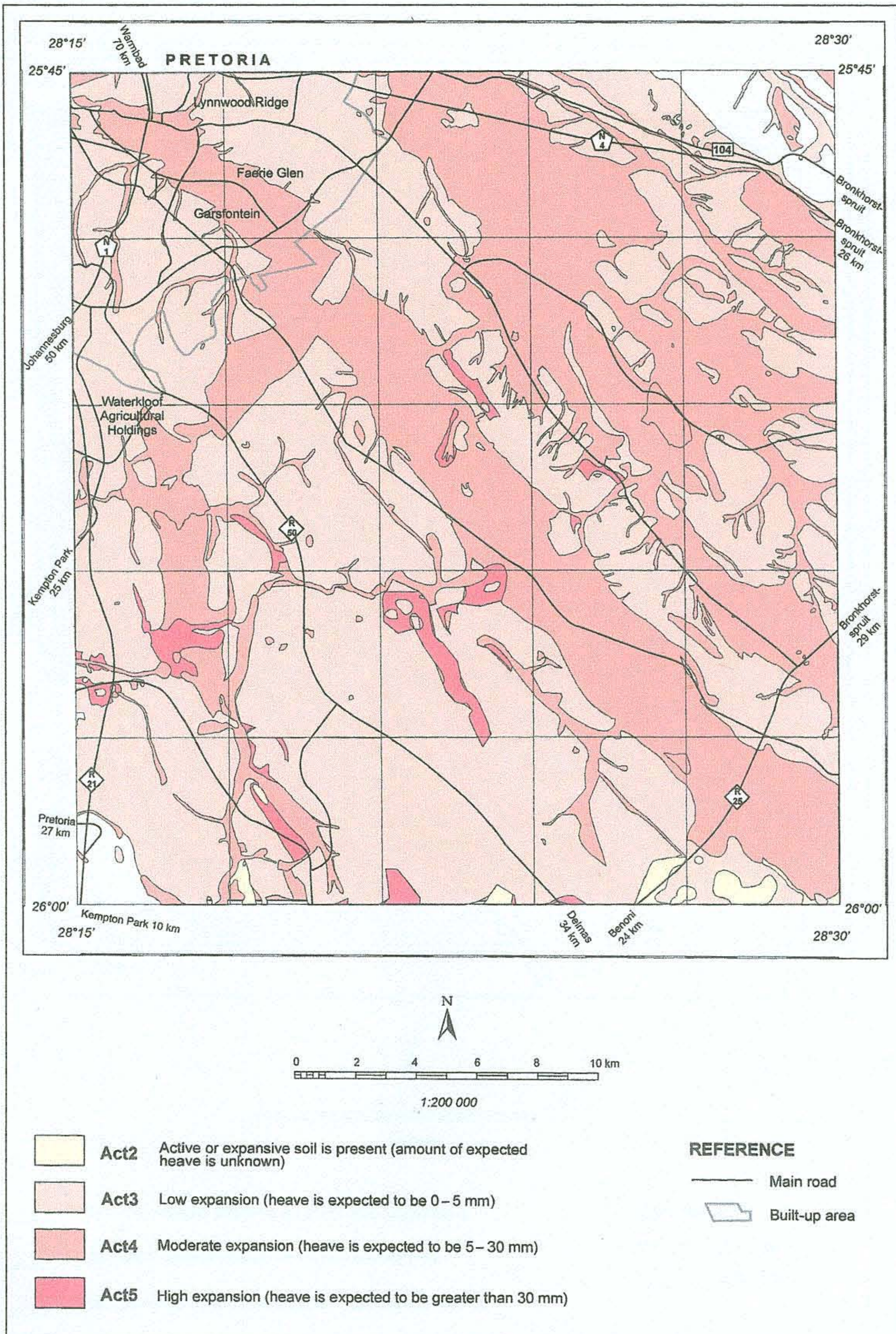
