WATER RESEARCH COMMISSION

THE ROLE OF GEOGRAPHIC INFORMATION SYSTEMS AND INTEGRATED ENVIRONMENTAL MANAGEMENT IN THE LANDSCAPE PLANNING OF CATCHMENTS.

By

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FOREWORD

Man's development actions change the landscape as he alters the land for food production, transport, housing, communication, industry, energy production and recreation, to name but a few land uses.

There is strong evidence that ecologically unsuitable locations of human activities are responsible for a great many of the environmental dysfunctions that plague our society.

Environmental problems are often difficult to solve because their causes and effects are not easily understood. When attempts are made to analyse causes and effects, the principal challenge lies in the organization of information into a framework that is logical, technically and scientifically defensible, and easy to understand, maintain and communicate.

When planners and decision-makers attempt to solve complex problems before a comprehensive cause and effect analysis is performed, serious risks are involved. These risks, according to Armour & Williamson (1988) are, *inter alia*: greater reliance on subjective reasoning, a lessened chance for scoping an effective problem-solving approach, impaired recognition of the need for additional information to reach full understanding, increased chances of making unsound decisions and lastly, a lessened chance of gaining approval and financial support for a project. This is also the case with the planning and management of catchments.

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In the writing of this study, the following publications were consulted for grammar and spelling:

1. The Concise Oxford Dictionary of Current English. 7th Edition. Oxford University Press. Oxford.
2. Hart's Rules for Compositors and Readers. Oxford University Press. Oxford.
3. The Oxford Dictionary for Writers and Editors. Clarendon Press. Oxford.
4. Fowler's Modern English Usage. 2nd Edition. Oxford University Press. Oxford.
5. Chambers Science and Technology Dictionary. The Chaucer Press. Suffolk.

The Harvard system is used for referencing.

ABSTRACT

The role of geographic information systems and integrated environmental management in the landscape planning of catchments

by

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The first part of this study explains the background of the goal, namely to model a procedure for evaluating environmental effects stemming from changes in land use and aiding planning decision-making. The river catchment is seen as a convenient geographic unit within which the planning process could be set.

Secondly GIS is described as a tool with which to present and manipulate data on natural resources (all of which act in unison as components of the natural hydrological cycle).

The study also attempts to classify and present data on natural resources in a way compatible with computerized GISs.
Thirdly the issue of integrated environmental management (as proposed by the Council for the Environment) is discussed as this forms the backdrop against which man's actions such as policy statements,

development programmes and projects which all influence our environment, should be measured.
In the last part a model is developed which allows us to note what man's needs are with regard to developments and policies and then to examine what natur's reaction to these proposals will be.

Ideally this examination should lead to various alternate solutions to the problem. Each solution can then be evaluated against various preset parameters and conditions and through a number of iterations should lead us to an optimum solution.

UITTREKSEL

Die rol van geografiese inligtingstelsels en geïntegreerde omgewingsbestuur in die landskapsbeplanning van opvanggebiede

deur

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Die eerste deel van hierdie studie verduidelik die agtergrond van die doelstelling, naamlik om 'n prosedure waarmee omgewingsinvloede wat voortspruit uit veranderings in grondgebruik geëvalueer kan word, te modelleer en wat ook vir besluitnemingsaksies tydens beplanning gebruik kan word. Die rivier-opvanggebied word in hierdie studie beskou as 'n geskikte en gerieflike geografiese eenheid vir die beskrywing van die beplanningsproses.

Tweedens word geografiese inligtingstelsels beskryf as 'n hulpmiddel waarmee data oor natuurlike hulpbronne (wat almal gesamentlik optree as komponente van die natuurlike hidrologiese siklus) voorgestel en manipuleer kan word.

In hierdie studie word ook gepoog om natuurlike hulpbrondata te klassifiseer en op 'n manier wat met gerekenariseerde geografiese inligtingstelsels versoenbaar is, voor te stel.

Derdens word die saak van geïntegreerde omgewingsbestuur (soos voorgestel deur die Raad op die Omgewing) bespreek aangesien dit die

agtergrond vorm waarteen die mens se aksies soos beleidstellings, ontwikkelingsprogramme en -projekte, wat almal die omgewing beïnvloed, gemeet word.

In die laaste deel van die studie is 'n model ontwikkel wat ons toelaat om van die mens se ontwikkelingsbehoeftes kennis te neem en dan vas te stel wat die natuur se reaksie teenoor hierdie voorstelle sal wees.

Dit word as die ideaal beskou dat hierdie ondersoek sal lei tot verskeie alternatiewe oplossings vir die probleem. Elke oplossing kan dan teen sekere vooraf vasgestelde parameters en voorwaardes geëvalueer word en deur verskeie herhalings van hierdie stappe kan ons gelei word na 'n optimale oplossing.

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CHAPTER 1. INTRODUCTION

1. STATEMENT OF PROBLEM

1.1 In South Africa, which is semi-arid, water availability is distributed disproportionately in time and space relative to changing needs (Conley, 1989).

As agriculture is the major land-user category in the RSA, an important consequence of agricultural development is the reduction in the type and/or amount of vegetation protecting the landscape (Aveyard & Sutherland in Scotney, 1988). Scotney (1988) further finds that this manipulation of many ecosystems has inevitably led to accelerated soil degradation, increased runoff and sediment loads and a growing contribution to nonpoint-sources of water pollution.

1.2 Historically the South African practices of environmental economics have been inadequate. Walmsley (1989) suggests that the custodians of the 'free goods of the environment' have not quantified the economic or social values of what they are protecting and therefore it becomes difficult to compete for resources (e.g. water resources and funding) with parties such as commerce, industry and agriculture, who can provide such values.

Traditionally these latter parties have over-utilized natural assets which have been treated as 'free goods' in the costing of their activities. The full value to society of those activities which negatively affect the environment is therefore not reflected in most costing calculations.

1.3 South Africa is facing a water supply crisis caused by a combination of factors, *inter alia*: low rainfall, high evaporation rates, and a growing population whose geographical demands do not conform to the distribution of existing exploitable water supplies (O'Keeffe, 1986a).

In recent years man's demand for natural resources, of which water can be considered most important, has increased dramatically, to the point where more and more shortages can be anticipated in critical areas. The present excessive consumption of our natural resources is having a detrimental effect on our environment. With this realization, man is becoming increasingly aware of the need for a better and integrated management of planet Earth's resources.

1.4 South Africa could be described as a basically water-poor country because of its relatively low total rainfall and especially the erratic nature of this rainfall. The Hydrological Research Institute (HRI)(1985) suggests that as competition for this scarce resource is increasing, more attention should be directed to management of the catchment, rather than the watercourse itself, as the source of water.

1.5 O'Keeffe (1986b) identified the major uses, misuses and the resultant damage to river catchment systems, namely:

1.5.1 AGRICULTURE (abstracts 73% of the total amount of water used in the RSA)

- Indiscriminate abstraction adversely reduces river flow.
- Destruction of riparian vegetation which plays an important role in river bank stabilization and which forms an integral part of river ecosystems.

- Increased sediment load caused by vegetation denudation, overgrazing, accelerated erosion, catchment mismanagement and cultivation.
- Deterioration of water quality caused by intensive irrigation which leads to salination of runoff and also by over-fertilization.

1.5.2 URBAN COMPLEXES (domestic water use comprises 8% of the total amount of water used in the RSA)

Urban complexes usually require some form of water storage, and these could have a marked affect on the downstream environment. Urban communities also generate huge quantities of waste, some of which could find its way into rivers.

- Reduced river flow. The magnitude of this effect can be ameliorated by water releases from impoundments.
- Storm-water drainage. Urban environments generally generate more run-off through the hardening of surfaces e.g. tarmac, roofs, etc. This runoff is mostly polluted by various substances occurring in a typical urban area.
- Sewage effluent. Urban sewage treatment works often do not keep up with rapidly expanding urban developments, leading to effluent high in plant nutrients and in turn leading to eutrophication.
- Urban refuse. Seepage from urban refuse dumping areas, normally located in valleys as land-fill, is highly polluted, containing pathogens and toxins.

1.5.3 POPULATION CONCENTRATIONS IN RURAL AREAS

- In the South African rural areas, many populations live in squatter and quasi-urban conditions near or along watercourses. These water resources are utilized not only as domestic water supply and irrigation for subsistence agriculture, but also as a sewage disposal system.

1.5.4 INDUSTRY

- Industrial development depends largely on energy, labour and water. The water resources near industries are utilized in a consumptive manner as well as for effluent disposal.
- Electricity production. In South Africa most of the electricity supply is generated at coal-based power plants and a nuclear plant. In both these methods water is used for cooling purposes, leading to thermal pollution of the water resources.
- Mining. Mining, being one of South Africa's major industries, requires huge volumes of water in most of the mineral extraction processes. Effluent resulting from these processes as well as seepage from mines are generally highly toxic and contain high levels of sulphuric and nitric acids.

1.5.5 RECREATION

- Much of South Africa's recreational activities are concentrated around inland waters. Dams and rivers are popular recreational spots and people come into direct contact with these waters. Contaminated water may therefore adversely affect the user's health.

2. MOTIVATION

The environmental problems described in sections 1.1 to 1.5 above and which are caused mainly by changes in land use, act as motivation for this study which will investigate methods and models for the landscape planning and management of catchments.

3. GOALS AND OBJECTIVES

3.1 Goal

The goal of this study therefore, is to develop a conceptual model to evaluate the environmental effect of changes in land use and development projects on the ecology of catchments, and to aid decision-making.

3.2 Objectives

To reach the stated goal, the following five main objectives are identified:

3.2.1 To understand the problems and issues involved in the planning and management of water resources in changing catchments. This is dealt with in Section 1 pp. 1-4.

3.2.2 To understand the role of computerized Geographic Information Systems (GIS) in such a decision-making model. In Chapter 2 this role is explained and expanded upon.

3.2.3 To understand the proposed Integrated Environmental Management (IEM) procedure as an aid to decision-making. The whole issue of IEM is dealt with in Chapter 3.

3.2.4 To understand the ecology of catchments. Under this broad heading is meant the nature of the hydrological cycle and the identification and categorization of critical natural processes and functions occurring in catchments. These natural processes and functions are discussed in Chapter 4. In Chapter 5 and Appendix E the critical data categories are identified and a classification system is proposed.

3.2.5 To develop a conceptual landscape planning model. In Chapter 6 this model is presented.

4. METHOD OF STUDY

The first step in the development of the model is to analyse and understand the problems involved in the planning and management of water resources in changing catchments.

The second step is to investigate the role which can be played by a computerized GIS in storing, displaying and manipulating natural and cultural data. GIS has become an essential tool for the management of environmental data and is especially useful in displaying and evaluating possible effects of development.

The third step is to develop an understanding of the IEM procedures as proposed by the Council for the Environment. The main purpose of this step is to aid decision-making with regard to the influence of development on the environment.

The fourth step is more specific and refers to an understanding of the ecology of catchments and the hydrological cycle. This knowledge is regarded as essential because the planning model is developed particularly for catchments. In order to facilitate the use of a GIS in the planning model, all natural and cultural data categories relating to catchments must be analised and represented in a GIS. Data classification presents one of the most important problems to the GIS user. It is felt that the extended section on natural data categories and classification, although necessary, could detract from the logical flow of the study and is therefore dealt with in Appendix E.

The last step in this study is the development of a conceptual landscape planning model. This involves, with the aid of GIS, integration of the IEM procedure with the opportunities and constraints of nature as well as with the landscape planning and management goals, resulting in a procedure which will aid decision-making. This will allow and guide development while at the same time conserving ecological values and resources.

5. GLOSSARY OF TERMS

The advent of computers and their application to natural resources related issues by means of GIS have led to a vocabulary that needs clarification to the uninitiated. In Appendix A p.167, a glossary of selected terms is presented.

6. REVIEW OF LITERATURE

6.1 Chapter 2: Geographic Information Systems

Meintjes (1989: 158-187) and Clarke, Cooper, Liebenberg & Van Rooyen (1987: 140-163) provide fully comprehensive glossaries of commonly used GIS terminology.

Of all central government departments it would appear that the Department of Water Affairs (DWA) has proceeded the furthest along the GIS road. Papers, memoranda and various other publications originating from their Directorate of Strategic Planning provided very useful references.

The Council for Scientific and Industrial Research (CSIR) (Clarke, *et al.*, 1987) have done pioneering work in the RSA with their proposed national standard for the exchange of digital geo-referenced information. Their approach was used in this study as a basis from which further developments flowed.

Computer companies with GIS interests, both in hardware and software, have over the past five years introduced the GIS concept to potential users in the RSA and have on occasion adapted GIS programmes sourced in the USA and Europe, for local conditions and applications. Publications by these GIS vendors were also sources of reference.

International conferences on GIS have been held in the USA and Europe since the 1970s and the proceedings of some of these conferences were invaluable sources of information. The first comprehensive conference on GIS in southern Africa (SAGIS 89) was held at the University of Natal (Pietermaritzburg) from 3 to 6 July 1989. Papers presented at this conference showed the extent to which the concept of GIS has been accepted and implemented in South Africa.

6.2 Chapter 3: Integrated Environmental Management

A new-found world-wide realization and appreciation of environmental issues, especially environmental degradation and pollution, have led to various governments, organizations and individuals to adopt an approach in which the environment is to be managed in an integrated, responsible manner.

In South Africa the Environment Conservation Act (Act 73 of 1989) was promulgated in June 1989. This Act has many implications for authorities, private companies and the individual, some of which are favourably accepted but some of which generated resistance, even at a very early stage.

Comments, treatises, conference papers and conference proceedings on the Act and the Integrated Environmental Management (IEM) procedure proposed by the Council for the Environment provided most of the literature reviewed for this chapter.

The IEM procedure (Council for the Environment, 1989) is integrated in the conceptual landscape planning model proposed in Chapter 6.

6.3 Chapter 4: The Hydrological cycle

An understanding of the natural hydrological processes (hydrological cycle) was considered a necessary prerequisite to arrive at a synthesis for catchment planning and management.

Basic hydrological issues such as ground water, surface-water, hydrography, sediment production and water quality as well as catchment morphology are covered in many publications. Dunne & Leopold

(1978); Leopold (1968) and Hewlett & Nutter (1969) were the main sources of information consulted in this regard.

The HRI (1985) did a pilot study on integrated catchment management in the upper Mooi and Mgeni catchments in Natal and their guide-lines and recommendations provided valuable insight.

Contributors to the river research programme under the auspices of the Foundation for Research Development (FRD) at the CSIR have published several scientific reports and these reflect the status of ecological research in South Africa. While none of these reports concern catchment planning specifically, they are nevertheless frequently referred to in this study.

McHarg (1969) is considered one of the pioneers in the ecology-based planning approach and even today, although his manual overlay techniques have been made easier with the advent of computer graphics, his underlying planning approach remains valid and is used in this study.

6.4 Chapter 5 and Appendix E: Critical data categories and classification systems for use with a GIS

6.4.1 CHAPTER 5

Scheepers (1987) proposed certain fundamental considerations concerning the classification of geo-referenced ecological data. The main groups or classes of data required for a GIS on catchments as proposed by De Meijere & Van de Putte (1987) is used as basis for the proposed classification system in this study. (See Appendix E.)

Clarke, *et al*. (1987) propose a national exchange standard (NES) for digital geo-referenced information in the RSA and although some criticism is expressed against their proposal, it is nevertheless considered a welcome first step in this country to put the data-exchange issue in some order and it is also frequently referred to in this study. The DWA (1989) developed their own classification scheme for geo-referenced data for use in their GIS and certain sections of this scheme are included in the proposal in Appendix E.

6.4.2 APPENDIX E

6.4.2.1 Geology

The South African Committee for Stratigraphy (SACS)(1980) lists and describes the various lithological classification approaches in use in South Africa. However, due to the fact that the lithostratigraphic classification system is considered most applicable for the purposes of this study, it is discussed in more detail, most of which was taken from SACS. Clarke, *et al.* (1987) provided an approach to the classification of geology which is aimed specifically at a GIS.

6.4.2.2 Climate and meteorology

Werger (Editor)(1978) provides a fully comprehensive work on climate as a component of his biogeographical and ecological studies of southern Africa. From this work by Werger, the section by Schulze & McGee (1978) on southern African climate was an invaluable source of information.

In the work by Schulze (1965) which contains a summary of the main characteristics of the surface climate of South Africa which were taken from eight other Weather Bureau publications, a wealth of climate statistics are shown. Solar radiation, cloudiness, surface temperature, humidity of the air, evaporation, winds, precipitation and climatic regions are discussed in this work. Whereas certain of these climate factors can be spatially depicted as isolines, the temporal data which form the bases for these maps, should and must be accommodated as non-spatial attributes of the spatial features.

6.4.2.3 Geomorphology

King (1967) provides a very comprehensive study on the geomorphology of southern Africa and his classification of geomorphological regions on this subcontinent is subscribed to in this study. Cooks (1987) describes the fundamental issues of geomorphology and from his study basic landforms are recognized and used as input for a proposed classification system for geomorphology. Clarke, *et al.* (1987) provided the initial classification upon which this study expands.

6.4.2.4 Pedology

From available literature on the classification of South African soils and from discussions with pedologists currently involved in proposed changes to the binomial soil classification of Macvicar, De Villiers, Loxton, Verster, Lambrechts, Merryweather, Le Roux, Van Rooyen & Von M. Harmse (1977), it is clear that we are not yet at the point of having a soil classification system acceptable to all and which comprehensively covers the state of our current knowledge of soils. The proposed changes to the system of Macvicar, *et al.* (1977) are accommodated in this study's proposal on soil classification.

Attention is also given to the land type maps and associated memoirs made available by the Land Type Survey Staff in South Africa.

Schulze (1985a) and Schulze, Hutson & Cass (1985) provide works on the hydrological characteristics of soils and this study borrows heavily from some of these works.

The soil classification approach of the FAO and its application in South Africa by Von M. Harmse (1978), as well as the soil suitability mapping approach of the United States Department of Agriculture - Soil Conservation Service (USDA-SCS), are covered in this study.

As Clarke, *et al.* (1987) did not attempt to classify soil according to a system of spatial features and associated attributes, the soil classification approach in this study is based primarily on work done by Dohse (1989).

6.4.2.5 Hydrology and hydrography

For the purpose of this study attention is given primarily to spatial hydrological features which can be represented on a map.

Various authors (in O'Keeffe, 1986b) classified South African rivers according to certain geomorphological characteristics, and as such there is some overlapping of the proposed classifications of geomorphology and hydrology. The classification systems proposed by the DWA (cf. Appendix C p. 178) and by Clarke, *et al.* (1987) (cf. Appendix B p. 169) are used as bases in the proposed hydrology classification.

6.4.2.6 Vegetation

Acocks' work was recently revised and republished (Acocks, 1988) and remains one of the most authoritative works on the mapping of southern African vegetation; frequent reference is made to this work. The biome classification approach of Rutherford & Westfall (1986) is used in this study to define spatial units of the first order.

Various other South African authors (Coetzee, 1983; Edwards, 1983 and Bredenkamp & Theron, 1985) worked on different vegetation classification approaches and reference is made in this study to some of these. However, it is suggested in this study that the classifications resulting from most of these studies should be accommodated as non-spatial attributes of spatial features as defined by Acocks (1988) and Rutherford & Westfall (1986).

6.4.2.7 Zoology

Rutherford & Westfall (1986) came to the conclusion that there are little data available on the distribution of most zoological taxa in southern Africa, particularly the distribution of ecologically functional groups. Deshmukh (1986) provides a concise definition of the ecological grouping's hierarchy *viz.:* organism, population, community and ecosystem.

Rutherford & Westfall (1986) refer to several authors who found that vegetation types do not necessarily determine animal distribution, but others (Smith, 1974 and Farrell, Van Riet & Tinley, 1978) nevertheless suggest vegetation formations as prime determinators of animal species distribution. The work of Clarke, *et al.* (1987) on biological classification is also referred to in this study's proposed zoological classification.

6.4.2.8 Land use and land cover

In the USA, authors such as Anderson, Hardy, Roach & Witmer (1976) and Jensen (1983) have done much work in establishing classification systems for land use and land cover (LULC), which are widely accepted. These systems are adapted to fit the land use classification category proposed in this study.

The advent of remote-sensing satellites and computers to manipulate the mass of digital data emanating from these sensors, have resulted in a proliferance of research on the beneficial application of this data (Shih, 1988; Jensen, 1983 and Dulaney, 1987). The section on land use classification from Clarke, *et al.* (1987) is also incorporated, with some modification, in the system proposed in this study.

6.5 Chapter 6: A conceptual landscape planning model

Lyle & Stutz (1987) come to the conclusion that literature on land use planning methods is scarce. They find that this is partly due to relatively little work having been done on definite planning methodology.

McHarg's (1969) work during the late 1960s of overlaying maps to eventually produce thematic maps indicating best or optimum solutions is considered systematic and scientifically sound. Some of the criticism against his work will be discussed later.

Also in the 1960s, Steinitz and his colleagues, as reported in Lyle & Stutz (1987), developed a modelling concept for urbanization based on the resolution of 'attractiveness' factors, which make a site desirable for urban uses and 'vulnerability' factors, which deal with ecological effect. The principal difference between most of these earlier deterministic approaches and the approach presented in this study, is the concept that map overlays alone should not lead directly to a site or development plan. A series of modelling steps should rather be applied to define the interaction between data describing geographically distributed variable and weighted values relating to given land use parameters. The resultant maps and other information should provide the basis for decisions that shape our landscape. This approach is clearly spelt out and applied in the work of Van Riet (1987).

CHAPTER 2. GEOGRAPHIC INFORMATION SYSTEMS (GIS)

1. INTRODUCTION

Traditional data handling methods can no longer cope with modern collection techniques such as remote sensing, aerial photography, electronic field books and telemetry, all of which can produce overwhelming volumes of data (Conley, 1989). Correspondingly therefore, advanced methods of data analysis and portrayal, as are possible with a GIS, are essential to obtain the maximum benefit from these new techniques.

In the past most of the water related management, planning and development issues were dealt with by the DWA using their own accumulated and centralized data. In contrast to this Conley (1989) finds that with increasing international water sharing, the growth of regional authorities and privatization, more people, including professional planners and decision-makers, are becoming involved with water related issues. As most of these people do not have access to all the data necessary for maintaining an overview of the whole situation, the DWA has developed facilities such as computerized data bases, a computerized geographical information system and interactive decision support systems to allow, among others, professional consultants to do water related planning.

Conley (1989) explains the purpose of these facilities as follows:

* Data bases: To record facts and, by means of computers, improve the convenience of data retrieval.
* Geographical information systems: To allow the combination of data sets in suitable interpretative relationships or models, thereby

generating new information not contained in the individual data sets.

