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):

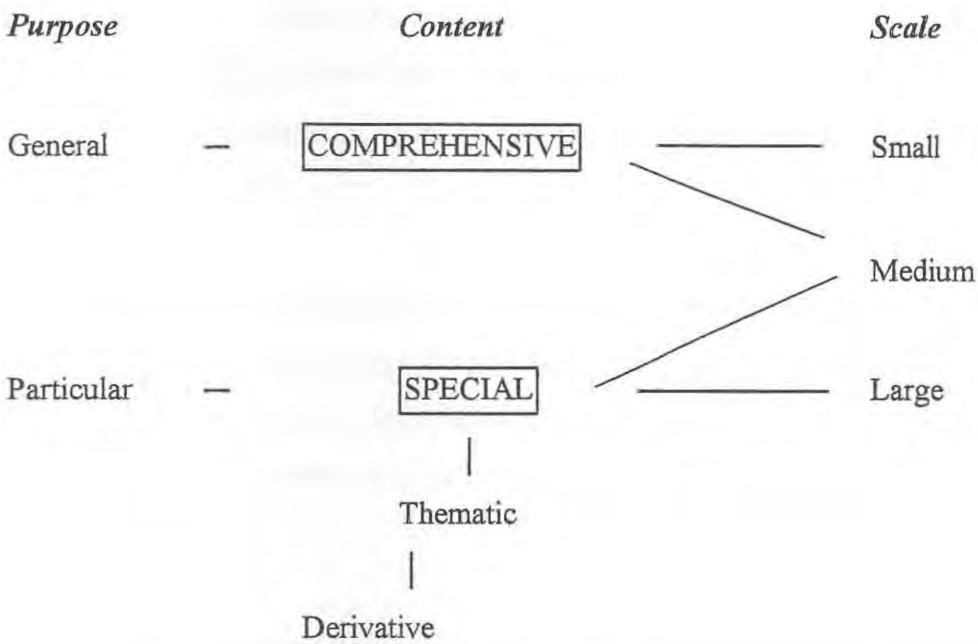

Diagram 1: Interrelationships of the various types of maps (after Dearman, 19991).

- **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.