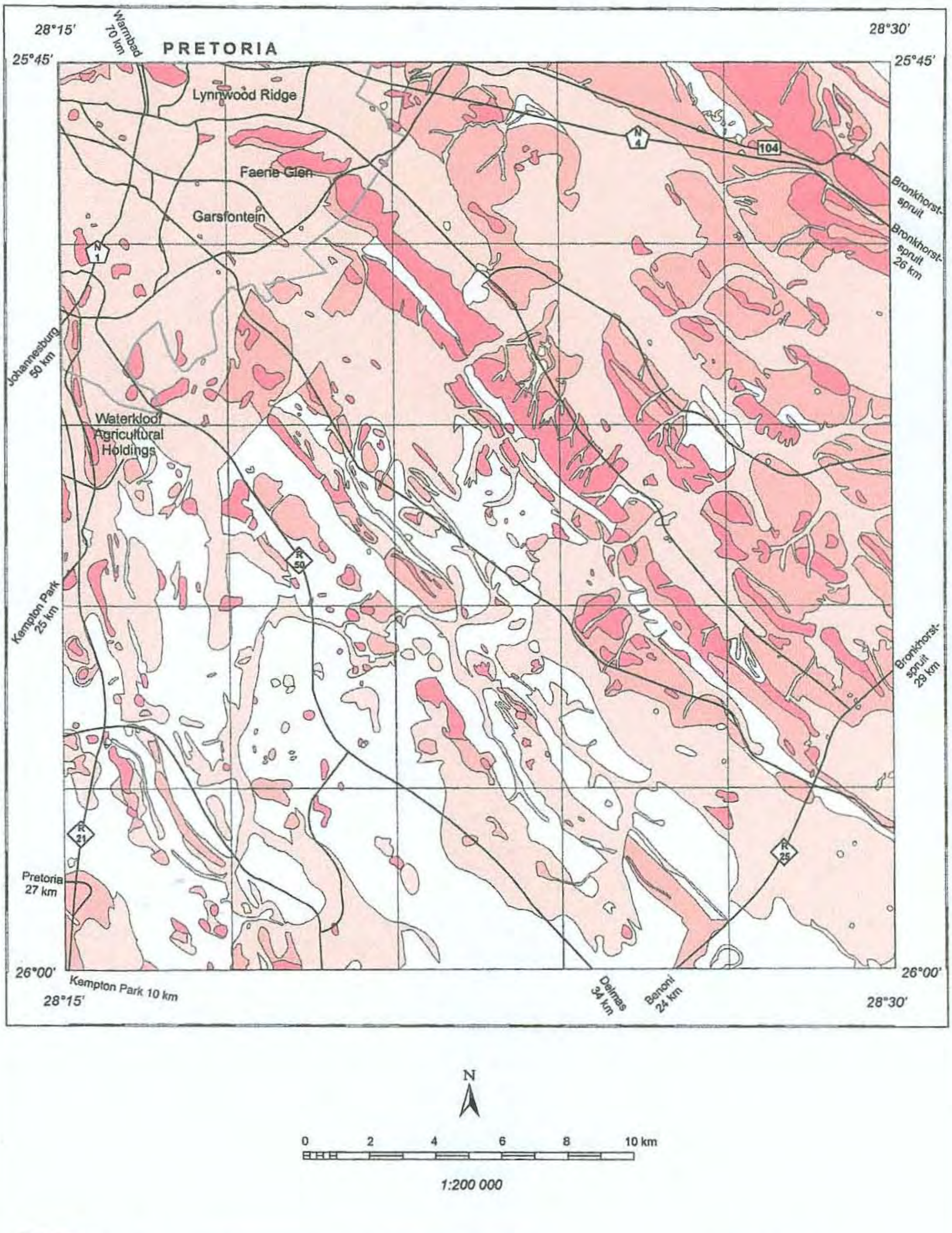