* Interactive decision support systems: To encourage the user to hypothesize and create alternative scenarios to determine what would happen if data sets or modelling parameters are varied or new ones introduced.

The DWA hopes to eventually reach a situation where any data required for water management and planning can be conveniently recalled and analysed at interactive work-stations (Conley, 1989). These actions typically include the following:

* Calling up the catchment of interest.
* Recalling hydrological data pertaining to that catchment.
* Creating alternative scenarios in which the following aspects can be investigated:

- siting of proposed developments;
- water availability;
- water rights;
- property ownership;
- conflicts with international factors;
- conflicts with environmental factors;
- conflicts with existing amenities;
- control by various authorities;
- demographic, agricultural and industrial trends affecting water use;
- rainfall, runoff and evaporation relationships;
- crop suitablility and plant-water requirements;
- geology and soil types;
- yield of dam and river systems;
- water quality;
- flood limits;

- servitude and compensation costs;
- design and costing alternatives; and
- financial, economic, benefit-cost and socio-economic analyses.

Conley (1989) finds that in a true GIS, the essence of the system is the ability to manipulate the data in a data base rather than the manipulation of graphic elements.

GISs have been proved suitable for running and displaying results of hydrological models such as rainfall runoff prediction, agrohydrological, eutrophication, salinity and system operations as well as orthogonal contouring, derived from digital terrain modelling (DTM).

2. THE ORIGINS OF GEOGRAPHIC INFORMATION SYSTEMS

The use of computers for alphanumeric information processing has been in operation for many years and since the 1960s computers were also used to present spatially oriented data.

During the 1980s the increasing use of computer-aided drafting (CAD) systems allowed architects, engineers and planners to visually present and edit geometric forms.

Such forms, however, did not allow the user to associate the necessary intelligence or attributes with any such drawing entity. Lines that depicted roads were still only lines, even though it could have different annotations and colours.

The user still had to interpret the line as being a road, with the result that no spatial calculations could be done on any captured mapping feature (Poolman, 1989).

Meintjes (1989: 25-37) describes the differences in structure and application between GIS and CAD in much detail.

3. DEFINITION OF A GEOGRAPHIC INFORMATION SYSTEM (GIS)

Geographic Information Systems (GIS) are those systems that allow the user to combine spatial data in the form of maps, plans, charts and non-spatial data (associated attributes) in a single interactive computerized system.

GIS is furthermore an integrating technology. It intersects and combines many different disciplines and professions. The latter includes civil engineering, landscape architecture, land surveying, remote sensing, hydrology, geology, pedology, biology and climatology. The integration of data on the basis of location, provides the user with a manipulatable abstract model of a real world situation.

The premise of a GIS is a geographically and topologically related collection of data, manipulated by means of various data base manipulation tools including programming languages, report generators and query facilities (Poolman, 1989).

Poh-Chin Lai (1988) describes a GIS as a computer-assisted and integrated environment for the creation, storage, retrieval, management, manipulation, analysis and display of geographical data.

Another definition of a GIS comes from Dueker (1987):
'a special type of information system in which the data base consists of (1) observations on spatially distributed features, activities or events, which are definable as points, lines or areas; and (2) procedures to collect, store, retrieve, analyse and display such geographic data'.

A GIS can be described as a computerized geographic mapping and alphanumeric data base managed by relevant software. It allows interactive capturing, management, manipulation and analysis of data and the presentation of data in graphical and non-graphical forms on screens and other devices such as plotters, printers, cameras and storage media (Conley, 1989).

4. COMPONENTS OF A GEOGRAPHIC INFORMATION SYSTEM

Any GIS normally contains the following major components (Marble, 1987; Teicholz & Berry, 1983).

* A data input subsystem which collects and/or processes spatial data derived from existing maps, remote sensors, etc.

* A data storage and retrieval subsystem which organizes the spatial data in a form which permits it to be quickly retrieved by the user for subsequent analysis, as well as permitting rapid and accurate updates and corrections to be made to the spatial data base.

* A data manipulation and analysis subsystem which performs a variety of tasks such as changing the form of the data through user-defined aggregation rules or producing estimates of parameters and constraints for various space-time optimization or simulation models.

* A data reporting subsystem which is capable of displaying all or part of the original data base as well as manipulated data and the output from spatial models in tabular or map form. The creation of these map displays involves what is called digital or computer cartography. This is an area which represents a considerable conceptual extension of traditional cartographic approaches as well as a substantial change in the tools utilized in creating the cartographic displays.

A significant reason for the growth of computer graphics lies in its role in the decision-making process. Information can be both digested and understood more easily when presented visually. Teicholz & Berry (1983) find that trends and anomalies in data are more readily discerned when information is rendered in graphic as opposed to numeric or tabular form.

In Figure 2.1 a schematic representation of the concept of a GIS is shown.

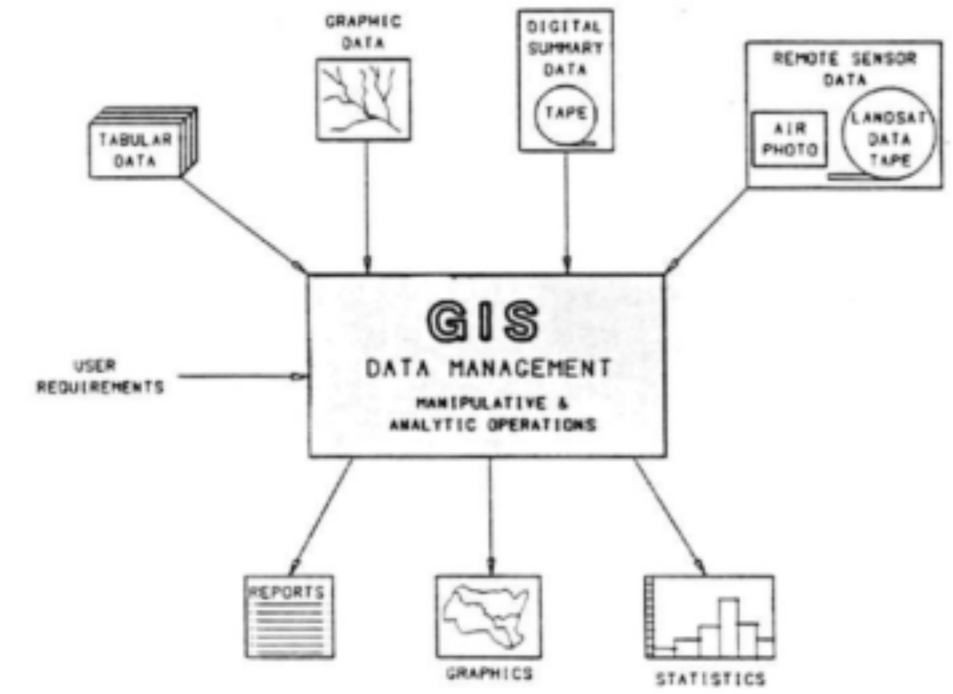


FIGURE 2.1: A SCHEMATIC REPRESENTATION OF THE CONCEPT OF A GIS
(KNAPP & RIDER AND TAKEN FROM TEICHOLTZ & BERRY, 1983)

A computer-based GIS is specifically made up from both the applications software (computer programme) and suitable hardware (computer) (Poolman, 1989). Added to these are the data bases and, as important, the people who manipulate the system in order to meet a specific set of objectives.

The large volumes and diversity in GIS data demand the use of a powerful data base management system to allow the user to be in a position from which to properly manage it. The spatial and graphics component of a GIS differs substantially from a CAD system in that a different data structuring system is used. Points and co-ordinates, as found in any CAD system, are represented by <u>nodes</u> in a GIS while common boundaries or line features are represented by <u>chains</u>.

Area-type features will consist of an enclosed polygon formed by <u>nodes</u> and <u>chains</u> which have direction, with the result that topological queries that relate to the left, right, inside or outside of a given feature can be investigated (Poolman, 1989).

Composite extractions, based on any combination of spatial and/or non-spatial attributes and queries, of both spatial and non-spatial attributes, are also features of a true GIS.

Polygons, lines or point features can, according to Brown (1986), be used in a GIS to delimit the following:

* Polygons:
  Land use, watersheds, soils, geology (surface and subsurface), terrain features, landownership, political and administrative boundaries.
* Line features:
  Roads, streams, infrastructure, contours and seismic lines.

* Point features:

  Landmarks, wells, infrastructure, area features too small to show as polygons and spot heights.

4.1 Features, attributes and topology

Features have spatial, i.e. fixed in time and space, and non-spatial, i.e. descriptive components, known as the attributes of the feature.

Properties or attributes can be associated with features such as drawing entities. This is useful for extracting and reporting purposes but the essential limitation remains the lack of topology. This refers to the spatial relationship between features such as points, lines and areas and the ability of the system to make topological deductions in terms of the spatial relationship between features.

Spatial analysis, when applied in any planning analysis, uses geometric manipulation to test whether specific points are within or outside the study area; whether points or areas are within a specified distance of say a road or river; or whether logical spatial relationships exist among features, e.g. whether points are connected, areas are adjacent, or lines form boundaries to specific polygon types. Meintjes (1989) finds that these functions and analyses are virtually impossible to perform in CAD.

Clarke, *et al.* (1987) emphasize the need for any GIS data base to provide a topological structure for spatial data, i.e. a structure that explicitly encodes the spatial relationships inherent in the data.

Clarke, *et al.* (1987) provide for two topological relations in their NES, namely:

* coincidence (refers to the sharing of spatial attributes, e.g. a shared boundary between two adjacent farms);
* exclusion (caters for area features that exclude contained 'islands', e.g. an island in a dam).

4.2 Raster and vector data

GISs utilize spatial data (features) in either raster or vector form, and some even in both.

Features may be created and displayed in vector form, i.e. positional data recorded as co-ordinate tuples forming nodes and chains or in raster form, i.e. data expressed as a tessellation of cells, with spatial position implicit in the ordering of the cells.

Remotely-sensed data usually come in raster format whereas manually-digitized data are normally in vector form. Software application programmes exist for automatic conversion of data from one format to the other.

The advantages and disadvantages of vector and raster data presentation are summarized by Burroughs (In Meintjes, 1989) as follows:

* Vector method advantages:
- good representation of phenomenological data structures;
- compact data storage;
- topology can be completely described with network linkages;
- accurate graphics; and
- retrieval, updating and generalization of graphics and attributes are possible.

* Vector method disadvantages:
- complex data structures;
- combination of several vector polygon maps or polygon and raster maps through overlay create difficulties;
- simulation is difficult because each spatial unit has a different topological form;
- display and plotting can be expensive, particularly for high quality, colour and cross-hatching;
- the technology is expensive, particularly for the more sophisticated software and hardware; and
- spatial analysis and filtering within polygons are impossible.

* Raster method advantages:
- simple data structure;
- the overlay and combination of mapped data with remotely-sensed data are easy;
- various kinds of spatial analyses are easy;
- simulation is easy because each spatial unit has the same size and shape; and
- the technology is inexpensive and is being developed further.

* Raster method disadvantages:
- volumes of graphic data;
- the use of large cells to reduce data volumes means that phenomenologically recognizable structures can be lost and there can be a serious loss of information;
- crude raster maps are considerably less attractive than maps drawn with fine lines;
- network linkages are difficult to establish; and

- projection transformation is time consuming unless spatial algorithms or hardware are used.

Meintjes (1989) concludes that raster and vector methods for spatial data structures constitute distinctly different approaches to modelling geographic information but seem to have become complementary in the modern GIS.

4.3 Digital elevation models

Any digital representation of the continuous variation of relief over space is known as a digital elevation model (DEM). Meintjes (1989) finds that this term is preferred to digital terrain model (DTM) for models containing only elevation data.

Although DEMs were originally developed for modelling relief, they can also be used to model or illustrate the continuous variation of any other attribute Z over a two-dimensional surface (Meintjes, 1989).

DEMs can be used for, *inter alia*:

* storage of elevation data for digital topographic maps in national data bases;
* cut-and-fill problems in road design and other civil engineering problems;
* three-dimensional display of land forms for landscape design and planning;
* analysis of cross-country visibility for landscape architecture purposes;
* planning routes of roads, location of water impoundments, etc.;
* computing slope maps, aspect maps and slope profiles that can be used to prepare shaded relief maps, assist geomorphological studies or estimate erosion and runoff; and

* replacing altitude with any other continuously varying attribute, to represent surfaces of, e.g. travel time, cost, population, indices of visual beauty, levels of pollution, etc.

Triangulated irregular network (TIN) is another method of elevation data display. In comparison to a DEM which uses a regular grid overlay over elevational points and then interpolates to generate a derived altitude matrix, the TIN is a terrain model that uses a sheet of continuous triangulated facets. Meintjes (1989) finds that unlike altitude matrices, the TIN allows extra information to be gathered on areas of complex relief. Consequently the data capturing process for a TIN can specifically follow ridges, streams, etc.

Burroughs (In Meintjes, 1989) suggests some other applications of DEMs in landscape architecture, such as:

* determining the boundaries of a catchment;
* determining catchment drainage networks;
* detecting ridge and stream lines;
* separating water-carrying from dry channels at different times of the year; and
* flood prediction and management.

5. METHODS OF DATA-CAPTURING FOR A GIS

Data, in a digital geo-referenced format, can be captured by a variety of methods, some of which include:

5.1 Manual digitization of existing analogue maps

5.2 Direct automated digitization of images captured by remote-sensing devices

Remote-sensing as a method of obtaining data includes the use of multi-spectral satellite imagery and aerial photography. Remote-sensing, however, is an indirect form of measurement which measures reflectance or radiation rather than specific hydrological parameters.

Conley (1989) finds that the use of satellite imagery reduces the tedium, time and cost of gathering and updating data with regard to the real-time management of water demands, updating inventories of land use and the current state of water resources. Other human activities can also be measured, such as increases in buildings, quarries, mines, waste dumps, roads and footpaths; all of which can contribute to erosion, increased runoff, pollution and sediment production.

According to Scotney (1988) remote-sensing systems, especially those which involve digital processing for use with GISs, offer many possibilities for making good the lack of adequate catchment information.

Remote-sensing, however, measures only the surface conditions that are being observed. It therefore follows that ground surface conditions, e.g. soils and geology cannot be accurately measured where there is ground cover such as forest vegetation.

Remote-sensing can be seen as a data source technology or an external array of information sources whereas GIS *per se* is a data processing technology also capable of internally generating data.

However, as Clarke, *et al.* (1987) point out, remotely-sensed data cannot be regarded as geo-referenced information until they have been geo-coded, regardless of what other processing may have taken place.

The reason for this is that information extracted from a remotely-sensed image prior to geo-coding is not in a form readily usable in a GIS.

5.3 Manual polygonization of aerial photographs

5.4 Automated rasterising of entire maps by electronic optical scanners

Data thus obtained can be converted to vector data by automated thinning of lines, extracting polygons and assigning labels.

6. USES OF GIS

Throughout the history of the development of GIS, the primary goal has been to take raw data and transform it, via overlays and other analytical operations, into new information which can support the decision-making process (Parent & Church, 1987).

GISs have their origin in the history of thematic cartography. Modern GIS evolved from the combination of increased computational capabilities, refined analytical techniques and a renewed interest in environmental and social responsibilities.

In a typical GIS, individually digitized topographic and cadastral features on a map can be stored separately, to be recalled in any combination required to emphasize important aspects.

Conley (1989) finds the transformation functions for compatability between different types of map projection very useful. These allow individual map sheets with different original projections and scales to be combined to form a continuous map.

Possible uses of a GIS include:

* Facility Management. This means the linking of the physical position of facilities to the descriptive attribute-type data for the maintenance and forward planning of facilities such as buildings, equipment, services, networks, etc..
* Land Information Management. Information about legal and cadastral boundaries, servitudes, ownership, zoning and demographic patterns, to name but a few mapable and describable features, which can be used by authorities and planners.
* Resource Management. When GISs are to be used to support managerial decision-making and not merely for computerized map production, they can be considered to be similar to other systems popularly known as MIS (Management Information Systems) or DSS (Decision Support Systems).

A topologically structured GIS will allow the user to capture the arbitrary spaces and regions, such as soil types, rainfall figures, crop yields, farmlands, forestry, geological surveys, mining, etc. (Poolman, 1989).

A GIS allows the user to access information at any required level of detail. The information can be viewed from a wide perspective for management purposes or be analized in detail.

This study concentrates on the use of a GIS for both land information and natural resources management. Only the use of information produced by a GIS can justify its existence; information systems have to support decision-making (De Meijere & Van de Putte, 1987). By applying a GIS, environmental planners can visualize disparate data elements which otherwise would have to be examined individually.

Any GIS can furthermore only be used effectively after sufficient data (spatial and non-spatial) have been captured so as to allow the extraction and synthesis of applicable and complete management reports and/or thematic maps. Eventually results must be structured into a digestible form for presentation to either decision-makers or the public (Olivier, Greenwood, Cooper, McPherson & Engelbrecht, 1989b).

7. APPLICATION OF GIS IN LANDSCAPE ARCHITECTURE

Meintjes (1989) interpreted the various typical categories of work of landscape architects in terms of their applicability to GIS as follows:

7.1 Ecological analysis and planning, comprising:

* activity analysis;
* data collection;
* data evaluation; and
* zoning proposals for optimum land use.

This category of broad planning requires all the applicable spatial and attribute data to be stored, updated, manipulated and evaluated. Overlaying certain thematic data to create new information and topologically querying this new data can be very useful.

7.2 Integrated environmental management (IEM), consisting of:

* proposal evaluation;
* impact assessment;
* decision-taking; and
* proposal implementation (cf. Chapter 3 p.37).

Data manipulation on a GIS and development proposals arising from the interpretation of this data, enable the user to consider integrated solutions regarding optimum environmental management and land use. These uses are, *inter alia*: conservation areas, recreation, agriculture, commercial, industrial and housing developments, and transportation corridors.

7.3 **Environmental impact assessment (EIA)**, also comprising:

* activity analysis;
* data collection;
* impact analysis;
* mitigation proposals; and
* decision-making.

EIAs form an integral part of IEM and in this category the capability of GIS to easily and quickly accept changes in parameters in order to perform alternative modelling functions or to produce 'what if' solutions is considered important.

7.4 **Landscape master plan**, consisting of:

* activity analysis;
* data collection;
* data evaluation;
* zoning and circulation; and
* development proposals.

The Institute of Landscape Architects considers the master plan a medium to control the planning and development of a certain area over an extended period. The data storage, updating and manipulation capability of GIS coupled to the polygon overlay of thematic maps, topological data extraction and query are useful tools in this category of work.

7.5 **Landscape design**, comprising, *inter alia:*

* activity analysis;
* data collection;
* zoning and circulation; and
* preparing a sketch plan.

Site analyses, client requirement determination, zoning and eventually preparing sketch plans can very well be made easier by the CAD components of a true GIS.

7.6 **Landscape construction**, consisting of:

* working drawings;
* specifications and bills of quantity;
* tender and contract documents; and
* supervision.

Meintjes (1989) does not consider GIS a prerequisite aid for these functions, but still considers the data base storage and access capabilities of a GIS useful here.

8. THE APPLICATION OF GIS IN SOUTH AFRICA

The author undertook a survey among delegates to the SAGIS 89 Conference held in Pietermaritzburg from 3 to 6 July 1989. This conference was the first conference on Geographic Information Systems in Southern Africa and the list of delegates shows that public, private, educational and research organizations were well represented.

One of the purposes of the survey was to determine the extent to which GISs were currently applied in South Africa and to try to discern future application trends.

A survey response of 31% (68 respondents) was obtained, representing 39 organizations.

In Table 2.1 the status of GIS application in southern Africa in 1989 among the organizations surveyed, is shown.

Table 2.2 (p.34) gives an indication of the fields of GIS application of existing and intending GIS users.

Table 2.1 The status of GIS application in southern Africa in 1989 among the organizations surveyed

Organization	Current users of GIS	Intending GIS users	Total	% of total
Central governmental organizations	2	5	7	18
Provincial/Regional governmental organizations	2	2	4	10
Local governmental organizations	6	1	7	18
Universities/Research organizations	3	5	8	20,5
Professional planning consultants	0	3	3	8
Public utility companies	1	1	2	5
Private companies	3	5	8	20,5
			39	100

Table 2.2 The existing and intended applications of GIS by the organizations surveyed

		Existing and intended GIS applications					
Organizations	Number	Regional/Urban planning	Natural resources planning and management	Utilities/Engineering planning and management	GIS research and development	Landscape architectural planning	Others e.g. demographic, social, cultural and economic studies/ activities
Central governmental organizations	7	5	6	3	3	1	-
Provincial/Regional governmental organizations	4	2	1	2	-	-	-
Local governmental organizations	7	6	1	7	2	1	1
Universities/Research organizations	8	5	6	2	3	1	-
Professional planning consultants	3	-	2	2	-	-	-
Public utility companies	2	-	1	2	1	-	-
Private companies	8	3	4	3	4	-	4
Total	39	21	21	21	13	3	5

9. CONCLUSIONS

To provide a better information and management service to more people faster and at a reduced cost, requires automation of data handling and an information management system.

Conley (1989) states that the DWA, in fulfilling its stated mission, which is: 'to ensure the ongoing equitable provision of water of adequate quantity and quality to all competing users of water at acceptable cost and assurance of supply under changing conditions', is continuing the gathering and dissemination of all necessary information by promoting and implementing the most appropriate modern methods and technology.

With the increasing use of GISs by institutions such as public utility corporations, municipalities, mining houses, universities and State departments, the DWA anticipates that it will be possible to exchange data between users so as to considerably enhance the efficiency of national water management (Conley, 1989). It is further anticipated to provide facilities to interrogate other data bases such as those of the Surveyor General, the Deeds Office, the Geological Survey, the Directorate of Forestry, and the National Atlas of Critical Environmental Components of the Department of Environmental Affairs.

Accordingly Conley (1989: 426) finds GIS 'the most promising tool available to enable decision makers to efficiently organize and digest large amounts of data, to perform analyses and to make informed decisions in consultation with other parties with least delay'.

To utilize and realize the full potential of the large volumes of data generated by remote-sensing devices and related sources, computerized GISs have become indispensible tools.

Conley (1989) suggests that the analytical power of a typical GIS, coupled to its easy access to data, should encourage an all embracing approach to problem-solving and stimulate the generation of fresh ideas to counter and pre-empt the growing challenges in water management.

Meintjes (1989) suggests that, in South Africa, the decision-making process with regard to environmental issues is changing from a representative democracy to one of participatory democracy. Both of these trends have tended to make the planning process more complex and to aid this process, landscape planners, as have other planning professions, have turned to computers.

Conley (1989) concludes by reminding the reader that continuous creative contributions to an organization's wealth of insight is the heartbeat of a successful information and decision system.

CHAPTER 3. INTEGRATED ENVIRONMENTAL MANAGEMENT (IEM)

1. INTRODUCTION

As rapid population increases lead to ever expanding urbanization, the resulting gradual deterioration of the environment has led to a new awareness of environmental protection and development within ecological restraints.

From this awareness, four fundamental guiding principles for landscape architects and planners emerge, namely:

* To relate all development projects to the environment.
* To use an interdisciplinary approach to find solutions.
* To propose and analyse various alternative solutions to a planning problem.
* To work openly in a consultative manner, preferably with public participation.

Integrated Environmental Management (IEM) makes it possible to reach the essential optimum compromise between man's conflicting priorities, namely: to <u>develop</u> and to <u>conserve</u> the environment simultaneously (Hall, 1989). Viljoen (1989) finds that the underlying principle of IEM of accepting and supporting controlled development, to be in contrast with the long held 'conservation' view that any development or human interference is seen as bad and unacceptable. Hulley (1989) states that 'the purpose of IEM is to ensure that the maximum benefit accrues to mankind by seeking a balance between meeting development needs and conserving the environment'.

Walmsley (1989) finds that, until recently, environmental issues have received little attention in political forums resulting in low status in terms of funding for appropriate research and management actions. Walmsley (1989) suggests that the definition of conservation of the International Union for the Conservation of Nature (IUCN), i.e. 'the management of the human use of the biosphere so that it may yield the greatest sustainable benefit to present generations whilst maintaining its potential to meet the needs and aspirations of future generations', should be built into the mission statements of those organizations involved in environmental management.

2. THE HISTORICAL BACKGROUND TO IEM AND THE LEGISLATIVE FRAMEWORK FOR ENVIRONMENTAL ISSUES

2.1 Historical background to IEM

Man, because he benefitted from the use of the earth's resources, has over centuries increased his numbers vastly and this in turn led to even more demands on its limited resources. In satisfying these demands, the environment is subjected to many changes, many of which detract from the quality of life.

Hulley (1989) suggests that since 1969 when the USA Federal Government enacted their National Environmental Planning Act (NEPA), development and planning agencies throughout the world have developed an increasing consciousness of their role and responsibilities for including environmental concerns in their own planning processes.

In the recent past various procedures were developed to assess environmental consequences of development proposals. Of these, the Environmental Impact Assessment (EIA) came to be the most widely recognized and accepted concept.

In Australia, the New South Wales Planning and Environment Commission set an Environmental Standard EI-4 (cf. Appendix F p.277) which, though it is called 'Principles and Procedures for Environmental Impact Assessment', can be compared to the IEM procedures advocated in the RSA.

Hulley (1989) finds that IEM in no way supplants EIA procedures but has rather developed from an appreciation for the value of EIA procedures as a means for evaluating largely unquantifiable advantages or disadvantages.

In discussing the impacts of river-flow modifying structures on the functions of river ecosystems and methods applied to counteract detrimental impacts, Bruwer & Ashton (1989), find that in the RSA many so-called EIAs have been conducted after the decision to erect a particular hydraulic structure has already been taken, and no alternatives therefore remained to be considered. They stress the importance of different levels of choice for each option lest the assessment should become nothing more than a prediction of unalterable effects. In this regard the following considerations need to be kept in mind:

a) 'the determinization of the impact of a water resource development on the river ecosystem is not strictly a part of the strategic planning phase though it is part of the project planning phase which originates during the strategic planning phase. Ecologists must become involved earlier in the planning of projects so that adequate provision can be made for minimizing impacts. Involvement at later stages of the project relegates the ecologists to attempts to mitigate impacts;

b) determination and assessment of ecological impacts is not an engineering discipline but consists of a multidisciplinary approach that has, in all successful examples worldwide, been the responsibility of an experienced project team under the guidance of a carefully selected project leader;

c) ecological considerations should be included at the same time and to the same depth as economic, social and political factors when deciding if a particular water resource development is necessary or desirable. During the period of progress from the strategic to the project phase, the intensity and depth of the environmental impact should be continuously evaluated and updated;

d) the responsibility of ensuring the establishment of a suitably experienced environmental impact project team rests with the planner; and

e) ongoing monitoring after completion of the development project in order to compare its performance against its clearly stated and ordered goals. This monitoring is to be designed and implemented by the project team to serve as feedback input into the adaptive management process.'

(Bruwer & Ashton, 1989: 14-15.)

Bosward (1980) found that since the Environmental Standard EI-4 was implemented in New South Wales, there has been a remarkable improvement in applying EIA procedures, resulting in protecting the environment from adverse impacts from ill-conceived developments. The Council for the Environment (1989)(hereafter referred to as 'the Council') finds that in the early days of EIA, environmental data gathering, evaluation and management techniques were not directed at providing input for the planning process and therefore EIA was perceived to be a negative 'reactive tool' concerned only with critically investigating the environmental implications of proposals that were in an advanced stage of formulation and even implementation.

Initially EIA was confined to specific projects and was not used to assess the sometimes 'more profound environmental consequences of policies and programmes.' (the Council, 1989: 3).

In 1984 the Council, after an extensive study of environmental management policies and procedures in other countries, concluded that, because many people still interpret EIA in the narrow sense, and view EIA as anti-development, a new term was needed to describe the process of guiding and documenting development proposals to ensure the protection and wise utilization of the environment.

The term chosen to describe this process was Integrated Environmental Management (IEM).

2.2 The legislative framework for environment issues

In the Draft Bill of Environment Conservation which preceded the Environment Conservation Act of 1989, the following statement of principles was set out (the Council, 1989: 5):

* 'Every inhabitant of the Republic of South Africa is entitled to live, work and relax in a safe, productive, healthy and aesthetically and culturally acceptable environment.
* Every human generation has a moral responsibility to act as trustee of its natural environment and cultural heritage in the interests of its own and succeeding generations.
* Every person or institution has an obligation to consider carefully all actions which may have an influence on the environment and to take all practicable means to ensure the protection, maintenance and improvement of both the natural and the man-made environments.
* The preservation of natural systems and processes is essential for the

meaningful survival of all life on earth.

* Living natural resources are renewable and can be utilized indefinitely with discretion, while non-living natural resources are finite and their utilization can be extended only by judicious use and maximal re-use.
* Co-ordinated and purposeful research is essential to gain and apply knowledge of all the facets of the environment and the interaction between man and environment, in order to reconcile provision for the reasonable needs of man with effective protection of the environment.
* Comprehensive and sustained tuition and interpretation and dissemination of information is essential for the establishment of an informed population for the promotion of rational utilization of the total environment.'

2.2.1 THE ENVIRONMENT CONSERVATION ACT, 1989 (ACT 73 OF 1989)

As it is generally difficult to implement public opinion and community norms as well as general policy on environmental issues, legislation often remains the only effective manner in which environmental issues are dealt with.

In the RSA this realization led to the eventual promulgation and approval of the Environment Conservation Act (Act 73 of 1989) in June 1989.

This Act enables the Minister of Environment Affairs to prescribe environmental policy that must be adhered to by all other Ministers, Administrators, local authorities and controlling bodies with regard to:

* the protection of ecological processes, natural systems and

exceptional natural beauty as well as the preservation of biotic diversity in the natural environment;

* the promotion of sustainable utilization of species and ecosystems and the effective application and re-use of other natural resources;
* protection of the environment against unnecessary disturbance, deterioration, defacement, poisoning or destruction as a result of man-made structures, installations, processes or products; and
* the establishment, maintenance and improvement of living environments which contribute to a generally acceptable quality of life for the inhabitants of the Republic of South Africa.

Section 21 of the Act identifies some of the activities which the Minister may deem as adversely affecting the environment. Section 22 enables the Minister to require, by means of proclamations, reports from professionals on the influence on the environment before approving any proposed action or development.

The required reports may include, according to Section 26 of the Act, a full Environmental Impact Assessment. This will especially be applicable in Class 1 cases where the impact on the environment is considered to be material. Section 40 of the Act ensures that all governmental bodies are also bound by the Act.

The Act repeals the following acts entirely:

* Environment Conservation Act, 1982. (Act 100 of 1982);
* Environment Conservation Amendment Act, 1983 (Act 45 of 1983); and the
* Environment Conservation Amendment Act, 1987 (Act 61 of 1987).

2.2.2 THE COUNCIL FOR THE ENVIRONMENT

The Council for the Environment was recognized under Section 4 of the Environment Conservation Act, 1989.

The general objectives of the Council, as described in the RSA Government Gazette (1989) are to advise the Minister of Environment Affairs on specified issues (specified under Section 2 of the Act) or any other issues which he refers to the Council or which the Council deems necessary and which pertain to the environment.

The Committee for Integrated Environmental Management (formerly known as the Committee for Environmental Impact Assessment) of the Council was responsible for the approach and procedures outlined in the document called Integrated Environmental Management in South Africa (see Council for the Environment, 1989). The Council subscribes to the philosophy that there is no inherent contradiction between the ultimate goals of conservation and development: 'both are concerned with improving social well-being in the present and in the future' (1989: 1).

3. PRINCIPLES, GOALS AND CONCEPTS OF IEM

3.1 Definition of terms

3.1.1 INTEGRATED

The term 'integrated', as used in IEM, refers to the <u>integrated</u> management of the environment. Historically, various planning and management actions of man relating to environmental issues were performed in relative isolation with regard to the other related and concerned disciplines. This unfortunate situation, over the years led to development projects displaying a lack of understanding and planning for vital issues.

Hall (1989) finds that, in what he terms the 'pre IEM era', it was common practice to assign separate briefs to the various environmental specialists to examine a proposed project prepared by professional planners. It was then expected of both environmental specialists and planners to reach consensus. The concept of IEM is to ensure that all related issues are considered from the inception stage of a development project. A holistic approach to planning and management is thereby ensured.

Smuts, quoted in Van der Zel (1985: 7) explained his concept of holism as follows:
'It is the very essence of the concept of the whole that the parts are together in a unique specific combination, in a creative synthesis which differentiates it from all other forms of combination or togetherness.'

3.1.2 ENVIRONMENT

In general terms the 'environment' is the scene in which we live and operate and it consists of both tangible assets and resources as well as systems, be it natural or man-made (Hall, 1989). Through time man has come to realize that all his actions have an influence on his environment. These actions include, *inter alia:* creation of practical facilities and the adoption of policies which modify the environment.

The term 'environment' is defined in the Act (RSA Government Gazette, 1989: 4) as 'the aggregate of surrounding objects, conditions and influences that influence the life and habits of man or any other organism or collection of organisms'.

3.1.3 MANAGEMENT

The term 'management' is used here to describe the planning, directing, authorization and monitoring of man's actions, specifically his development projects and policies. Hewlett (1981) refers to management as the continuous process of decision-making.

3.1.4 DEVELOPMENT PROPOSAL

The terms 'development proposal' and 'proposed action' are used as synonomous in this study to indicate any proposal (including conservation proposals) intended to improve some aspect of human well-being, whether it involves modification or preservation of the natural or built environment (the Council, 1989).

3.2 The concept of IEM

Though IEM relies on procedures, it remains essentially a philosophy and a formalized approach in recognition of the need for man to plan his activities thoroughly and properly so that no consequence escapes attention and remains unrecognized (Hall, 1989). This process is complex because IEM must be universally applicable, from policy formulation through to specific projects and to project implementation. The people or parties involved in IEM include the developers, professional planners and specialists, the various authorities as decision-makers and last but not least, the public. It is important to realize that a high level of communication between these people or parties is essential as each cannot play their own role in a vacuum (Hall, 1989).

Bosward (1980) states that the concept behind the 'Principles and Procedures for Environmental Impact Assessment' in New South Wales, Australia (cf. Appendix F p.277) and which can be compared with IEM in the RSA, is to bring about:

* Better planning and design of development proposals from the environmental point of view.

* Proper consideration of environmental factors by public authorities when determining the acceptability or otherwise of development proposals.

3.3 The IEM process

3.3.1 GENERAL PROCEDURES FOR IEM

Even though any approach to IEM should be in accordance with the stated basic principles or concepts, the procedures involved may vary widely, depending on the nature of the project.

The IEM concept allows for the classification of all development and conservation actions into one of three categories which form a natural hierarchy, namely:

* Policies - statements of general intent that guide the formulation of specific actions.
* Programmes - sets of plans for specific actions, in order of merit and on a time-scale, for giving effect to policies.
* Projects - discrete, focused actions to meet certain specific programme objectives (Hulley, 1989).

Planning for any one of these three categories generally follows four stages, ranging from the initial concepts to final implementation, namely:

* Stage 1: Proposal generation.
* Stage 2: Proposal assessment.
* Stage 3: Proposal selection or decision.
* Stage 4: Proposal implementation.

The Council (1989) feels, while recognizing that in practice there may sometimes be overlapping or interaction between certain stages, and some may be repeated, that it is still useful to regard these four stages as discrete processes in order to attain a clear understanding of the development process.

In Figure 3.1 (p.49) a schematic diagram is shown which illustrates the general IEM procedure. While this diagram sets out the main procedure satisfactorily, certain steps need further elucidation:

3.3.1.1 Stage 1: Proposal generation

This stage is concerned with formulating a proposed action, as well as viable alternatives to the action, for meeting some purpose or need (the Council, 1989).

Step 1: The purpose and need for the development proposal should be defined.

Step 2: Viable alterative ways to meet the objectives should be investigated before a final formal proposal is formulated. This search for alternatives is to be encouraged because it often results in a proposal which is potentially more acceptable to all parties concerned. The Council (1989) even proposes that while the private sector proponents should be encouraged to consider alternatives that would still meet the objectives, public sector proponents should be required to explicitly consider alternatives for meeting the purpose and need of the original proposal. Alternatives, which vary both incrementally and fundamentally should be developed and explored.

Step 3: Possible environmental effects of the final proposal and viable alternatives should be investigated before they are submitted.

Step 4: The most promising version of the proposed development and

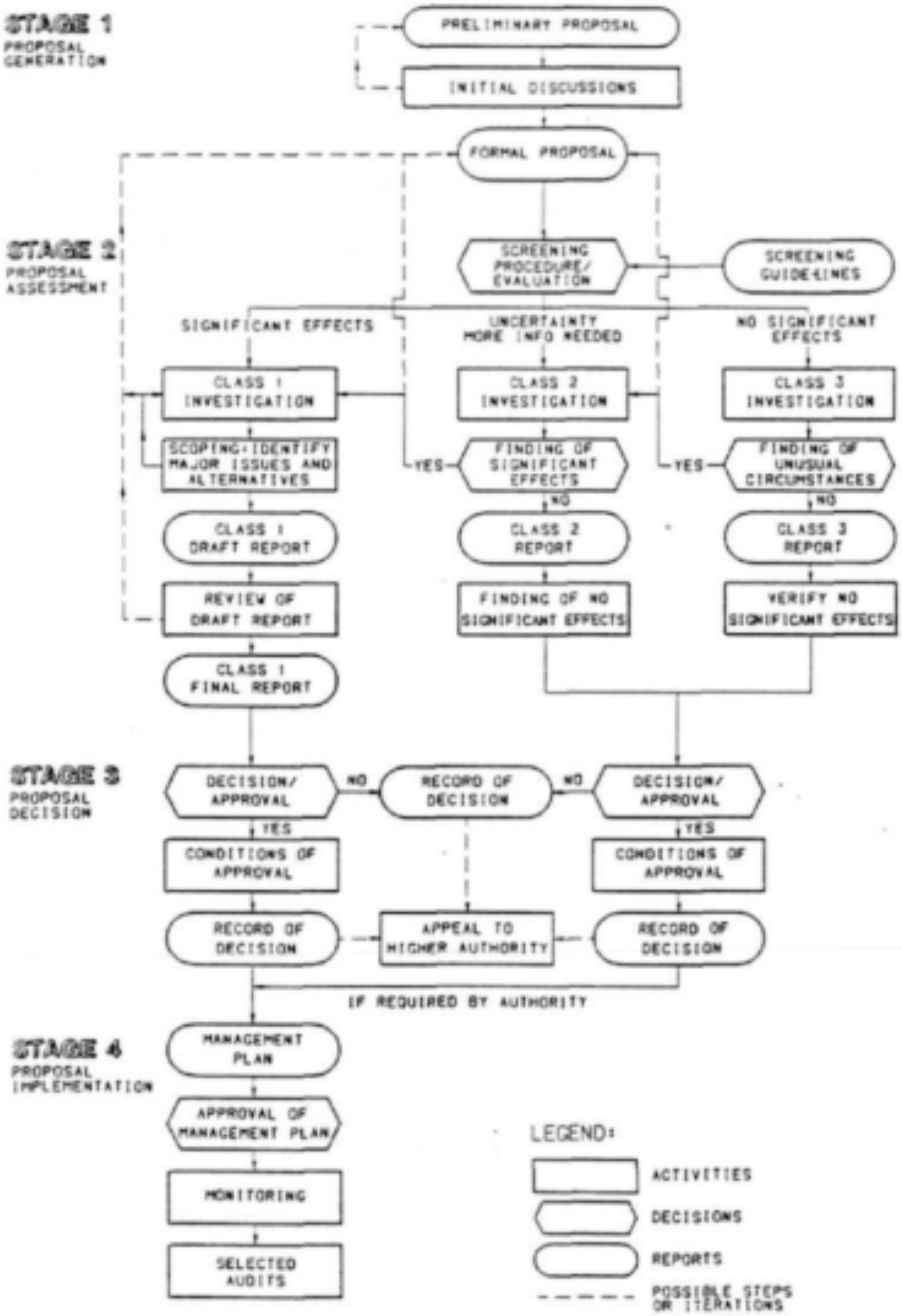


FIGURE 3.1: SCHEMATIC DIAGRAM TO ILLUSTRATE THE GENERAL IEM PROCEDURE (FROM THE COUNCIL FOR THE ENVIRONMENT (1989) AND ADAPTED BY AUTHOR)

its viable alternatives are formulated and submitted for formal assessment in Stage 2.

3.3.1.2 Stage 2: Proposal assessment

This stage is concerned with investigating and evaluating the proposed action and one or more leading alternative actions (the Council, 1989) and was traditionally called Environmental Impact Assessment or EIA.

Step 1: Consult the screening guide-lines to ascertain the level of assessment required. Screening guide-lines may include lists of actions and types of environments (so-called sensitivity maps). All development proposals fall into one of three classes which can be identified in this screening procedure. Each class requires a different level of investigation or assessment:

* a Class 3 proposal is highly unlikely to have any significant environmental impacts, and therefore only a perfunctory assessment needs to be done to confirm that there will be no significant impacts.
* a Class 2 proposal may or may not have significant environmental impacts, and therefore a relatively brief investigation can be done to determine whether any impacts will be significant. The environmental aspects that might be investigated are, *inter alia*:
  - Socio-economic effects relating to noise pollution, compatible land use, air quality, water quality, historic and cultural resources, economics, light emissions, solid waste, infrastructure, community services, work opportunities and health aspects.
  - Biotic communities such as endangered and threatened

species.

- Topographical features relating to wetlands, flood-plains, coastal zones, rivers, estuaries and farmlands.
- Geological features including mineral resources, top-soil conditions and foundation conditions.

* a Class 1 proposal is likely to have significant environmental impacts, and should therefore be subjected to the most rigorous form of environmental assessment.

In addition to the stated environmental aspects to be investigated in a Class 2 assessment, the Council (1989: 24) suggests that the following questions be asked and answers sought during a Class 1 assessment:

'* How will the ecosystems and natural features in the area be affected?
* How will the social, cultural, historic and economic charcteristics of the area be affected?
* What is the local, regional, national and even international value of the resources which could be significantly impacted?
* Are there any significant or long-term risks?
* Are the impacts long-lasting and are they irreversible?
* Will the impacts give rise to secondary or higher-order impacts?
* What can be done to avoid or mitigate these impacts?
* What groups will be differently affected by the various impacts and exactly how will they be affected?
* What is the magnitude of these impacts and just how significant are they?'

Step 2: Conduct the appropriate level of environmental investigation as determined by the screening process. The emphasis should be on discovering ways in which adverse impacts can be avoided or mitigated.

The Council (1989) suggests that even proposals that do have major environmental implications can sometimes be investigated and assessed in a short time and at a reasonable cost by identifying significant impacts early on and focusing on them. They stress that the key is to undertake an assessment that is appropriate to a given proposal.

Step 3: By means of a scoping exercise involving the affected public and relevant authorities, determine the major issues to be focused upon and search for viable alternatives.

The Council (1989) recognizes two types of scoping, namely:

* public scoping: to seek input from special interest groups, representatives of public organizations and members of the general public.
* authority scoping: to seek input from all local, regional, provincial and central government bodies or parastatal organizations with responsibilities, interests or special expertise relevant to the proposal. Consider issues concerning all the different interest groups. Steps 3 and 4 will apply only to Class 1 proposals.

Step 4: After publically reviewing the draft Environmental Report and amending it if so required, a final Environmental Report is submitted. According to the Council (1989: 17) this report should present, at an appropriate level of detail (depending on the class of assessment), descriptions of, *inter alia*:

* the purpose and need of the proposal;

* modifications or viable alternatives to the proposed action;
* activities associated with the proposed action (and those of any alternatives);
* the affected environment;
* the potential environmental impacts;
* the groups of people that would be affected by these impacts;
* possible measures to avoid or mitigate adverse impacts and enhance beneficial impacts.'

3.3.1.3 Stage 3. Proposal selection or decision

This stage is concerned with identifying and formally approving the action or proposal which is in the best overall interests of society (the Council, 1989).

Step 1: Decide upon the action or development to be authorized after consideration of the findings of the Environmental Report. This option should be in the best overall interest of society.

Step 2: Specify conditions, if any, of the approval. Steps 2, 3 and 4 apply only to Class 1 proposals. The authority may require of the proponent to prepare and submit an environmental management plan.

Step 3: Record the decision and any conditions in a document that is available to the general public.

Step 4: Allow opportunity for appeals by the proponent or by any party concerned.

The Council (1989) feels that it is beyond their scope to outline a specific appeals procedure but recommends that there should be time limits on both the filing of and ruling on appeals, all in an effort to minimize time delays and cost.

3.3.1.4 Stage 4. Proposal implementation

This stage is concerned with ensuring that the approved action is successfully implemented (the Council, 1989). For Class 1 proposals this will involve the following steps:

Step 1: In some cases the authorities will require from the proponent to develop a practical management plan for implementation of the development. This management plan must include, *inter alia:*

* control systems and review procedures to be followed in case of development design changes;
* special environmental training for contractors' personnel;
* procedures for liaising with the community on large projects;
* post-construction environmental restoration and rehabilitation plans; and
* guide-lines and responsibility allocation in an operation and maintenance manual, if the project requires this.