Figure 19: The area covered by potentially collapsible soils and the severity classes thereof in the Rietvleiam 2528 CD map sheet



	Exc2	Excavatibility problems are anticipated (unspecified)
	Exc3	Slight excavatibility problems (can be hand dug).
	Exc4	Moderate excavatibility problems (backactor is required)
	Exc5	Severe excavatibility problems (blasting and/or power tools are required)

REFERENCE

Main road

Built-up area

Figure 20: The excavatability characteristics of the soil and the severity classes thereof in the Rietvleiam 2528 CD map sheet area

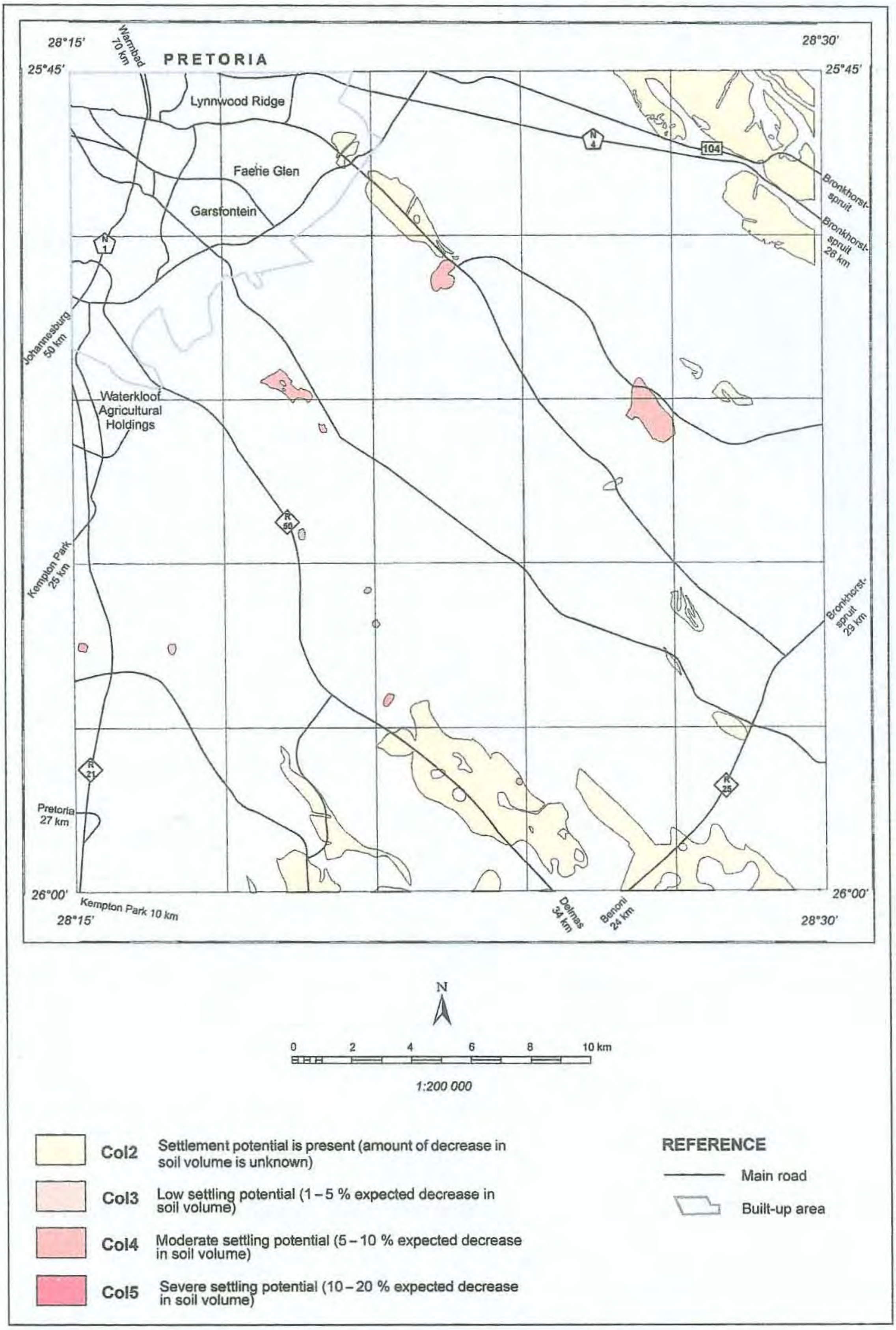


Figure 21: The area covered by potentially collapsible soils and the severity classes thereof in the Rietvleiam 2528 CD map sheet area