Step 2: Have the management plan approved or amended by the authority concerned.

Step 3: Monitor the execution of the management plan and arbitrate in disputes during the implementation of the action. The monitoring of selected significant environmental variables will identify, mitigate and hopefully prevent possible harmful trends before it becomes too late to ameliorate or prevent them (Hulley, 1989).

Step 4: After a period of time has elapsed, undertake selected audits to suggest how the IEM process can be improved.

3.3.2 SPECIFIC INVESTIGATION PROCEDURES

In Figures 3.2, 3.3 and 3.4 the complete procedures for dealing with and investigating Class 3, Class 2 and Class 1 development proposals

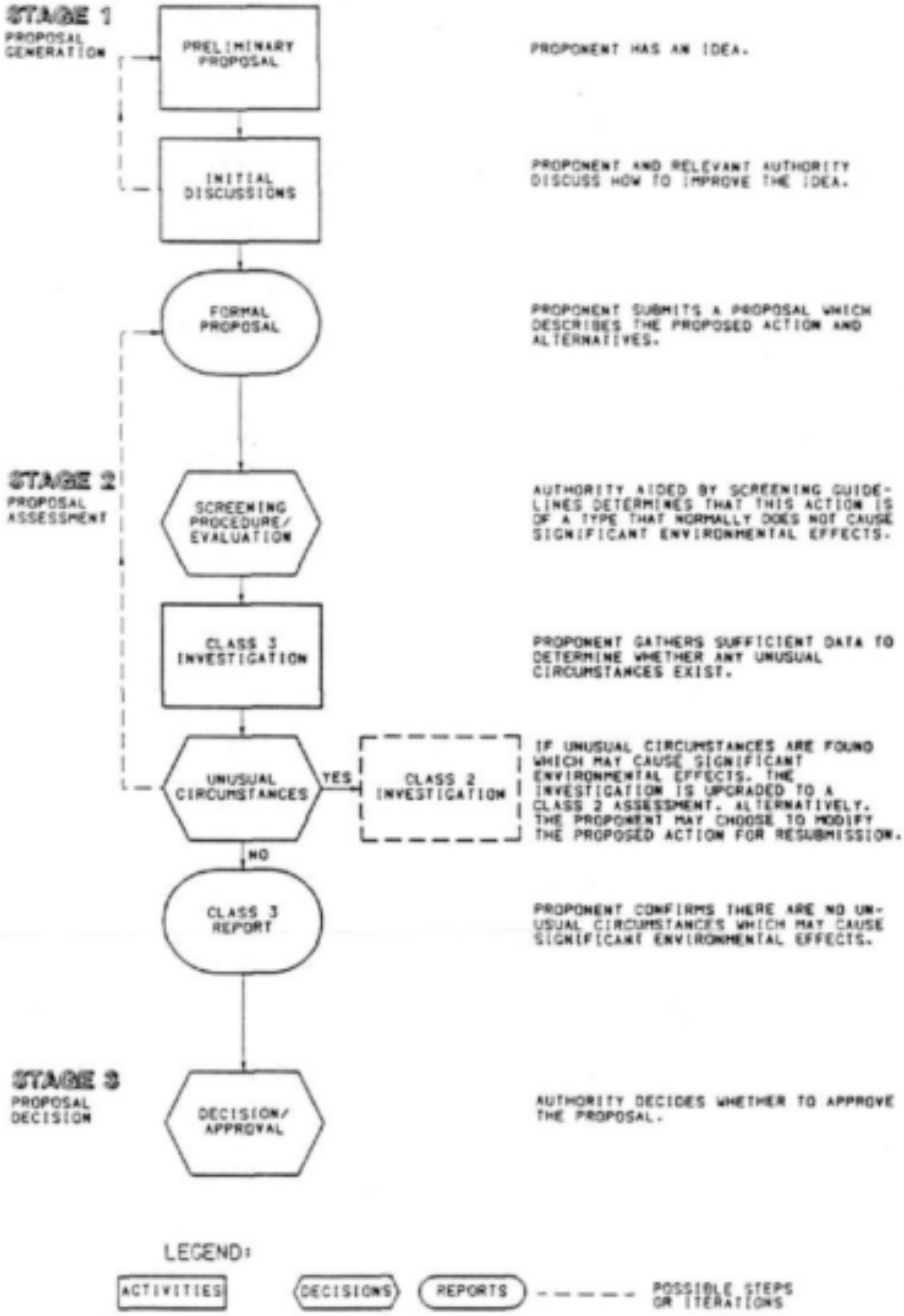


FIGURE 3.2: PROCEDURE FOR INVESTIGATING CLASS 3 PROPOSALS
(FROM THE COUNCIL FOR THE ENVIRONMENT (1989) AND ADAPTED BY AUTHOR)

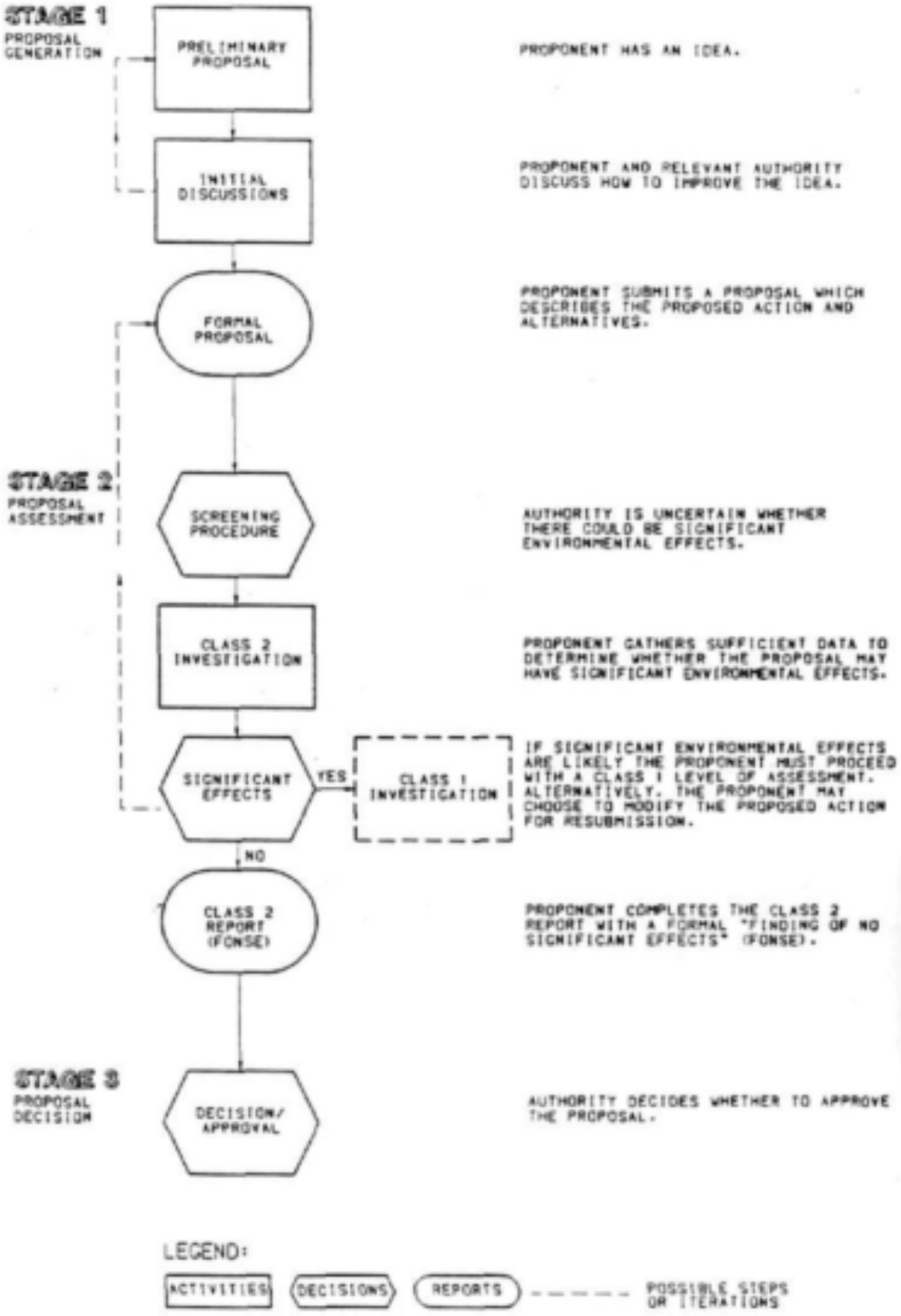


FIGURE 3.3: PROCEDURE FOR INVESTIGATING CLASS 2 PROPOSALS
(FROM THE COUNCIL FOR THE ENVIRONMENT (1989) AND ADAPTED BY AUTHOR)

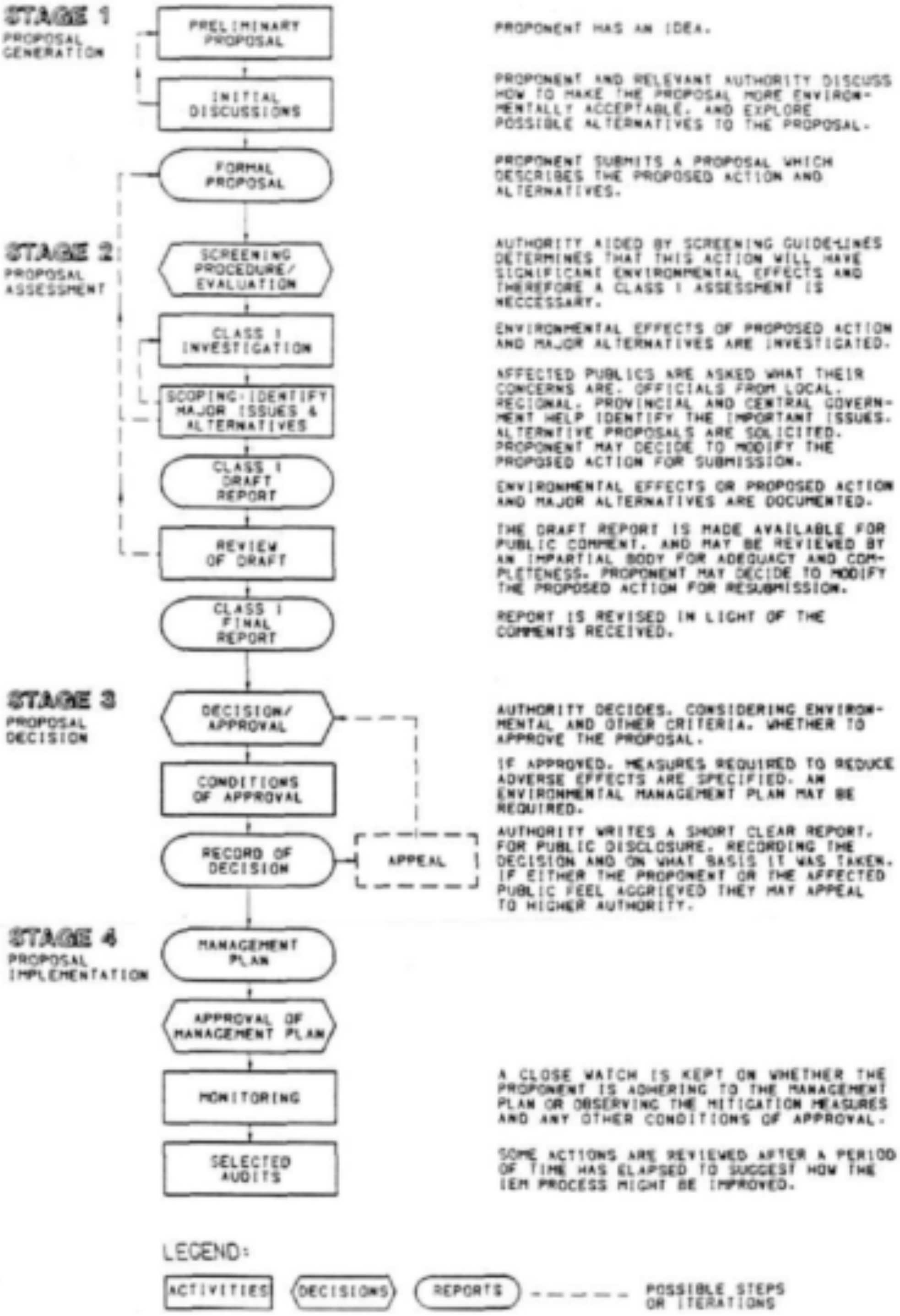


FIGURE 3.4: PROCEDURE FOR INVESTIGATING CLASS I PROPOSALS
(FROM THE COUNCIL FOR THE ENVIRONMENT (1989) AND ADAPTED BY AUTHOR)

are shown. Procedures for Classes 3 and 2 (Figures 3.2 and 3.3) are shown up to Stage 3: Proposal selection, while for Class 1 investigation procedures (Figure 3.4), all four stages are described.

3.3.3 THE PEOPLE INVOLVED

Hall (1989) suggests that ideally, the first step to be taken in the IEM procedure once it has been established whether a Class 1, 2 or 3 investigation is required, is to decide on the people to involve and to form them into a team. Communication channels can thus be established and responsibilities allocated.

In practice, however, this first step will not always be possible, because the services and input of others will become necessary as the project develops.

With reference to the IEM stages and steps described in Section 3.3.1, the various people and disciplines involved can be described as follows:

3.3.3.1 Stage 1: Proposal generation

Hulley (1989) refers to examples where landscape architects acted as the principal agents and with specialist input from, *inter alios*: town planners, architects and engineers (re water, sewerage, roads, etc). In some cases the role of principal agent later devolved upon town planners but still with specialist input from other planning professions. The proponent may also meet with the controlling authority in this stage to hold preliminary discussions on the feasibility of the proposed development.

3.3.3.2 Stage 2: Proposal assessment

In the screening procedure, the landscape architect may again act as co-ordinator of the activities of the various specialists. Hulley (1989) stresses the importance of the independant input of environmental specialists, in the same way as economic or technical specialists are providing their independant input. The Council (1989) appears to assign the screening procedure to the Controlling Authority, thus absolving the developer from responsibility.

Should the screening exercise indicate significant effects and therefore requires a Class 1 investigation, the planner, (as defined in Section 4.4.1) must act as co-ordinator in the scoping exercise to determine the magnitude of major issues and their alternatives.

Hulley (1989) finds that the planner will probably also be responsible for the draft environmental report and, after review, the final report. This practice is in contrast with the USA where the controlling or determinating authority normally prepares environmental impact statements or reports. These statements may then be subjected to judicial review in courts (Bosward, 1980).

In Australia, as in the RSA, it is the accepted procedure to require of the developer, or a consultant acting on his behalf, to prepare an environmental impact statement, while the relevant controlling body acts as the assessing or determining authority.

3.3.3.3 Stage 3: Proposal selection or decision

As this action rests with controlling bodies or authorities, the planner will probably only be required to clarify certain issues included in the report under consideration. Consultations between the developer and controlling body may at this stage require the presence of the planner.

3.3.3.4 Stage 4: Proposal implementation

Hulley (1989) suggests that the planner's responsibility, in conjunction with the panel of specialists, will be to ensure the incorporation of environmental factors previously identified, into the detailed planning and development process.

3.4 Methods for preparing and presenting Environmental Assessment Reports

Because of the diversity of the environment and development proposals, flexibility is necessary in order to present all the attributes of the environment, the components of the development proposal and their resulting interactions.

Bosward (1980) finds that most of the work up to 1980 has been devoted to the development of techniques and formats for analysing and issuing environmental assessment reports. He distinguishes between two approaches which have emerged in this regard, each with a different application:

3.4.1 A SYSTEM OF OVERLAYS

In this system, developed by McHarg (1969), attributes of the land are thematically mapped on overlays. Usually those attributes which are adverse to the proposal, are prominent. By superimposing these overlays, areas of land most favourable for the intended purpose become apparent.

Canter (1977) finds that McHarg's method does not predict actual environmental effects but rather only the areas of greater or lesser impact. However, it does identify those locations for which more detailed studies may be conducted.

Bosward (1980) finds McHarg's system particularly suitable for collecting environmental information on broad, large scale projects such as flood-mitigation works, but considers it to be cumbersome for dealing with isolated development projects. This system's spatial representation of environmental factors effectively isolate areas of high or low potential for adverse environmental effect. Although Bosward (1980) considers it to be an expensive technique because extensive data collection is necessary, it does help in clarifying and displaying, variable environmental situations. This is especially true for development proposals where visual matters are important.

3.4.2 MATRIX CHARTS

This system, developed by Leopold and others in 1971 and outlined in the United States Geological Survey (USGS) Circular 645 (Bosward, 1980), uses a matrix which incorporates a reference check-list and a range of effects on the environment that relates to the proposed development or action. Bosward (1980) finds this method suitable for particular development projects.

The purpose of this system is to list possible environmental effects and a magnitude estimate of each. Each effect is also rated for importance and the magnitude and importance are combined in a summary evaluation.

Bosward (1980), in his description of Leopold's method, suggests that development actions should be placed along a horizontal axis and environmental characteristics or reactions along a vertical axis. A slash is placed diagonally across each block where interaction occurs. In the upper corner a number is inserted, ranging from 1 to 10 depending on the magnitude of the effect, and in the lower corner a number is inserted also ranging from 1 to 10 to indicate the importance of the effect or action.

Canter (1977) finds that one of the attractive features of the Leopold matrix is that it can be expanded or contracted, i.e. the number of development actions and environmental factors can be increased or decreased. Canter (1977: 186) furthermore states:
'The primary advantages of the Leopold matrix are that it is very useful as a gross screening technique for impact identification purposes and that it can provide a valuable means for impact communication in terms of a visual display of the impacted items and the major actions causing impact'.

This matrix chart serves as basis for the text of the environmental assessment report. Bosward (1980) lists various subsequent systems that evolved from the Leopold method.

Bosward (1980) notes that these matrix charts can quickly become complicated on larger development projects with the result that important issues don't readily stand out. Where a development project comprises many component actions and phases, separate matrix charts are usually needed to distinguish their environmental effects.

3.4.3 ECONOMIC/ENVIRONMENTAL COMPARISONS

A cost-benefit analysis is often used by controlling bodies or authorities and professional consultants to assess benefits that a development may bring to a community or organization in comparison with the estimated cost of the development. It is also used to compare alternative proposals from an economic point of view. Bosward (1980) suggests that these analyses should be limited to issues that are economically quantifiable and that a separate assessment be made of environmental matters that cannot be defined in monetary values.

4. COMMENTS ON THE IMPLEMENTATION OF IEM

4.1 Devolution, deregulation and privatization

Viljoen (1989) finds the concept of IEM to be in agreement with the stated constitutional policy of the RSA of devolution of functions, but cautions that the principles of IEM do not easily fit in with the policy of deregulation and privatization. IEM is essentially a regulating mechanism for development. Viljoen (1989) finds the policy and motives behind IEM more acceptable than the regulations intented by the Environment Conservation Act and suggests the immediate acceptance of IEM by all concerned before it is considered necessary to issue regulations in terms of the Environment Conservation Act and thereby set aside the IEM process. This potential conflict situation can be defused by community norms and public pressure brought to bear on the developer and which forces him to implement IEM voluntarily.

On the other hand, sections of the Environment Conservation Act 1989 (Act 73 of 1989) could be, according to Viljoen (1989), difficult to reconcile with the policy advocated by IEM. In this regard he refers to Section 22 of the Act which enables certain authorities, at their discretion, to either refuse or grant authorization for an activity. Viljoen (1989) argues that these conditions of the Act and associated regulations and the underlying policy of IEM are difficult to implement simultaneously for a specific project.

4.2 The role of controlling bodies in the implementation of IEM

For the purpose of this study controlling bodies are taken to include public authorities and parastatal organizations which direct development and have decision-making authority.

Viljoen (1989) emphasizes that IEM will have to be adressed and integrated on all three tiers of government in the RSA, namely: central, regional and local government. In addition, several government instituted development-oriented corporations and parastatal organizations such as ESKOM and ISCOR are involved with large scale developments which influence the environment.

Economic realities will probably render the relatively sophisticated and expensive procedure of IEM beyond the means of Black and other smaller local authorities (Viljoen, 1989). Aspects such as cost, deadlines and urgently needed Black housing, seriously impair the full implementation of IEM procedures. Viljoen (1989) suggests a simplified version of IEM which will enable any senior official to implement the principles of IEM, even if on a superficial basis.

The various controlling bodies are all under pressure to provide, with limited resources, in the ever increasing demands of an urbanizing population.

The process of IEM demands additional time, expertise and funds; demands that will be met differently by different controlling bodies.

Bosward (1980), in reviewing the implementation of environmental impact assessment in Australia since 1975, found that controlling bodies or determining authorities were inexperienced in this process. They had difficulty in advising of their requirements in advance and did not have, within their organizations, sufficient expertise to consider and evaluate environmental issues that could arise from a proposed development.

Controlling bodies act within a framework of legislation, policy and community norms expressed as public opinion (Viljoen, 1989). Environmental regulations and ordinances stemming from legislation are enforceable and are intended to create a system through which responsibilities are allocated and actions monitored.

Environmental policy should create guide-lines according to which all sectors of the community can act to the benefit of the communities concerned. These guide-lines can, for instance be used to investigate the important issues of land use planning. Viljoen (1989) found that well-considered guidelines are a luxury rarely affordable in the RSA society where the identification and application of land for urgently needed low-cost housing are often done on a political rather than an ecological basis.

Viljoen (1989) foresees little difficulty in implementing IEM in clearly specified and delineated single projects such as roads, water supply schemes or electricity generating plants, but finds that practical problems may arise with regional activities such as agriculture and forestry; activities which he feels the IEM process does not cater for.

The implementation of IEM for regional actions are furthermore constrained by state boundaries. Environmental damage or mismanagement cannot be limited to within political boundaries.

Viljoen (1989) concludes by identifying factors such as other current requirements, financial support, administrative requirements and existing levels of expertise required by IEM as the main factors inhibiting the acceptance and implementation of IEM by local authorities.

4.3 The role of developers in the implementation of IEM

Botha (1989) finds that within 'White' RSA, the enormous demands for the provision of Black housing would have a serious influence on the full application of IEM and the thrust of the IEM process would therefore be directed at the first world enclaves remaining within 'White' RSA.

Botha (1989) suggests that many developers of real properties may perceive the involvement of burocracy through IEM in all developments as meddling with their privelege to take responsible decisions on the most effective utilization of their properties. They may feel that the well established principle that the application of private assets, unless in conflict with the general interest of society, remains the individual's right, could be undermined by IEM.

The Council (1989) admits that there may be several reasons why a developer may be reluctant to co-operate fully with the relevant authority or to involve the public, especially in the proposal generation and assessment stages, one of the reasons being confidentiality. A proponent may stand to lose time and money should details of his proposal become known before he has obtained the necessary permits which will legally safeguard his interests. The public sector proponent may also be apprehensive should a premature announcement or 'press leak' of a proposed development trigger various speculative actions which might not be in the public interest.

Botha (1989) notes that the South African Property Owners Association (SAPOA) advocates the following criteria regarding any development control process:

* Developers should be free and indeed encouraged to develop their properties with certain parameters.
* These parameters should be clearly defined so as to lead to greater confidence among developers.
* Any development control process should be as brief and effective as possible.

Compared to these criteria, Botha (1989) criticizes the IEM process with regard to:

* Acknowledgement of existing rights (he does however note, with appreciation, the provision of compensation for loss under Section 34 of the Act).
* The introduction of a long and complicated administrative process which involves burocracy, which he feels, has little interest or understanding of the economic use of property. He states:
  'The property development industry cannot accept that IEM will, in the long run, save time, money, effort and worry (author's translation).
* The cost of implementing the IEM process. He suspects that the cost will eventually have to be borne by the developers. This in turn will affect the price of land and developments for the end user.

Botha (1989) describes SAPOA's counter proposal as follows:

* A sensible balance needs to be struck between essential fixed property development which, in turn, creates jobs and wealth and on the other hand, unbridled development.
* In order to accomplish this goal, SAPOA proposes:

- Fixed property development permitted in terms of existing land use legislation should be affected as little as possible.
- The three-class classification of activities is endorsed. These preliminary assessments will give the developer an indication of the degree of possible effects and will enable him, at an early stage, to decide whether to continue with a development.
- Land should be graded in terms of its environmental significance in an 'Atlas of Environmentally sensitive areas'.
- Developers should submit an Environmental Statement at the onset of a proposed development.
- Fully detailed and motivated reasons for any rejection of applications should be given by the Authorities. This issue is partly covered by sections 35 and 36 of the Act. Boards of Appeal at a local level should sit on a regular or *ad hoc* basis.
- A time limit should be set for the approval, in principle or otherwise, of all development applications.
- Authorities should have the capacity to administer any such IEM procedure.
- Policies and priorities must be defined clearly and concisely at Central Government level before they are devoluted to Regional or Local levels.

4.4 The role of planners and environmental specialists in IEM

4.4.1 PLANNERS

For the purpose of this study, Hulley's (1989) definition of a planner is accepted, namely: 'Those professions which commonly initiate, plan or act as the principal agent in the planning and execution of developments, which could have significant impact on the environment.'

Hulley (1989) finds that in the RSA the lack of compulsion to conduct socially accountable investigations into all aspects of development proposals presents a severe challenge to all planners. Acceptance of this accountability will be ensured by the adoption of IEM.

The professional planner cannot abdicate his responsibilities for the safety, specification and cost control of a project and is therefore in a position where these responsibilities require of him to assume the leadership role in a planning team consisting of, *inter alios*: civil engineers, architects, landscape architects, geologists, pedologists, botanists, ecologists, quantity surveyors and geographers. It is also required from the professional planner to acquaint himself with the language and techniques of other related environmental specialists.

4.4.2 ENVIRONMENTAL SPECIALISTS

While it is not expected of an environmental specialist to be familiar with the details of all the other related fields, he should at least understand the whole planning process and be able to see his own role and responsibilities against this whole.

Raimondo (1989), while commenting on 10 case studies in which he was involved as a member of the Environmental Evaluation Unit at the University of Cape Town (UCT), reached the following conclusions with regard to the role of Environmental Specialists:

* They were involved in key roles in the proposal generation and assessment stages.
* They were not involved in any Class 3 assessments.
* They were involved in key roles in Stages 1 and 2 for Class 2 assessments.

* They were only involved in certain Stage 2 steps, namely conducting an appropriate level of investigation and determining the scope and focus of an investigation for Class 1 assessments.

Raimondo (1989) concluded by offering the following recommendations to Environmental Specialists with regard to their role in IEM:

* They should take the leading role in:
  - conducting an appropriate level of investigation;
  - determining the scope and focus of assessments in the Assessment Stage of Class 1 and 2 investigations.
* Developers should carry out Class 3 investigations with advice from Environmental Specialists only where appropriate.
* Environmental Consultants should be included as part of the planning team at Stage 1: Proposal generation.
* As the roles of the planning professions and environmental consultants often overlap, their respective roles should be clarified or regarded as interchangeable depending on their levels of expertise in a specific project.
* Developers should be encouraged and assisted to maximize the environmental considerations at Stage 1: Proposal generation, to save time and costs in fruitless expenditure.

4.5 The role of the public in the implementation of IEM

Viljoen (1989) considers public opinion a powerful controlling mechanism which even regulates controlling bodies since the latter are intended to serve the community. He also finds that, due to the local nature of most development projects, local communities have a real responsibility and a contribution to make towards projects in their areas.

Van Riet (1989a) divides public involvement in IEM into two broad categories, namely: consultation and participation.

4.5.1 PUBLIC CONSULTATION

Van Riet (1989a) sees consultation as the consideration of information received from the public by the developer and on which he need not necessarily act. He furthermore observes that it seems to him as though the public tends to interpret any development proposal put to them for comment and support, as a *fait accompli* and therefore tends to be very critical. This reaction by the public is perceived by the developer as being merely negative and obstructive and they may therefore be reluctant to involve the public in the planning process.

According to Van Riet (1989a) methods of public consultation include the following:

* advertisements or press announcements of proposed developments on which the public are invited to comment;
* surveys of representative samples of potentially affected people; and
* consultation with special interest groups.

4.5.2 PUBLIC PARTICIPATION

Public participation can be defined as a 'continuous, two-way communication process, which involves promoting full public understanding of the processes and mechanisms through which environmental problems and needs are investigated and solved by the responsible agency' (Canter, 1977: 220).

On the other hand, public participation is perceived by Van Riet (1989a) to imply active involvement by the public in the planning process at one, more or all of the stages of the process. Even though the involvement of public participation is often seen as onerous, a waste of time and delaying the finalization of a development plan, if done correctly, it can prove to be financially rewarding and beneficial to the developer. Van Riet (1989a) cautions against underestimating the value of public participation.

According to Van Riet (1989a) the value of public participation is as follows:

* People taking part in the exercise are educated in many issues of the holistic approach to planning and development.
* After being a part of an IEM exercise, members of the public generally appreciate their environment and its sensitivities more.
* Participation gives the public confidence in the planning professionals, specialists, developers and the relevant authorities.
* Knowing that members of the public have contributed in, assisted with and accepted proposals put to them, politicians and controlling bodies are more inclined to approve such proposals.

Van Riet (1989a) suggests that public involvement may take many forms, *inter alia*:

* Via a formal public hearing at which interested parties are invited to give testimony.
* Via workshop meetings to discuss and find solutions to issues.

He furthermore advises that these public meetings be conducted by a skilled facilitator and according to ground rules explained to participants beforehand.

These public meetings should also not be once-off affairs in that the public must be able to see that their input is included in finalizing the development plans.

Even though public participation entails a considerable amount of time and therefore also expenses for the developer, Van Riet (1989a) remains convinced of its ultimate benefits to the developer.

Bosward (1980) finds that in Australia the need for public awareness and some degree of public participation has come to be recognized and that controlling bodies have an obligation to bring matters that could impair the environment to the attention of the public and to provide them with the opportunity to comment.

4.6 General comments

Bosward (1980), in reviewing environmental impact statements or reports that have come to hand in Australia, finds that the most unsatisfactory aspects of such reports relate to:

* The inclusion of considerable scientific information which is irrelevant to decision-making.
* The omission of other information which is relevant, or poor presentation of it through lack of plans, diagrams, photographs, data or statements.
* Attempts to universally apply a standard format of presentation without modification to display the diversity of features and factors that occur in differing circumstances.
* The use of complicated systems of value judgements and point scores in matrix charts rather than factual statements concerning impacts on the environment that are relevant to decision-making.

With reference to Botha's (1989) SAPOA proposal for an 'Atlas of Environmentally Sensitive Areas' (cf. Section 4.3 p.68), it should be pointed out that Greyling & Huntley (1984) presented a Directory of southern African conservation areas in which descriptions of, *inter* *alia*: location, geomorphological and other physical features, dominant flora and fauna, all endangered species, soils, hydrology and infrastructure are given. While these areas are all proclaimed conservation areas, they nevertheless provide a useful guide to environmental factors in those regions.

In this study the emphasis is on natural resources data and the consideration thereof for planning purposes. Canter (1977) however, suggests that socio-economic factors and cultural resources are recently becoming of more interest in environmental impact assessment when compared with the pure physical environmental factors. He points out that the geographical area to be considered for cultural resources should not be limited to the specific area where developments will occur but should extend to encompass the whole cultural region.

5. CONCLUSIONS

Hall (1989) considers the IEM concept as one which offers a practical approach which can resolve the problems of achieving an ideal balance between the conflicting priorities of the development and conservation of the environment.

In the RSA the implementation of IEM is affected by the disparate economic situation among the various population groups. Viljoen (1989) finds that while the better developed sectors of the community can find the time, money and energy to investigate the influences of development on the environment, the majority of people in this country are involved in a battle for survival.

For IEM to eventually succeed and become part of society, it has to be accepted as an integral part of the policy and strategy of all planning and development bodies. To succeed in the long run, IEM needs to be implemented on an ongoing basis. Viljoen (1989) suggests that, due to fresh insight brought about by countrywide urbanization, a climate has been created in which IEM will be more readily accepted than 20 years ago.

He is convinced that IEM will come into its full right in the RSA society where 90% of the population will shortly be urbanized. It should be borne in mind that IEM is not a unique process but rather a continuous action and should therefore be included in the planning and decision-making policies of controlling bodies. If this is not done, subsequent evaluation of development proposals by specialists could lead to repeated confrontations, delays and loss of confidence between all concerned. Van Riet (1989a) feels that public participation in the IEM process can elicit a positive response and provide meaningful input for inclusion in the development proposal.
Finally, IEM should not be seen as a guarantee against wrong decisions about developments, but IEM can limit wrong decisions if correctly implemented (Viljoen 1989).

CHAPTER 4. THE HYDROLOGICAL CYCLE AND HYDROLOGICAL MODELLING

1. INTRODUCTION

Braune (1989) finds that, in line with developments overseas, there is a broadening of the hydrological discipline in the RSA. This move manifests itself in a number of recent national developments, *inter alia*:

* The recognition of water for environmental management as a user category similar to water for domestic, industrial and agricultural uses.
* A move from a pollution control to a water quality management approach.
* A shift in emphasis from specific water projects to whole catchment planning.
* A move to high technology information systems including remote-sensing, digital image and geographical information systems (GIS).

McHarg (1969), in commenting on the inclusion of a discussion on matter, natural cycles and nature in general in his study, states that the diagnostic and prescriptive powers of a rudimentary ecological approach to conservation and development issues, carry more weight and have more value than arguments based on 'plaintive bleeding-heartism' (1969: 55).

McHarg (1969) considers nature as an interacting process, responsive to laws, constituting a value system and offering intrinsic opportunities and limitations to human uses.

In describing the importance of water in all the processes of nature, McHarg (1969) uses the theoretical example of a single drop of water in the upper regions of a catchment which may appear and re-appear as cloud, precipitation, surface-water in streams and lakes or as ground water; it can participate in plant and animal metabolism, transpiration, condensation, decomposition, combustion, respiration and evaporation.

The same drop of water may appear when considering climate, microclimate, water supply, flood, drought, erosion control, industry, commerce, agriculture, forestry, recreation, scenic beauty, clouds, stream, river and sea. McHarg (1969) concludes that water can thus be seen as an indicator of the interaction of natural processes and that any human action which leads to changes to any part of nature will affect the whole.

Terrestrial natural processes require water; in turn fresh water processes are inseparable from the land (McHarg, 1969). It then follows that land management will affect water and water management will affect land processes.

Water quality and quantity are related to both land and water management and McHarg (1969) is convinced that knowledge of water and terrestrial processes will enable man to discriminate between lands that should remain in their natural condition and those lands on which certain uses can be allowed.

2. HYDROLOGY AND THE HYDROLOGICAL CYCLE

It is often useful for planners to have a conceptual framework within which to analyse environmental problems and planning issues or to anticipate the consequences of development. Dunne & Leopold (1978) suggest that the hydrological cycle provides such an ideal framework.

Within this framework human modification of land and water resources can be analized. Dunne & Leopold (1978) find that people are the major agents in the hydrological cycle. They alter the land surface, manipulate the quantities of water in various stages of storage and radically change the concentrations of sediment, solutes, heat and biota. A great many planning issues that confront a planner can therefore be analised by considering the paths that water takes, what water is doing at various stages along each path and how the quantity and quality of water is altered by human action.

2.1 Hydrology

Hewlett & Nutter (1969: 2) defined hydrology as ' ... the study of water in all its forms on, in and over the land areas of the earth, including its distribution, circulation and behaviour, its chemical and physical properties, and the reaction of the environment, including living things, <u>on</u> water'.

Hydrology can also be defined as the science which deals with the processes governing the replenishment and depletion of the water resources of the land areas of the earth (Schulze, 1985b). As such hydrology centres in understanding and describing rigorously the various components of the hydrological system.

The science of hydrology underlies watershed management, which is defined by Hewlett & Nutter (1969: 2) as ' ... the management of the natural resources of a drainage basin primarily for the production and protection of water supplies and water based resources, including the control of erosion and floods, and the protection of aesthetic values associated with water.' The natural system for the purpose of this study, is seen as the hydrological cycle operating in a catchment and which contains processes that are of benefit to man.

2.2 The hydrological cycle

The hydrological cycle refers to the cycling of water from the ocean and land into the atmosphere and back again, including all the pathways and processes connected with the storage and movement of water in its liquid, gaseous and solid forms. (Hewlett & Nutter, 1969).

They estimate that approximately 50% of all solar energy that reaches the earth's surface is used to vaporize water. Some of the solar heat energy develops convection currents in the atmosphere which, in turn, helps to move the evaporated water from ocean to land and around the world.

Nace, quoted by Hewlett & Nutter (1969) determined the distribution of all water as follows:

Salt water	97,137%
Fresh water	
Ice and snow	2,240%
Ground and soil water	0,612%
Freshwater lakes	0,009%
Rivers	0,001%
Atmosphere	0,001%
Total	100%

As most of the fresh water occurs in polar ice and permanent snow-caps, we deal only with a very small percentage of total water supply in the form of ground water, lakes, rivers and atmospheric moisture.

In analyzing the annual movement of water, in both liquid and gaseous form, Hewlett & Nutter (1969) estimate the following:

Evaporation from oceans:	40%
Precipitation on to oceans:	37%
Net inland transfer:	3%
Evaporation from land:	7%
River flow into oceans:	3%
Precipitation on to land:	10%
Total	100%

The general water cycle, in an over simplified way, can be schematically represented as shown in Figure 4.1.

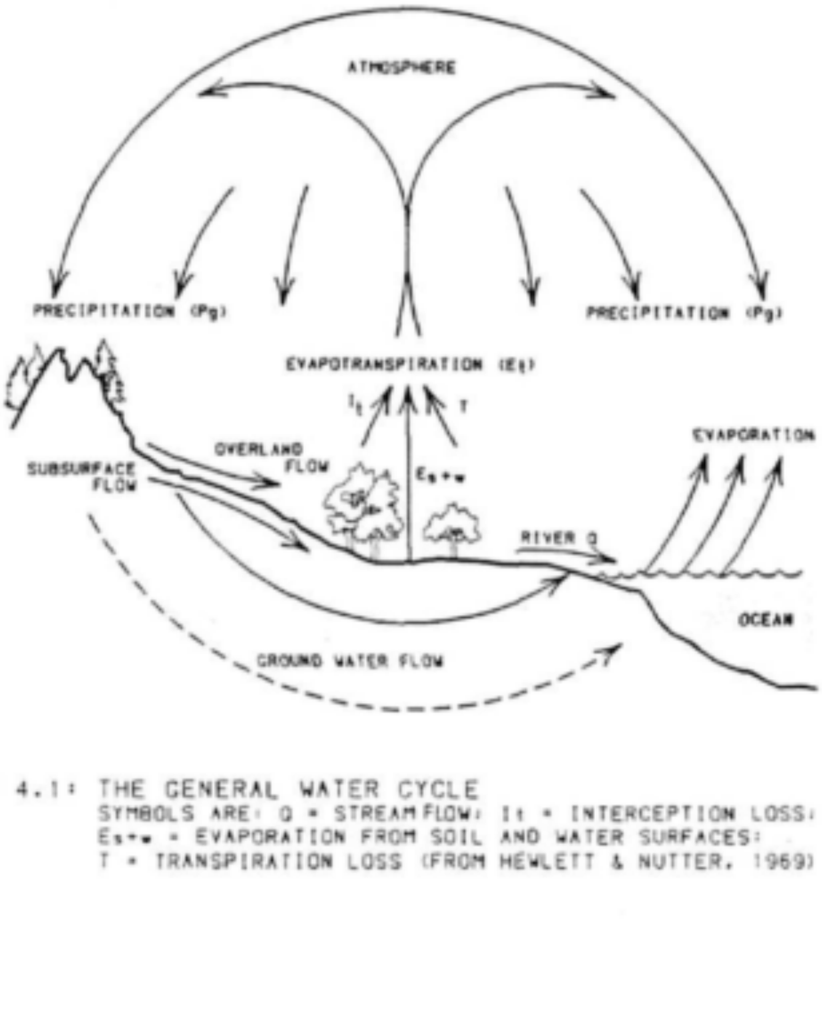


FIGURE 4.1: THE GENERAL WATER CYCLE
SYMBOLS ARE: Q = STREAM FLOW; I_t = INTERCEPTION LOSS; E_{s+w} = EVAPORATION FROM SOIL AND WATER SURFACES; T = TRANSPIRATION LOSS (FROM HEWLETT & NUTTER, 1969)

3. HYDROLOGICAL VARIABLES

3.1 Ground water

The saturated subsurface zone (or phreatic zone) contains the largest source of unfrozen fresh water in the world. Dunne & Leopold (1978) estimate that it constitutes 21% of all the world's fresh water and 97% of all the unfrozen fresh water.

In Figure 4.2 the occurrence and characteristics of ground water are diagrammatically shown and described.

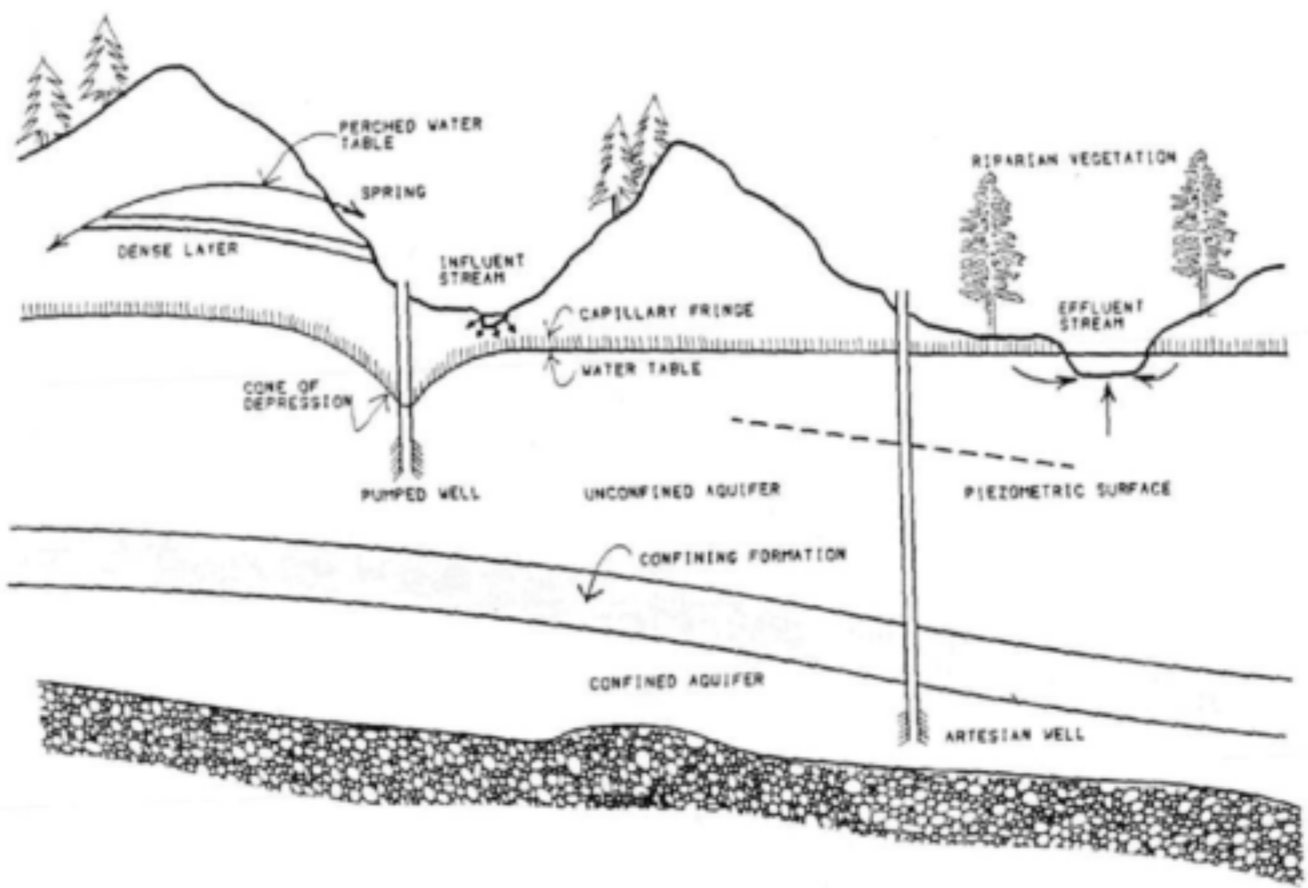


FIGURE 4.2: OCCURRENCE AND CHARACTERISTICS OF GROUND WATER
(FROM HEWLETT & NUTTER, 1969)

However, some terms do need further elucidation:

* capillary fringe: a short distance above the water table where saturation occurs at pressures less than atmospheric pressure;
* effluent stream: a stream fed by ground water;
* influent stream: a stream losing water to ground water;
* confined aquifer (artesian aquifer): where water is confined below a relatively impermeable geologic formation. This water is under pressure and as a result will rise into wells penetrating the confining stratum;
* piezometric surface: an imaginary line projected across the water levels in a series of artesian wells; and
* flowing wells : when the piezometric surface is above the ground surface.