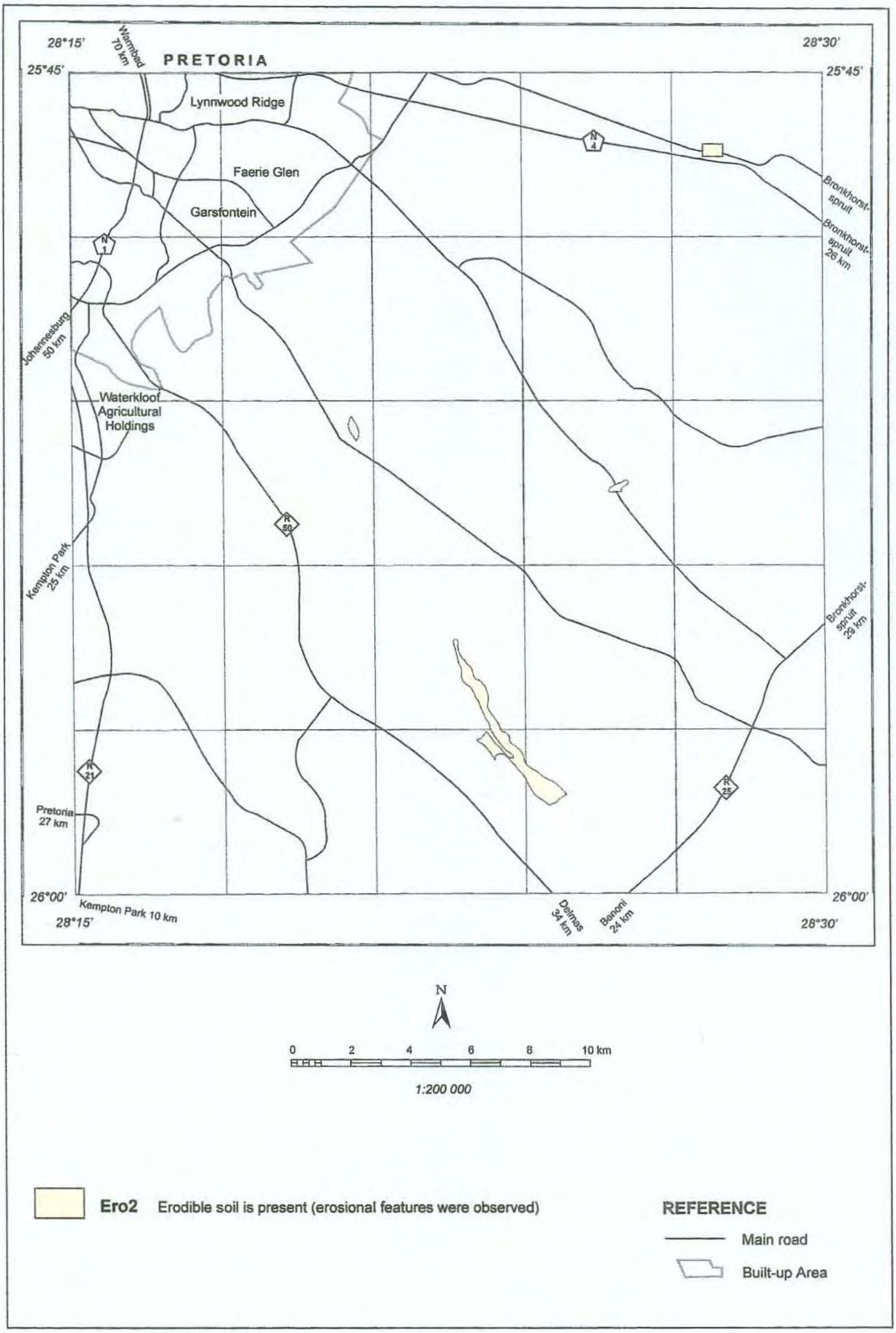


Figure 22: The area that exhibit erodible soils in the Rietvlei Dam 2528 CD map sheet