3.2 Surface-water runoff

Surface runoff constitutes the major portion of precipitation which we are able to harness for beneficial use. It is therefore our most important water resource and Hobbs (1981) considers it extremely important that we research those factors which affect the quality and quantity of this primary source.

The paths taken by water (see Figure 4.3 p.83) determine many of the characteristics of a landscape, the generation of storm runoff, the uses to which land may be put and the strategies required for wise land management.

An appreciation of runoff processes therefore allows the planner to recognize present constraints, to predict the consequences of the various forms of developments and thus prevent possible problems. Information about runoff-producing areas is a useful input for zoning regulations.

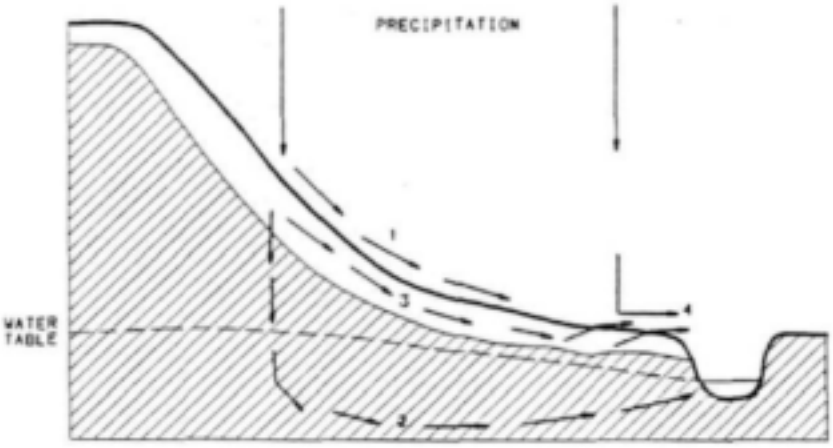


FIGURE 4.3: POSSIBLE PATHS OF WATER MOVING DOWNHILL (PATH 1 IS HORTON OVERLAND FLOW; PATH 2 IS GROUND WATER FLOW; PATH 3 IS SHALLOW SUB-SURFACE STORM FLOW; PATH 4 IS SATURATION OVERLAND FLOW, COMPOSED OF DIRECT PRECIPITATION ON THE SATURATED AREA PLUS INFILTRATED WATER THAT RETURNS TO THE GROUND SURFACE. THE UNHACHED ZONE INDICATES HIGHLY PERMEABLE TOPSOIL, AND THE HATCHED ZONE REPRESENTS LESS PERMEABLE SUBSOIL OR ROCK).
(FROM DUNNE & LEOPOLD, 1978)

Depending on certain soil properties such as depth, surface conditions and layering, the extent of certain components of the hydrologic cycle e.g. infiltration capacity, infiltration rate and hence runoff are determined.

A knowledge of runoff generation methods is useful in the catchment planning process for several reasons. Dunne & Leopold (1978) find that it allows one to recognize those parts of a landscape that are likely to be major contributors of either storm runoff or ground-water recharge.

Dunne & Leopold (1978) find that when an area is developed for urban purposes, the immediate hydrological effect is to increase the area of low or zero infiltration capacity and to increase the efficiency or speed of water transmission or runoff in channels or conduits.

The total amount of water ending up in a river or stream, and which can be called stream flow, is made op from surface water runoff, precipitation directly on to the stream and subsurface and base flow. The latter two concepts are illustrated in Figure 4.4.

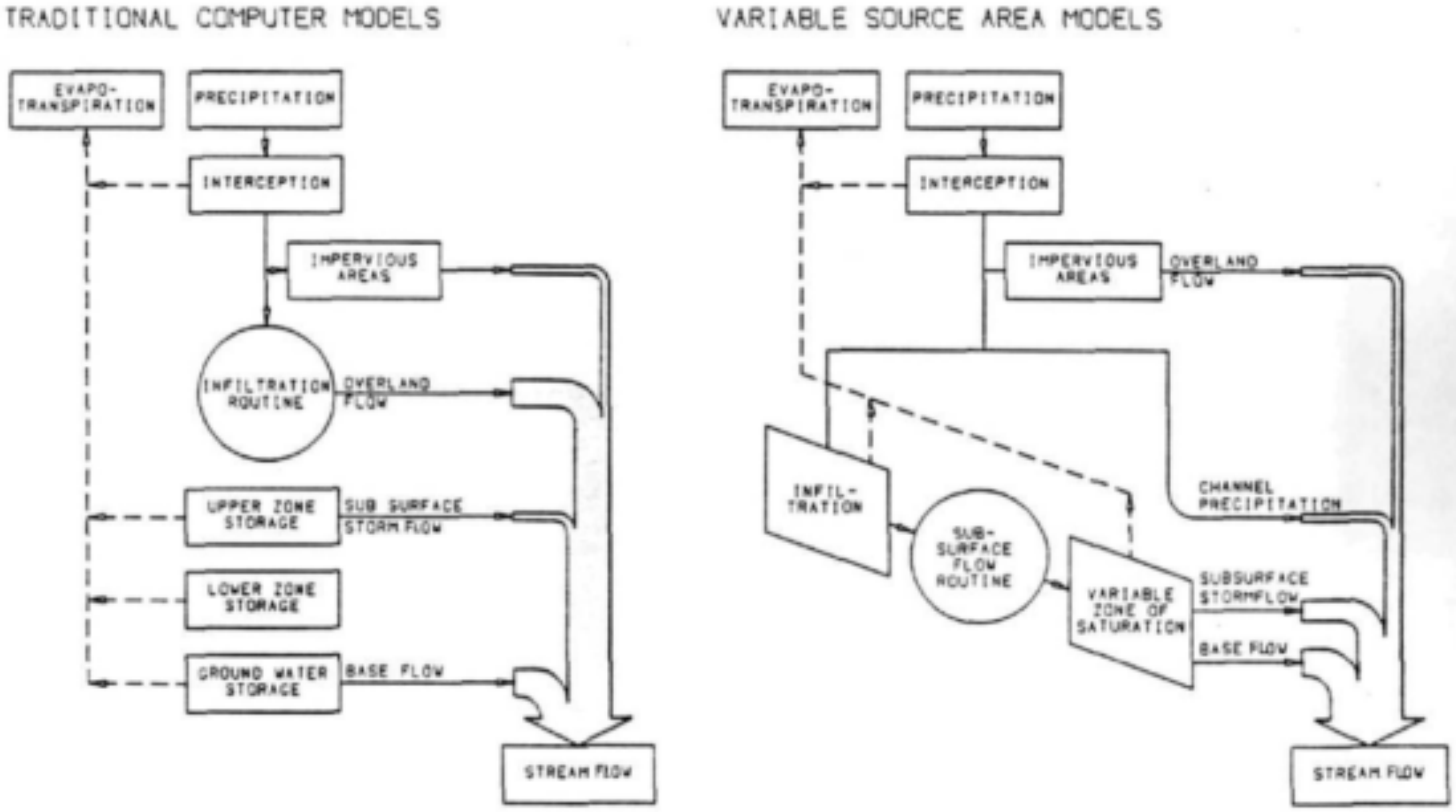


FIGURE 4.4: MODELS OF THE RUNOFF PROCESS, REFLECTING VARIOUS VIEWS OF HOW SOURCE AREAS GENERATE STREAM FLOW
THE MAIN DIFFERENCE BETWEEN TRADITIONAL AND VARIABLE SOURCE AREA MODELS LIES IN THE ROLE OF INFILTRATION (AFTER HEWLETT AND TAKEN FROM ROGERS & VAN DER ZEL, 1989)

The rapidity with which precipitation becomes stream flow is called the hydrological response of that particular catchment or sub-catchment. Normally this hydrological response is expressed as a percentage calculated by dividing direct runoff by precipitation (Hewlett & Nutter, 1969).

They define direct runoff as the sum of channel precipitation, overland flow and subsurface storm flow.

This is an over-simplification of the situation because, apart from direct runoff, stream flow includes base flow as well.

Runoff, which according to Leopold (1968) spans the entire regimen of water flow, can be measured by the number and characteristics of rises in stream flow. The percentage of area made impervious and the rate at which precipitation is transmitted across the land to stream channels are two principal factors governing the water-flow regimen (Leopold, 1968).

Land use determines the permeability of land to precipitation, and the density, size and characteristics of tributary channels determine the water-flow rate across land.

The volume of runoff is governed primarily by infiltration characteristics which in turn are related to land slope, soil type and type of vegetative cover (Leopold, 1968). The volume of runoff is also therefore directly related to the percentage of impervious surface land uses such as buildings, pavings, streets, etc.

Runoff volumes inversely affect subsurface and base flow, and soil moisture storage.

The nature of the catchment's surface e.g. paved, tilled, grassed and afforested (thus, the land use) will determine the amount of overland flow compared to subsurface and base flow. The intensity of storms or precipitation, catchment form, antecedent dry period, soil surface and subsurface moisture condition also influence the contribution of the various flow mechanisms. Hart & Allanson (Editors)(1984) remark on the present trend in some areas to reduce the catchment vegetation cover. Consequently storm flow increases at the cost of reduced base flow. This problem is also manifested in more common and damaging flash floods in these areas. In Figure 4.5 (p.87) a typical land parcel (in this instance a map of Georgia, USA) with its basin and regional direct runoff percentages, are shown. Broader scale regions such as geomorphological 'provinces' may be grouped together to determine regional runoff averages compared to individual drainage basin averages. The relationship between direct runoff and precipitation has been found to be curvilinear rather than linear, with increasing runoff coefficients with increasing precipitation (Hart & Allanson (Editors), 1984).

3.3 Lag time

The term lag time is used for stating the temporal relation between the rainstorm and the runoff. Lag time is defined by Leopold (1968: 3) as:

'the time interval between the centre of mass of the storm precipitation and the centre of mass of the resultant hydrograph'.

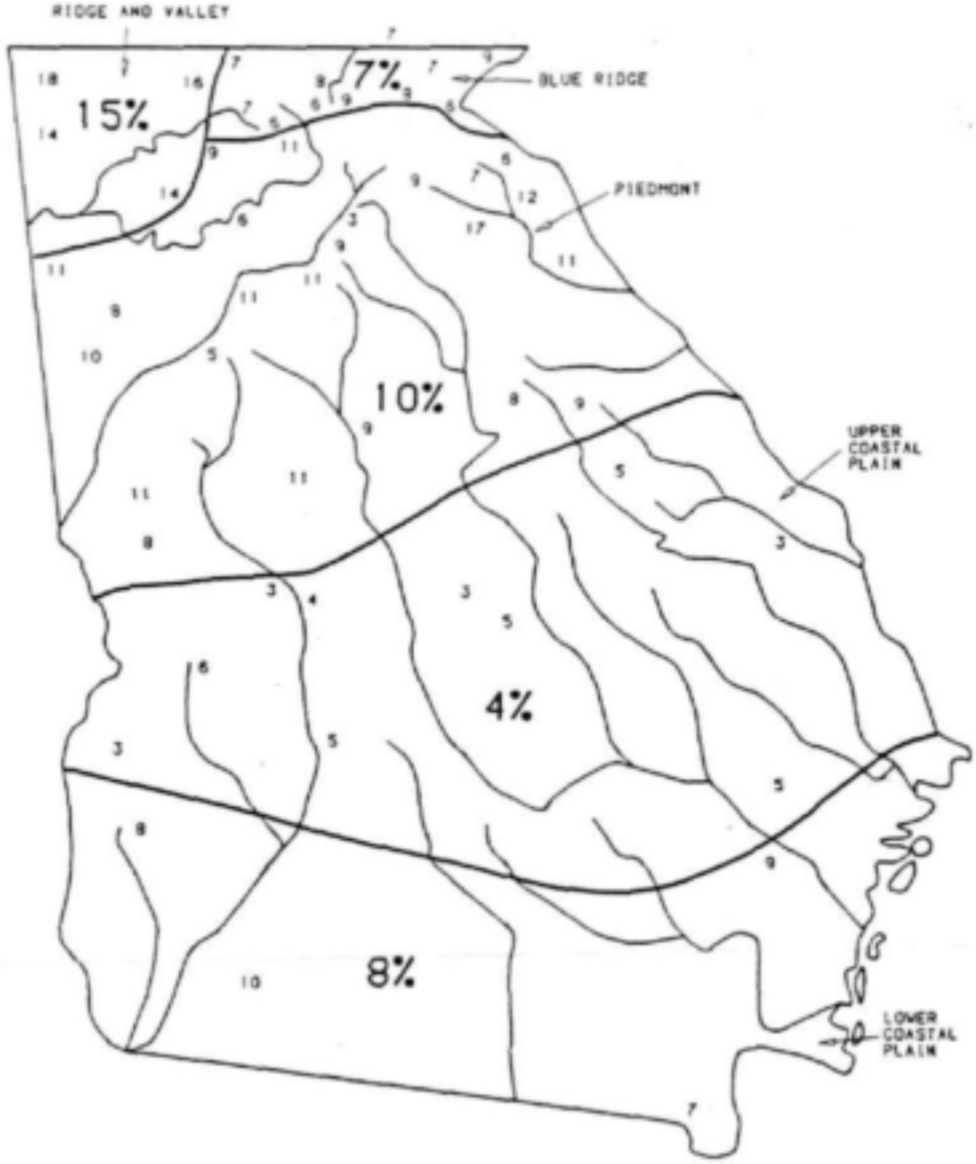


FIGURE 4.5: MAP OF GEORGIA USA SHOWING THE AVERAGE PERCENTAGE OF ANNUAL PRECIPITATION WHICH BECOMES STORM FLOW (DIRECT RUNOFF). THE LARGE FIGURES ARE REGIONAL AVERAGES. THE SMALL FIGURES ARE LONG-TERM AVERAGES FOR INDIVIDUAL BASINS. (U.S.G.S. AND U.S. WEATHER BUREAU RECORDS AND TAKEN FROM HEWLETT & NUTTER, 1969)

In Figure 4.6 this relation is shown. Lag time is determined as a function of two catchment parameters, namely: the mean catchment slope and the catchment length.

Lag time may be altered materially by the effects of urbanization in the catchment area. As water generally runs off quicker from streets, artificial channels, storm sewers and roofs than from natural vegetated areas, this decreases the lag time. It therefore follows that as the time required for a given amount of water to runoff decreases, the peak rate of runoff or flood peak increases.

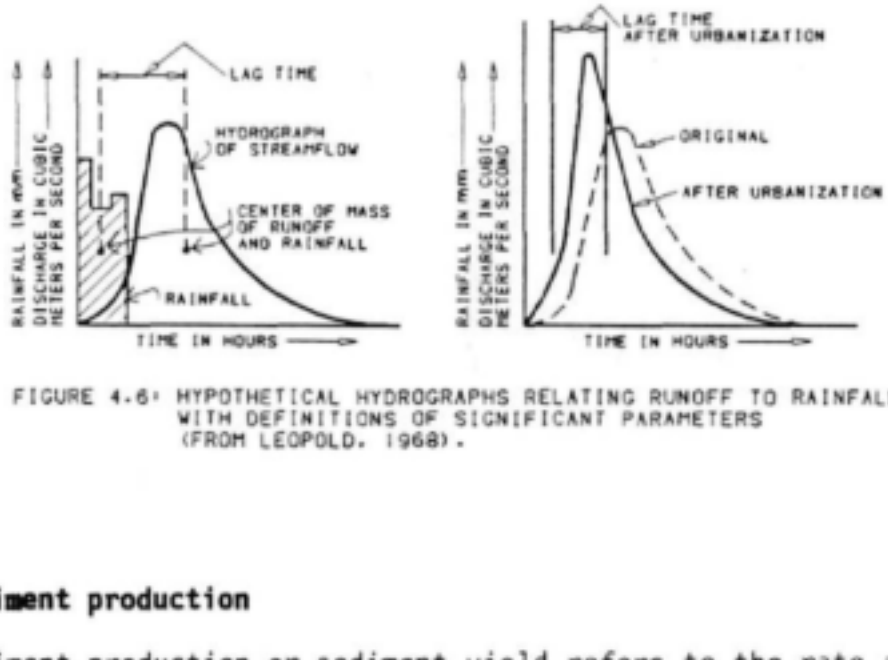


FIGURE 4.6: HYPOTHETICAL HYDROGRAPHS RELATING RUNOFF TO RAINFALL WITH DEFINITIONS OF SIGNIFICANT PARAMETERS (FROM LEOPOLD, 1968).

3.4 Sediment production

Sediment production or sediment yield refers to the rate at which sediment passes a particular point in the drainage system, usually expressed as volume or mass per unit of area per unit of time (tons/ha/yr) (Dunne & Leopold, 1978).

Because precipitation falls on the landscape, and is aided by the action of biological agents, it breaks down rocks by weathering, forming soil and rock debris, and dissolving some of it.

The precipitation also feeds the river, carries the dissolved load and moves the weathered debris.

The principal effect of land use on sediment yield comes from the exposure of the soil to storm runoff (Leopold, 1968). The baring of ground during urbanization, construction works, tilling, etc. are some of the major land uses affecting sediment production.

Leopold (1968) found that sediment yield from urban areas tend to be larger than from unurbanized areas. Studies in the eastern United States showed that urbanized and developing areas yielded between 5 and 200 times more sediment than unurbanized catchments (Wolman, quoted in Leopold, 1968).

Most sediment carried by a stream is moved by high flows. Leopold (1968) estimated that for a stream in Pennsylvania USA with a catchment area of 80 900 ha, 54% of the total yearly transported sediment is carried by flows that occur on average about three days each year.

Sediment yield is directly related to land slope. In various studies it was found that the rate of erosion is proportional to the 1,35 power of land slope and to the 0,35 power of slope length (Horton & Musgrave and quoted in Leopold, 1968). Sediment yield is therefore more sensitive to land slope than to slope length but remains positively correlated with both.

Sediment is widely considered to cause pollution and it has become important to be able to predict sediment delivery from catchments and to assess its influence during catchment planning and management.

Crosby, Smithen & McPhee (1981) find that there is, as yet, no simple procedure for predicting the influence of land use on sediment production in a catchment. They find that the Universal Soil Loss Equation (USLE) forms the basis for most current empirical prediction procedures.

The USLE was developed in 1954 by the USDA and Purdue University. It is important to note that the USLE was initially developed from a wealth of data and therefore the component factors have a statistical rather than a physical origin.

Crosby, *et al.* (1981) find that the equation is essentially valid for estimating average annual soil loss due to sheet and rill erosion over a long period (10-20 years), and should not be used to provide soil loss estimates for individual storms or single seasons.

The USLE soil loss equation is as follows:

$$\mathbf{A = RKLSCP}$$

where A = computed soil loss per unit area (t/ha)

R = rainfall and runoff factor

K = soil erodibility factor

L = slope-length factor (dimensionless)

S = slope-steepness factor (dimensionless)

C = cover and management factor (dimensionless)

P = support practice factor (dimensionless)

The individual factors listed above and their application in South Africa are dealt with by Crosby, *et al.* (1981: 190-206) and a discussion is therefore outside the scope of this study.

3.5 Water quality

With quality of water is meant the physical, chemical and biological attributes that affect the suitability of water for agriculture, industry, drinking, recreation and other uses.

All land uses affect water quality. Agricultural use tends to increase nutrients in streams. These nutrients are derived from excretion products of farm animals and commercial fertilizers. Bosch, Alletson, Jacot-Guillarmod, King & Moore (1986: 60) emphasize the ever-increasing stress placed on the water courses within catchments caused by the 'insidious underground drainage of fertilizers, biocides and sewage (e.g. sewage from septic tanks)'. These factors represent the major non-point sources of pollution.

Leopold (1968) found that although change in land use from agriculture to residential tends to reduce these nutrients, this tendency is counteracted by urban pollutants such as oil and other petroleum products. The net result is a generally lower water quality which can be measured by the balance and variety of organic life, quantity of dissolved material and by the bacterial level in streams.

More specifically, the effects of increased urbanization on water quality are manifested in an increase of dissolved solids and a decrease in the dissolved-oxygen content, as well as in a decrease in ground water quality due to an increased area of imperviousness and decreased lag time which lead to flashier floods with higher flow peaks and lower flows during non-storm periods.

In a developing country such as the RSA, unplanned and unco-ordinated urbanization of rural areas is sometimes, at least during the initial stages, associated with septic tank sewage disposal and borehole supply of drinking-water.

Soils normally contain a flourishing fauna of micro-organisms which tend to destroy or adsorb pathogenic bacteria seeping from a septic tank installation. The effectiveness with which soils accomplish this cleansing is dependant on various factors, *inter alia:*

* soil texture and structure;
* position of groundwater table;
* distance that pollutants travel through a seepage field; and the
* rate at which pollutants travel through a seepage field.

Fine textured soils tend to become easily clogged with bacteria and other pollutants. Soils with pronounced structure are less effective cleansers than apedal soils as the former contain more pathways along which pollutants can travel unchecked (Leopold, 1968).

Studies by Olson & Wayman and Page & Robertson (quoted in Leopold, 1968) indicate that the position of the water table is critical, as a pollutant, once having reached the ground water level (saturated flow), is transmitted virtually without further cleansing. These authors' work also indicate little cleansing of or change in dissolved pollutants effected by movement through soil.

As a general rule of thumb for planners, Leopold (1968) suggests that, for soil cleansing to be effective, contaminated water must move through unsaturated soil for at least 30 metres. In Table 4.1 (p.93) minimum absorption areas for domestic septic tank drainage disposal systems for various soil textures are shown.

Leopold (1968) also considers it prudent to maintain at least 100 m between a septic tank effluent point and a stream channel if suitable protection of water quality is to be achieved. It should however be kept in mind that even this minimum setback does not prevent dissolved materials, especially nutrients such as nitrates, phosphates and chlorides, from reaching and enriching stream water and thus potentially encouraging the growth of algae and otherwise creating a biotic imbalance (Leopold, 1968).

TABLE 4.1: MINIMUM ABSORPTION AREAS FOR DOMESTIC SEPTIC TANK DRAINAGE DISPOSAL SYSTEMS IN VARIOUS SOILS
(FROM US PUBLIC HEALTH SERVICE IN DUNNE & LEOPOLD, 1978 AND METRICATED BY AUTHOR)

SOIL TEXTURE	m^2 ABSORPTION AREA REQUIRED FOR EACH BEDROOM IN DWELLING
GRAVEL AND COARSE SAND	6.5
FINE SAND	8.4
SANDY LOAM	10.7
CLAY LOAM	14.0
SANDY CLAY	16.3
CLAY WITH SMALL AMOUNTS OF SAND AND GRAVEL	23.2
HEAVY CLAY	UNSUITABLE

In their study on wetlands, Sather & Smith (1984) stress the important effects which wetlands have on water quality. They found that water, passing through wetlands, are subject, *inter alia*, to the following changes:

* sediment binding of particles in the water. Pollutants are readily absorbed or adsorbed by mineral and organic sediments which then become buried in the substrate;
* decomposition of organic substances in the water by micro-organisms;
* reduction of water velocity as it enters the wetlands; and the
* uptake of dissolved substances in the water by the metabolic activities of wetland flora. These substances may include, among others, toxic materials and certain nutrients such as nitrogen and phosphorous.

3.6 Recreation potential

The recreational or amenity value or potential of rivers is adversely affected by three factors (Leopold, 1968) namely:

3.6.1 STABILITY OF THE STREAM CHANNEL

A channel which is gradually enlarged by increased floods caused by increased urbanization, tends to have unstable and unvegetated banks, scoured or muddy channel beds and an accumulation of debris.

3.6.2 ACCUMULATION OF ARTIFACTS

The artifacts of civilization such as beer cans, oil drums, plastic containers, bits of timber, bits of steel wire, - 'the whole gamut of rubbish from an urban area' (Leopold, 1968: 3) accumulate in the stream channel and on flood plains. While this may not significantly affect the hydrological function of the stream, it does affect the recreational potential adversely.

3.6.3 THE BALANCE IN THE STREAM BIOTA

The addition of nutrients to a stream promotes the growth of plankton and algae which in turn disrupts the balance in the stream biota. Leopold (1968) found that this problem is manifested in the covering of rocks in clear streams with slime, increases in water turbidity and odours eminating from the stream.

3.7. River ecological conservation status

As O'Keeffe (1986b) points out, conservation criteria for rivers are those characteristics of rivers by which their conservation should be judged. Newbold (In O'Keeffe, 1986b) identified a number of standard criteria for nature conservation which, for the purpose of this study, can be made applicable to catchments. They are, *inter alia*:

* Naturalness (the extent to which the catchment rivers have been artificially altered from their natural state by man).
* Diversity (the natural genetic and/or species diversity of the biota in the catchment as well as to the diversity of habitat in the system).
* Rarity (of species or habitat is important both in terms of the intrinsic value of rarities and their use as first indicators of habitat degradation).
* Fragility (indicates the resilience of river systems in catchments to interference and the level of threat of further interference).
* Geographical position (is important because it affects the threat status of a river and because different use priorities are applicable to heavily populated catchments when compared with remote rural ones).

These criteria however, apply largely to priorities for nature conservation in the narrow sense and O'Keeffe (1986a) propagates the view that rivers in their catchments should be conserved from a holistic point of view in which the river is seen as a renewable resource which can be exploited for multiple uses; the overall aim being to maximize its uses with minimal detriment to its essential functions. In this regard O'Keeffe (1986a) lists some of the river uses and functions as follows:

River functions:

* landscape drainage;
* water supply;
* sediment transport;
* nutrient transport;
* water transport;
* water purification;
* nutrient recycling;
* biotic dispersal;
* vegetation maintenance;
* biotic habitats; and
* ground water recharge.

River uses:

* abstraction for domestic, industrial, agricultural, forestry and fishery use;
* recreational;
* conservation; and
* educational and scientific.

Man interferes with river ecosystems in catchments in four basic ways, namely:

* Consumptive abstraction of water.

* Creation of flow discontinuities by the erection of hydraulic structures such as barrages, dams and weirs with the resultant desynchronization of processes and events through managed discharges into receiving streams.
* Pollution of rivers by pollutants in various forms and strengths.
* Transfer of water between catchments.

(Davies & Day, 1989.)

In Table 4.2 some ecological effects on rivers downstream of various types of flow modification structures are shown.

TABLE 4.2: SOME ECOLOGICAL EFFECTS ON RIVERS DOWNSTREAM OF DIFFERENT TYPES OF FLOW MODIFICATION STRUCTURES
(FROM O'KEEFFE, et al. 1989)

TYPE OF FLOW MODIFICATION	TOTAL FLOW	FLOODS	SEASONALITY	WATER QUALITY	PREDICTABILITY	SUSPENDED SEDIMENT CONCENTRATION	WATER TEMPERATURE RANGE	BIOTIC DIVERSITY
IMPOUNDMENT	DECREASE	DECREASE (MODERATE FLOODS)	DECREASE	IMPROVEMENT OR DETERIORATION	INCREASE	DECREASE	DECREASE	DECREASE (USUALLY)
FLOOD CONTROL IMPOUNDMENT	NO CHANGE	DECREASE	DECREASE	NO CHANGE	NO CHANGE	DECREASE	NO CHANGE (USUALLY)	NO CHANGE (USUALLY)
INTERBASIN TRANSFER:								
DONOR RIVER	DECREASE	NO CHANGE	INCREASE	DETERIORATION	DECREASE	NO CHANGE	INCREASE	DECREASE (USUALLY)
RECIPIENT RIVER	INCREASE	NO CHANGE	DECREASE	IMPROVEMENT	INCREASE	DECREASE	DECREASE OR INCREASE	VARIABLE
RUN-OF-THE-RIVER ABSTRACTION	DECREASE	NO CHANGE	INCREASE	DETERIORATION	DECREASE	NO CHANGE	INCREASE	DECREASE (USUALLY)
CATCHMENT MODIFICATION	NO CHANGE OR DECREASE OR INCREASE	INCREASE	INCREASE	DETERIORATION	DECREASE	INCREASE	NO CHANGE	DECREASE (USUALLY)

3.8 Land use modifications

Some modifications are designed to improve the catchment's water resources but as Schulze (1981) points out, others are carried out for purposes unrelated to water, but with hydrological side-effects. In all cases our aim should be to predict all possible effects before any modification is carried out.

Schulze (1981) suggests hydrological modelling as the most likely means of making these predictions in any environmental impact assessment.

The primary hydrological effects of land use modifications according to Schulze (1981) are as follows:

* Increase or decrease in water yield.
* Increase or decrease in peak flows.
* Increase or decrease in low flows.
* Increase or decrease in surface-water quality.
* Increase or decrease in ground water supply.
* Increase or decrease in ground water quality.

The various modifications caused by land use and their hydrological effects are tabulated in Table 4.3 p.99.

In addition to those hydrological effects listed above, it must be realized that land use changes affect every event in which precipitation is transformed into measurable products of a catchment, e.g. water, sediment or vegetation growth (Schulze, 1981).

TABLE 4.3: Typical land use modifications and their possible hydrological effects (Larson and taken from Schulze, 1981)

Land use Modification	Hydrological effects: Increase/Decrease in:					
	Water Yield	Peak Flows	Low Flows	Surface-Water Quality	Ground Water Supply	Ground Water Quality
Modify vegetative cover (density or species)	X	X	X	X		
Inhibition of land evaporation or transpiration	X		X			
Modify soil conditions (tillage, mulching, etc)	X	X	X	X		
Modify land surface geometry (contouring, terracing, etc)	X	X		X		
Install subsurface drainage systems			X			X
Operate irrigation systems			X		X	X
Urbanization, road construction	X	X	X	X		

3.9 Conclusions

There are four interrelated but separable effects of changes in land use on the hydrology of that area, namely:

* changes in peak flow characteristics;
* changes in total runoff;
* changes in water quality; and
* changes in the visual aspects of hydrological amenities.

(Leopold, 1968.)

He finds that of all land use changes affecting the hydrology of an area, urbanization is by far the most forceful. Davies & Day (1989: 18) come to the same conclusion.

As urbanization increases, concomitant activities during the construction period increase the sediment yield many thousands of times. Higher peak flows result from increased runoff and decreased lag time - all factors resulting from increased urbanization. Leopold (1968) finds that these factors emphasize the need to provide temporary storage upstream to counteract the tendency of urbanization to increase the number and size of high flows.

McHarg (1969) finds that urbanization proceeds by increasing the density within and extending the perifery, always at the expense of open space. Traditionally this growth has been totally unresponsive to natural processes and their values to society. McHarg (1969: 57) states that 'Optimally, one would wish for two systems within the metropolitan region - one the pattern of natural processes preserved in open space, the other the pattern of urban development'.

Furness (1989) found that water quality in many regions of South Africa is deteriorating mainly due to salination, eutrophication and pollution by micro-pollutants and to a lesser extent to erosion, faecal and organic pollution.

Van der Merwe & Grobler (1989) have proposed a new approach to water quality management. This approach is based on four principles, namely:

* The desired quality of a water resource is determined by its present and/or intended uses. This quality should be stated as a list of water quality objectives.

* It is accepted that the water environment has a certain, usually quantifiable, capacity to assimilate pollutants without detriment to predetermined quality objectives.
* The assimilative capacity of a water body is part of the water resource and, as such, must be managed judiciously and shared in an equitable manner among all water users for the disposal of their wastes.
* For those pollutants which pose the greatest threat to the environment, because of their toxicity, extent of bio-accumulation and persistence, a precautionary approach aimed at minimizing or preventing inputs to the water environment should be adopted.

4. CATCHMENT MORPHOLOGY

4.1 Introduction

A catchment (also sometimes known as drainage basin or watershed) is the area of land that drains water, sediment and dissolved materials to a common outlet at some point along a stream channel.
A catchment can also be described as the drainage basin of a river. Bounded by other catchments, its geographical area covers all the land that drains into one river system, from the source to the estuary (Bosch, *et al.*, 1986).

For the purposes of management, a catchment may be divided into subcatchments, and thus include areas specifically associated with various aspects of water storage and drainage patterns.

The geology, geomorphology and pedology of the land influence the behaviour of all hydrological events in a drainage basin or catchment.

Hydrological events or responses are, *inter alia*, the quality of water runoff or loss from a drainage basin, the water storage capacity in both the bedrock and weathered mantle (soils), the quickness of response of stream flow after storms and the distribution of stream flow volumes throughout a year (Hewlett & Nutter, 1969).

In turn, water also acts as a main influence in shaping landforms. Fluvial morphology deals with the effects such as erosion and sedimentation which stream flow has on the land.

4.2 Morphology

As water tends to flow from the land to the sea, it becomes organized into a drainage system which reflects the geological structure and geomorphology of the land. Drainage systems are divided by topographic or surface-water divides to form catchments. (Hewlett & Nutter, 1969.) In Figure 4.7 the nature of a typical drainage basin or catchment is shown and certain characteristics are described.

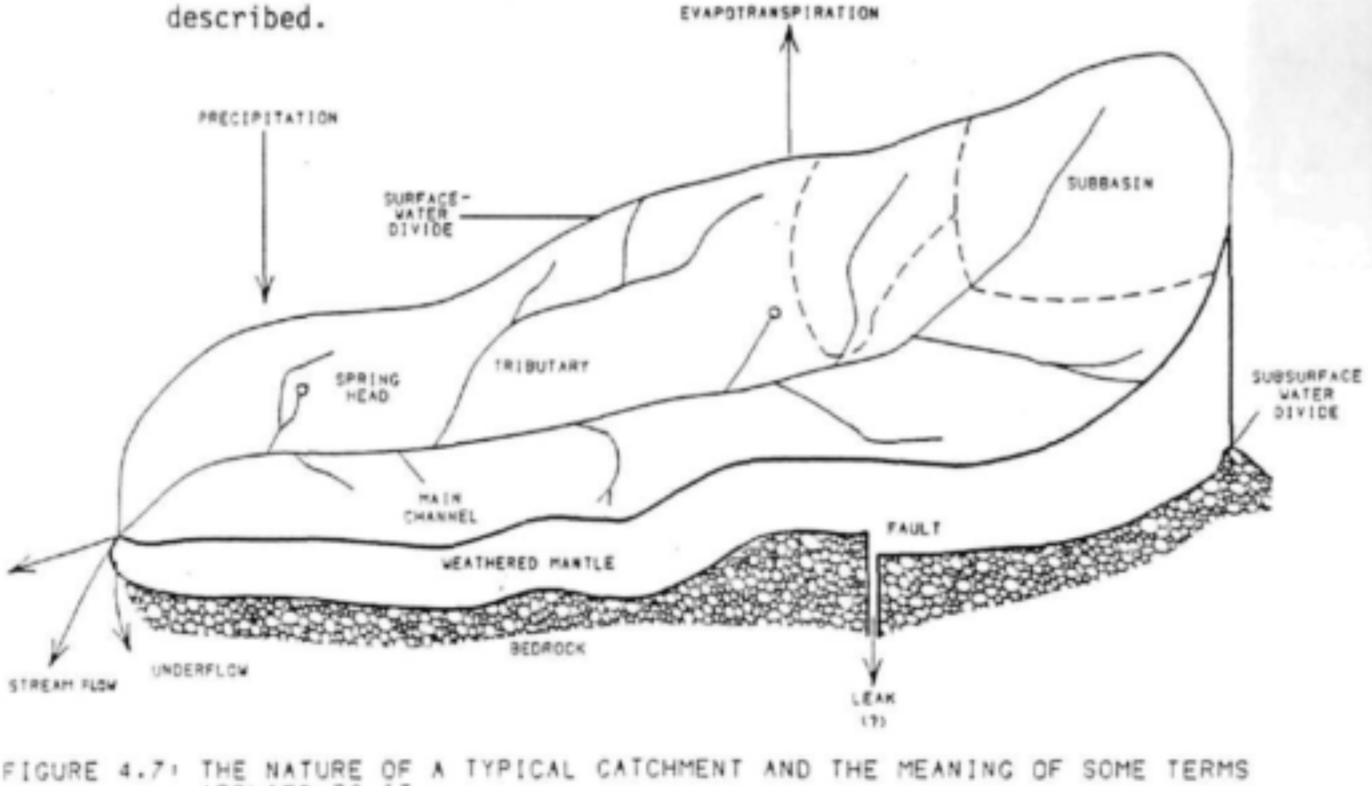


FIGURE 4.7: THE NATURE OF A TYPICAL CATCHMENT AND THE MEANING OF SOME TERMS APPLIED TO IT
(FROM HEWLETT & NUTTER, 1969)

Different drainage patterns evolve with time. These include dendritic, rectangular, trellis on folded terrain and trellis on dissected coastal plains.

In Figure 4.8 these variations are shown. The variations occur mainly due to the nature of underlying geological formations, faults in the rock formations, slope angle and slope length.

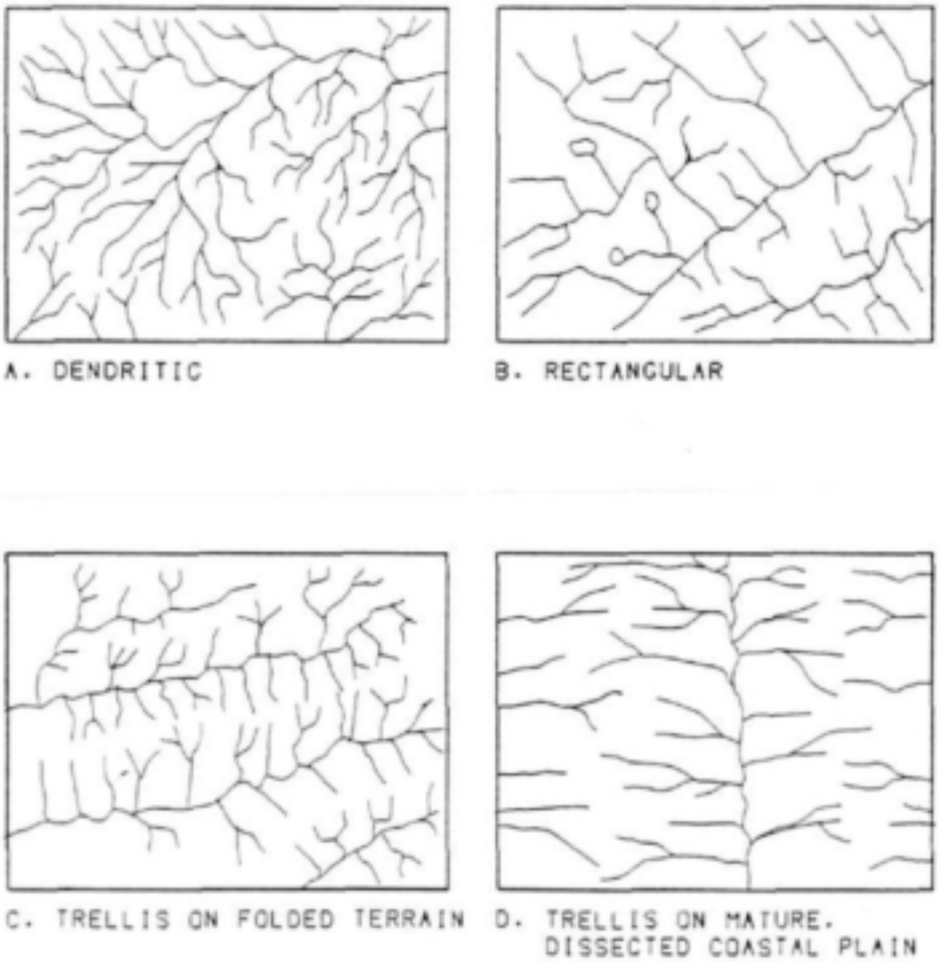


FIGURE 4.8: COMMON DRAINAGE PATTERNS
(FROM HEWLETT & NUTTER, 1969)

Certain topographic features of catchments such as its size, shape, relief, gradient, drainage density and pattern significantly influence the hydrological performance of a catchment (Bosch, *et al.*, 1986).

Figure 4.9 p.105 shows a schematic representation of a catchment's water balance.

Streams and rivers are also classified by the period during which flow occurs:

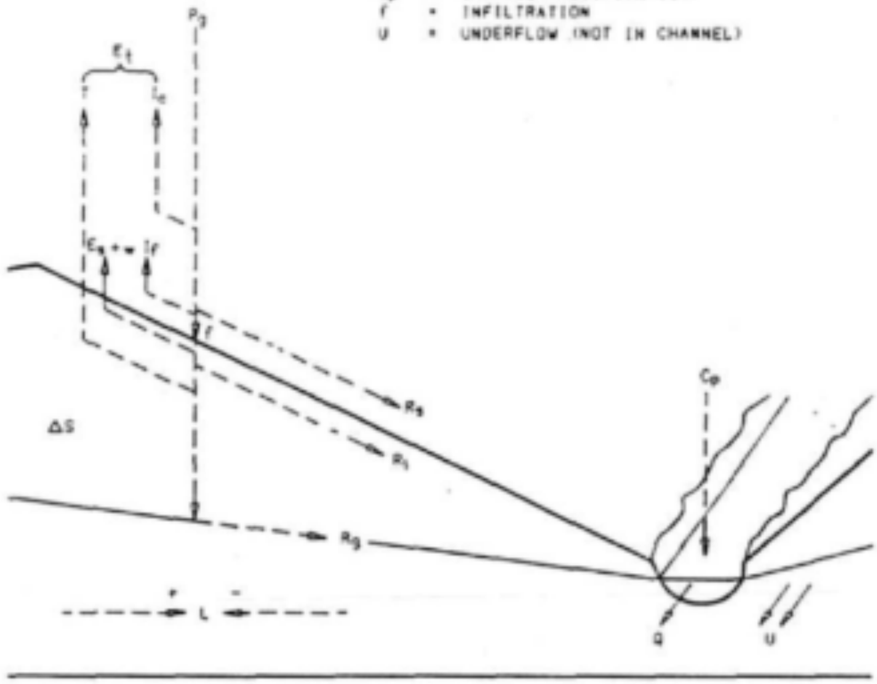
* Perennial flow persists for 90% or more of the year in a well defined channel.
* Intermittent flow occurs only during the wet season (50% or less of the year).
* Ephemeral flow occurs only for a short period after an extreme storm in channels not well defined.

(Hewlett & Nutter, 1969.)

Streams and rivers may also be classified into orders reflecting the ordering or hierarchy of network branches. In Figure 4.10 p.106 a typical catchment with streams numbered in orders is schematically shown. The same hierarchy of orders can also be applied to catchments.

Surface-water and subsurface water divides do not necessarily coincide. In many complex geological formations such as tilted strata and strata with different permeability, it is often difficult to determine into which surface catchment precipitation and subsurface water will flow.

P_g = GROSS PRECIPITATION
T = TRANSPIRATION (LOSS)
I_c = CROWN INTERCEPTION (LOSS)
I_f = FOREST FLOOR INTERCEPTION (LOSS)
E_{s+w} = EVAPORATION FROM SOIL AND WATER (LOSS)
E_t = TOTAL EVAPORATION AND TRANSPIRATION (LOSS)
Q = STREAM FLOW
ΔS = CHANGE IN STORAGE WITHIN BASIN
L = LEAKS IN OR OUT OF BASIN
R_s = OVERLAND FLOW
R_i = SUBSURFACE STORM FLOW
R_g = GROUND WATER OUTFLOW (BASE FLOW)
C_p = CHANNEL PRECIPITATION
f = INFILTRATION
U = UNDERFLOW (NOT IN CHANNEL)



PRECEPTS:

1. TERMS USED REFER TO RATES AND VOLUMES OF WATER FLOW AS WELL AS TO PROCESSES OF FLOW.
2. COMPLEXITY ARISES BECAUSE RATES AND VOLUMES OF FLOW VARY GREATLY IN TIME AND SPACE.
3. OVER A PERIOD OF TIME, A CATCHMENT BASIN BALANCES THE WATER ACCOUNT THUS:

$$P_g = (T + I_c + I_f + E_{s+w}) + Q + \Delta S \pm L + U$$

FIGURE 4.9: SCHEMATIC REPRESENTATION OF THE WATER BALANCE IN A CATCHMENT
(FROM HEWLETT & NUTTER, 1969)

FIGURE 4.10: STREAM ORDERING BY THE RULES PROPOSED BY STRAHLER (DUNNE & LEOPOLD, 1978)

5. CATCHMENT MANAGEMENT

5.1 Introduction

Hydrological studies of catchments are considered the first step in the implementation of an integrated catchment management policy. Conley (1989) distinguishes three important aspects of such studies, namely:

* The collection and evaluation of data.
* The analysis of the information gathered.
* The formulation of strategies and proposals for implementation.

Data collection consists of a comprehensive survey of the catchment to identify all factors influencing the utilization of its water resources. Included herewith are factors such as the catchment's shape, topography, geomorphology, geology, soils, vegetation and water bodies. Sediment production is estimated, land use is mapped, ecologically sensitive areas are identified and mapped and past and present water use is determined (Conley, 1989).