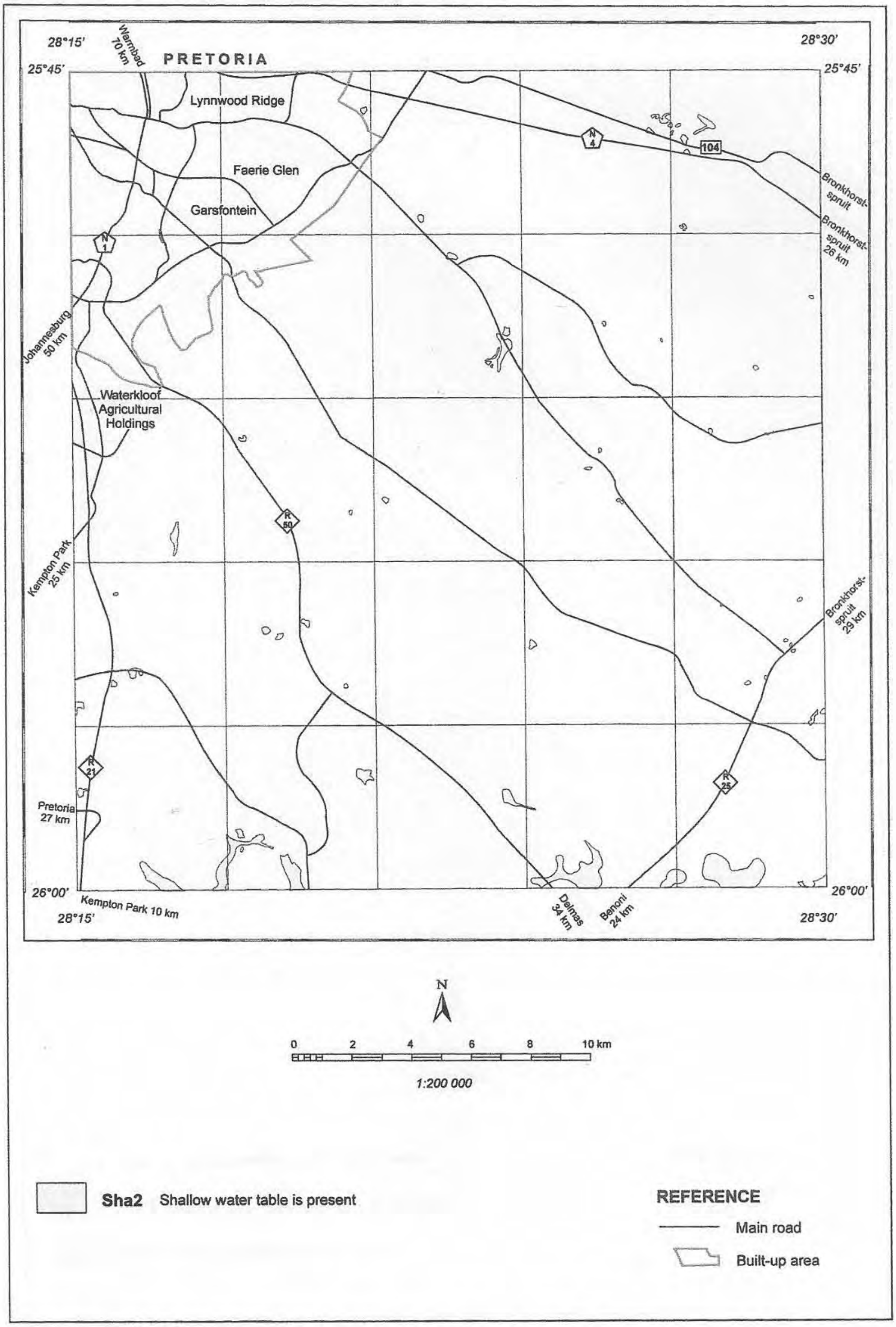


Figure 23: The area that exhibit a shallow water table in the Rietvleiam 2528 CD map sheet

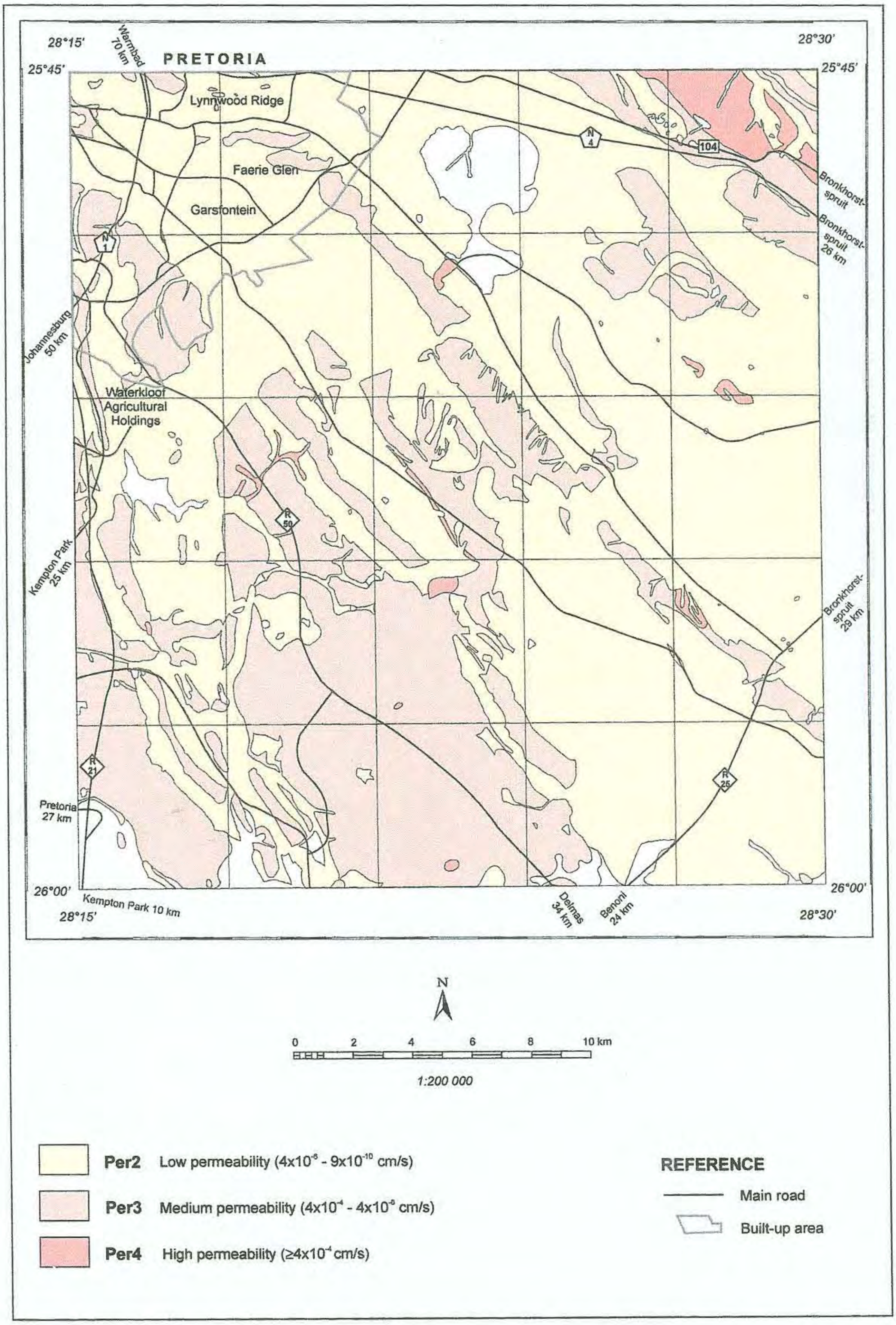


Figure 24: The expected permeability of the soils in the Rietvleiam 2528 CD map sheet area