In the RSA there are many cases of rivers having been converted from perennial to intermittent seasonal flows over the last 300 years. It has now been shown (Chutter, in O'Keeffe, 1986a: 21) that precipitation has not decreased significantly over this time and therefore 'these changes must be ascribed to catchment mismanagement leading to erosion, siltation of rivers, with consequent turbidity, unstable river beds, loss of fauna and possible changes in the water temperature regimes'.

Rivers exist as longitudinal ecosystems in their own right but still as part of the catchment ecosystem. Disturbances within the catchment should be recognized as potentially disruptive to all of the river ecosystem downstream (Bosch, *et al.*, 1986).

Ferrar (1989) considers the difficulties of managing the ecological systems in a catchment towards some vaguely perceived 'optimum sustainable state' to be immense and predisposed to failure. This is especially the case with rivers, characterized as they are by extreme dynamics, fluvial functions and other attributes e.g. their special biodiversity and socio-economic values.

Ferrar (1989) finds that, what he terms 'water engineering management', is far advanced due to the RSA water situation and demand, when compared with the general level of catchment management.

Factors such as water abstraction for irrigation, water use for waste disposal, soil erosion and the extremes experienced in the RSA with regard to floods and droughts necessitate our understanding of how catchments and their associated rivers function ecologically.

In the RSA the River Research Programme, under the auspices of the FRD at the CSIR, intends to stimulate research activities into the role of catchments and rivers in South Africa's landscapes of the future.

Hewlett & Nutter (1969) distinguish the following factors which, at the beginning of the 20th century, led to the concept of catchment management:

* Increasing knowledge of the hydrologic cycle and its role.
* Growing population pressure on land and water.
* Unforseen demands for water created by technology and relative high living standards in most developed countries and by rapid population increases in developing countries.
* New and complex problems with water, *inter alia*: flood plains, pollution, settlements in arid lands and many others.
* The realization that individual rights must yield to public regulations.
* The recognition of the catchment as the best natural unit for resource planning and management.

A catchment is an area of land drained by a river and its tributaries. From the point of view of resource management a catchment is a relevant geographical delimitation. It forms a system whose constituent parts are interlinked by the hydrological sub-system (De Meijere & Van de Putte, 1987).

In Australia there has also been a rapidly growing commitment to the concept of integrated or total catchment management. The catchment is identified as the basic resource management unit. Pilgrim (1989) views the catchment as an integrated system, within which there is a close interaction between water and land resources and their surrounding environment. He finds this approach particularly desirable where there are conflicting or competing land and water uses.

McHarg (1969) however, suggests that there are consistencies in natural factors such as geomorphology, soils, hydrological patterns, plant associations, wildlife habitats and even land use and that these can well be examined through the concept of the physiographic region, rather than a catchment area. He finds that while the river catchment is a hydrological unit, it is not a physiographic one and, 'if one seeks a more finite division of land, the physiographic region offers this character to an unequalled degree.' (1969: 127).

5.2 Definition of catchment management

Catchment management can be defined as the comprehensive development of that area, making productive use of natural resources and simultaneously protecting them.

De Meijere & Van de Putte (1987) describe the purpose of catchment management as creating a stable system (stable from a resources point of view) by balancing the often conflicting objectives of production and conservation.

Kleynhans (1986) distinguishes three approaches to catchment management, namely:

* Manipulative management (the manipulation of the ecosystem for, *inter alia*, conservation objectives.
* Legislative management (the introduction of legislation to prohibit certain activities and developments).
* Passive management (the protection of certain areas by declaring them reserves or by failing to provide facilities and/or access to an area to prevent their exploitation).

5.3 Objectives of catchment management

The river catchment is usually the most appropriate geographic unit for managing water and associated land resources in order to gain the full benefits of multi-purpose use and to reconcile competing demands by optimum combination of uses (Olivier, McPherson, Pullen, Conley, Van Zyl, Van Aswegen & Langhout, 1989a and Van Zyl, 1989).

A set of rules for use as basis for international co-operation in sharing of water resources was drawn up by the International Law Association at a meeting in Helsinki in 1966.

Use of the Helsinki rules in international drainage basins requires the monitoring and analysis of many factors. Olivier, *et al*. (1989a) sum these up as follows:

- the geography of the basin, in particular the extent of the drainage area in the territory of each basin state;
- the hydrology of the basin, in particular the contribution of water by each basin state;
- the climate affecting the basin;
- the nature of past and present water utilization;
- the economic and social needs of each basin state;

- the population that depends on the water of the basin in each basin state;
- the comparative costs of alternative means of satisfying the economic and social needs of each basin state;
- the avoidance of unnecessary waste;
- the availability of other resources;
- the practicality of compensation to a basin state as a means of resolving conflict among users; and
- the degree to which the needs of a basin state may be satisfied without causing substantial injury to a co-basin state.

De Meijere & Van de Putte (1987) have formulated five general objectives of catchment area management:

* Erosion control: maintenance of productive and ecologic characteristics of the land.
* Sediment control: reduction of the sediment content of rivers to reduce siltation downstream.
* Flood control: reduction of peak discharges to reduce flood damage.
* Employment: creation of productive employment to absorb autonomous or induced population growth (migration).
* Production: increase the overall productivity in the watershed.

The weight given to each of these objectives is watershed-specific.

Olivier, *et al*. (1989a) state that integrated catchment management requires the simultaneous assessment of all relevant factors upstream and downstream. Included among these factors to be assessed are changes in demand patterns, runoff, sedimentation, pollution, eutrophication and flood discharges.

5.4 Objectives of catchment planning

Planning is an element of resource management. De Meijere & Van De Putte (1987) describe the aim of planning as the influencing of processes which, without intervention, would lead to undesirable results.

They furthermore lay down four conditions which have to be fulfilled if planning is to be effective:

* It must be possible to make projections (modelling).
* It must be possible to judge the outcome of these projections, i.e., criteria for assessment have to be available.
* It must be possible to actively influence the processes under consideration.
* Information on the effects (qualitative and quantitative) of these actions must be available.

Because planning is mainly concerned with what happens in the future, its essence is making projections of developments over a certain time period.

Problems occurring in catchments require the implementation of management principles, one of which is catchment planning and this should preferably be done according to a logical and holistic planning model.

6. REQUIREMENTS OF A CATCHMENT PLANNING AND MANAGEMENT MODEL

6.1 Goals and data requirements

Hobbs (1981) suggests that the relations between and interactions of the many factors affecting the hydrologic cycle are frequently complicated and difficult to quantify and hence become a fertile field for the development of planning and management models.

Van der Zel (1985) presents five requirements for an effective catchment planning and management model. While they are intended for mountain catchments specifically, they are sufficiently broad-based and can therefore, reasonably be applied to all catchments. These requirements are:

* Goals relating to economics, vegetation, hydrology and recreation must be able to be combined and mixed realistically for various objectives.
* Simple and sophisticated data, intelligent guesses and precise measurements must be able to be used and should be mutually consistent. Each data item should, without reducing the importance and relevance of other data, contribute towards achieving the stated goals.
* Emphasis should be on local data, influences, management alternatives and prevailing conditions.
* Any model structure must be able to be combined with models for adjacent areas, regions, country and even global ecological models.
* It should be easy to update or change the model's variables so that alternative solutions and scenarios can be determined quickly and accurately.

Leopold (1968) found that, in order to be interpreted hydrologically, the details of land use patterns must be evaluated and expressed in terms of hydrological parameters which are affected by land use.

In turn, these parameters become hydrological variables by which the effects of alternative planning models can be evaluated.

De Meijere & Van de Putte (1987) consider the following information as necessary input in a catchment planning and management model:

* the information necessary to make projections;
* information on management objectives and the criteria derived from those objectives for measuring any achievement or results; and
* information on the effects of possible actions.

6.2 Socio-economic variables

Socio-economic variables in a catchment can broadly be separated into those which are either consumptive or non-consumptive (Sather & Smith, 1984).

The consumptive category includes those products and resources, usually food, fuel, water or fibre that are physically removed or harvested for human utilization.

The non-consumptive category includes those variables which have values such as scenic, recreational, educational, aesthetic, archeological, heritage and historical.

Sather & Smith (1984) find that these non-consumptive values have, until recently, been relegated to a secondary status when compared with functions linked directly to ecological, physical or economic concerns. The reason for this state of affairs can partly be ascribed to the lack of a standard measure for intangible and tangible functions that would allow comparisons between the two.

6.3 Visual/Aesthetic considerations

A principal goal of environmental planning in catchments is to maintain or enhance the amenities of landscapes.

Dunne & Leopold (1978) suggest that development plans, whether they be for urban construction, flood control, transportation facilities etc. are too often concentrated on the structural and architectural aspects but with scant attention to the visual, ecologic and aesthetic concerns.

These concerns can be seen as values to society and consist of two parts: how the landscape looks and how the natural processes operate. Both the maintenance of landscape beauty and the operation of the ecosystems without undue degradation, are among the chief functions of landscape architects.

Dunne & Leopold (1978) note that landscape amenities are often concentrated in areas where water is present, along rivers, dams, lake-shores or at least on valley floors created and maintained by the river channel system. Aesthetics of the catchment, therefore, is an essential part of modern hydrology as far as the environmental planner is concerned.

Dunne & Leopold (1978) are convinced that landscape architects or planners will be called upon more often to evaluate certain hydrologic aspects of a proposed development such as the non-monetary or aesthetic values of a hydrologic system or its components.

To be able to do this, landscape architects employ a variety of techniques to measure, assess, weigh, rank and compare various alternative solutions for the proposed development.

Fabos, and Melhorn, *et al.* (in Dunne & Leopold, 1978) classify these techniques into basically three types, namely:

* Graphic methods: The designation of land cells or units in which

each unit has a combination of factors that could be weighed. From these weighted or ranked unit maps can be generated.

* Interview and viewing methods: Individuals are interviewed or exposed to a series of pictorial images of alternative sites and scenarios. These methods have two goals, namely:
  1. the psychological attributes that determine individual preferences; or
  2. the pragmatic ranking of scenes in order of preference to obtain a quality ranking.
* Matrix methods: These have much in common with graphic methods. Key elements are chosen to describe the characteristics of a site or scene and are then rated in a matrix for their relative presence or absence.

7. CONCLUSIONS

Walmsley (1989) finds that to date South African river research activities have been dominated by ecologists, mostly with zoological interest, with the result that much is known about biota but relatively little input has been obtained from chemists (water quality specialists), botanists, geomorphologists and hydrologists.

Walmsley (1989) is convinced that, in order to quantify the amount of water required for environmental management, a multi-disciplinary research team is needed which has a common understanding of the complexities of catchment and river ecosystems.

As research requires funding, Walmsley (1989) found that in the past far too little funds have been allocated to determine minimum water allocation for environmental management.

An examination of the 1988 research funding allocations by the Water Research Commission (Figure 4.11) showed that no funds were allocated for this purpose (Walmsley, 1989).

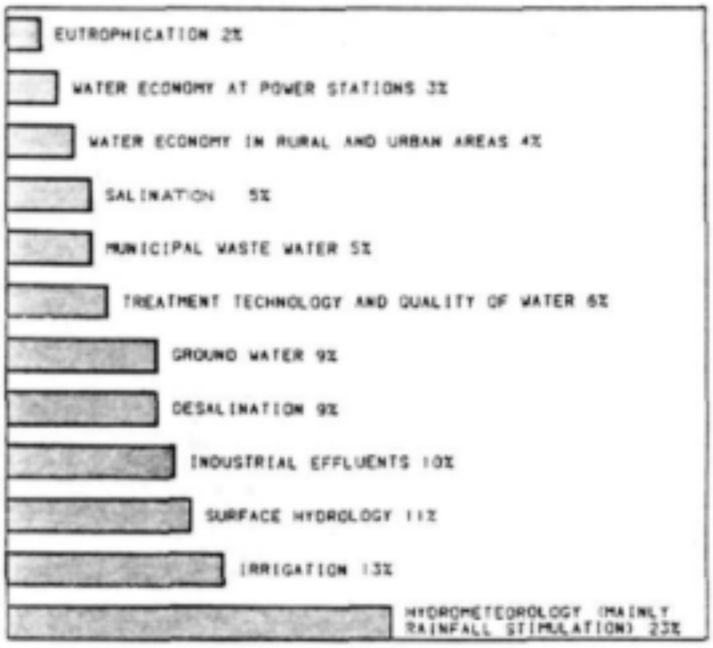


FIGURE 4.11: ALLOCATION OF FUNDS TO VARIOUS WATER RELATED RESEARCH AREAS DURING 1988
(WATER RESEARCH COMMISION ANNUAL REPORT AND TAKEN FROM WALMSLEY, 1989)

The river catchments of the RSA are intersected by numerous political boundaries. These include borders between tribal and privately owned land, between national states and the RSA and between the RSA and adjacent independant countries. These boundaries fragment water resource planning and make an integrated catchment management approach extremely difficult (HRI, 1985). Situations of joint interest in common water resources between the RSA and neighbouring independant states and national states now pertain in virtually every major river catchment in the region.

Van Zyl & Pullen (1988) conclude that the overriding challenge in the further development of water resources in southern Africa is to satisfy the political requirements arising from the common interest in the resources among co-basin states. In the past political issues arose mainly because of the disparity between states in their various stages and intensities of development and the understandable natural desire and drive of each state with a backlog to catch up with development and to reach a situation of perceived parity.

Stone, Lane, Russel & Best (1986) consider the two main problems occurring in catchments as the reduced and stressed hydrological resource potential as well as a degraded ecological conservation status. They state the principal causes as being:

* Change of flow volume (ratio of runoff from rainfall).
* Change of temporal aspects of flow (decrease in flow days/seasonal volumes).
* Change in water quality due to salination and increases in nutrients and sediments.

Factors contributing to the problem are:

* Dams, diversions and abstractions.
* Land use changes, overgrazing, bush clearance, afforestation, land drainage and erosion.
* Urbanization (effects on the hydrograph and water quality).
* Channel modification (temporal and quality effects).
* Agricultural pollution (irrigation return-flows and fertilization).
* Urban and industrial pollution.

As the supply and diversity of natural resources continue to diminish, it has now become mandatory for planners to consider the introduction and maintenance of man-made elements such as factories, roads, infrastructure services and hydraulic constructions in the light of the limitations of the affected natural resources such as forests, waterways, soil types, geological formations, other flora and fauna. It is their essential task to ensure urbanization in harmony with the natural system and to avoid unplanned development that breaks down ecological and eventually human values.

CHAPTER 5. CRITICAL DATA CATEGORIES AND CLASSIFICATION SYSTEMS FOR USE WITH A GIS

1. INTRODUCTION

In order to implement an integrated catchment management policy as discussed in the previous chapter, studies need to be undertaken of each catchment. Such a study typically consists of three phases:

* Collection and evaluation of data.
* Analysis of the information thus gathered.
* Formulation of strategies and proposals for implementation.

2. CRITICAL DATA CATEGORIES

Data collection consists of a comprehensive survey of the relevant catchment basin to identify all the factors influencing utilization of its water resources (Olivier, *et al.*, 1989a).

These factors can be of a physical nature such as the catchment's topography, geology, geomorphology, soils, climate, hydrology and vegetation.

De Meijere & Van de Putte (1987) identify three main groups of data that will be required for a GIS on catchments, namely:

* Data on natural resources, land forms, topography, climate and vegetation from which classifications for mapping purposes can be made.

* Data on the use of those resources by the population. These include land uses such as farming activities, settlement areas, industries, etc..

* Data on the social and economic environments in which this use of resources takes place. Population growth, income, expenditure and social infrastructure are some of the categories in this group.

The level of information ultimately required from the creation of scenarios or models will determine the type and level of data to be classified and inputted.

This data must also be structured so that the calculation of changes of the values for all planning criteria induced by changes in one of the variables, is allowed.

McHarg (1969) finds that in an ecological approach to understanding the nature of catchments, the first considerations are usually the geological history and climate of the catchment, for they, acting in conjunction with each other, created the basic geomorphology of the catchment. The current morphology, with climate and lithology, can be invoked to explain the pattern of streams, the distribution of ground water and its relative quantities and qualities.

The movement of sediments, some by fluvial processes and the other from deposition, reveals in turn, the pattern, distribution and properties of soils. When climate, topography, the water regimen and soils are known, the incidence of individual or association of plants becomes clearer. Animals are all either directly or indirectly plant-related and knowledge of the plant communities' age and condition should explain the distribution of animals (McHarg, 1969).

3. CLASSIFICATION SYSTEMS FOR ECOLOGICAL AND OTHER GEO-REFERNCED DATA

3.1 Introduction

Clarke, *et al.* (1987) finds that, as geo-referenced information consists of all information that refers to the man-environment system and which can be localized in space and time, the basic entity should be the feature which has spatial and non-spatial attributes.

In any exchange of geo-referenced information, the features (both spatial and non-spatial) exchanged, need to be classified according to a known feature classification scheme to ensure the correct identification of features by the receiver (Clarke, *et al.*, 1987). In order to facilitate this, the need arises for a standard classification scheme that can be used by a majority of users. Guide-lines should, however, also be established and recognized for the design of other classification schemes, albeit schemes in successful use or specialized applications for which the standard classification scheme does not cater (Clarke, *et al.*, 1987). In these cases it will be the supplier's responsibility to ensure that the recipient is aware of the structure of the particular classification scheme being sent to him.

Classification is the arrangement of features into classes or groups and Clarke, *et al.* (1987: 9) suggests that it 'must be done on the basis of the qualitative characteristics of the objects, such as their function, and not on their quantitative characteristics.' Van Riet (1989b, pers. comm.) stresses that in any classification scheme, the sequence of classes or groups is important and should not merely be a list of categories.

Scheepers (1987) suggests the following fundamental considerations concerning classification and mapping systems for ecological and other geo-referenced data:

* Classification systems should be robust. They should be useful and

applicable for specialist and non-specialist alike over an extensive area and over an extended period. They should not become redundant with time.

* The classification and mapping should place the area concerned, in its proper perspective with respect to the state of knowledge of the area at the time.
* The classification must clearly indicate the known inadequacies of the system in respect of insufficient knowledge, areas where it is (probably) inapplicable and for which it is not intended. This is important to obviate its misuse by the uninformed and unwary. Both the researcher and the user often try to make a classification provide the answers to too many questions simultaneously.
* In order for a survey classification to be most cost-effective, it is essential for the user to indicate exactly what is required and for what purpose it is intended to be used.
* Any mapping exercise should represent a distinct improvement in information content and practical utility over existing maps. If an existing map is sufficiently useful, it is a costly and superfluous exercise to resurvey, reclassify and remap an area unnecessarily. If it is considered to be necessary, a new survey, classification and/or mapping exercise should make maximum use of previous work by reworking, re-interpreting and remapping earlier data, classifications and maps as far as practicable.

For practical usefulness, maps should focus on the more obvious areas of relevance for practical application, e.g. availability and potential value for grazing and flora/vegetation conservation, current veld condition and trend.

3.2 Global systems

The U.N. Environment Programme based in Switzerland maintains and upgrades a Global Resource Information Data base (GRID). Some of the data sets presently held in GRID include those shown in Table 5.1.

TABLE 5.1 A partial list of data sets presently held in GRID (from Mooneyhan, 1987)

PARAMETER	COVERAGE
Political boundaries	Global
Natural boundaries	Global
Elevation	Global
Soils	Global
Vegetation index (weekly - 156 weeks)	Global
Precipitation anomalies (monthly)	Global
Surface temperature (days/nights - monthly)	Global
Ozone distribution (monthly)	Global
Vegetation	Africa
Vegetation index (seasonal)	Africa
Water sheds	Africa
Rainfall (mean annual)	Africa
Number of wet days (mean annual)	Africa
Wind speed (mean annual)	Africa
Protected areas	Africa
Background air pollution	Eur/N. America

Scotney (1988) suggests that, as remote sensing techniques are more implemented worldwide for catchment management, the acceptance and implementation of a national present land use and land cover classification system which is multi-level and open-ended, to allow flexibility, becomes imperative. This national system should preferably be compatible with international systems where practical.

According to Scotney (1988) the following categories of land information are required for integrated catchment planning and management:

* climate;
* soils;
* land form (geomorphology);
* aspect;
* geology;
* vegetation;
* hydrology;
* land uses;
* landownership; and
* administrative controls.

3.3 A national exchange standard (NES) for digital geo-referenced information

In any exchange of geo-referenced information, the features or entities that are exchanged need to be classified according to a known feature classification scheme so that the receiver can correctly identify those features (Clarke, *et al.*, 1987).

The basic unit of information can be called a feature. Its characteristics are defined by the non-spatial attributes attached to that feature Clarke, *et al.* (1987). They stress that care should be taken when reaching the point where the classifying of a feature should stop and the description of its characteristics (or the non-spatial attributes) should start.

Clarke, *et al.* (1987) suggest the following guide-lines for the design of a feature classification scheme:

* The classification scheme must be based on feature entities, either real or abstract.
* The scheme should be scale independent. The characteristics of a feature, especially those of a quantitative nature, must be described by its attributes and not by a further breakdown in the feature classes.
* The scheme should have a hierarchical structure of variable levels.
* The scheme should ensure that there is no loss of information. Non-spatial attributes are seen as lists coupled to features but with the attribute value either fixed (predefined) or variable.
* The scheme should ensure consistency. Aliases should be given for feature classes, especially since various disciplines often have different names for the same features.
* A coding scheme may be used for shortening the feature class names.
* It should be possible to use only a subset of the classification scheme.

Clarke, *et al*. (1987) presented a national standard for the exchange of digital geo-referenced information. In their report they propose a classification system of features and their attributes. They do not intend however, for their system to be imposed as a compulsory classification but suggest that as the structuring of data bases differs from organization to organization and between different digital mapping and geographical information systems, it makes good sense to have a national standard for the exchange of digital geo-referenced information.

The NES has been designed to exchange any and all information that can be fixed in time and space. For most purposes, this will be any information that can be fixed to the Earth's surface, above or below it. One could consider almost any information about people and their activities within the scope of the NES.

Clarke, *et al.* (1987) suggest a standard feature classification scheme with the features structured on a variable level hierarchical basis. Level 1 being the major class with subsequent breakdowns to sublevels, e.g.

Level 1: Geomorphology.

Level 2: Land form.

Level 3: Flood plain.

In their version 1.0 of the standard feature classification scheme they propose twelve Level 1 major classes, namely:

1. Biology.
2. Building and structure.
3. Climatology and Meteorology.
4. Communication network.
5. Control surveys.
6. Geology and geophysics.
7. Geomorphology.
8. Hydrology and hydrography.
9. Land use.
10. Oceanology.
11. Pedology.
12. Social and cultural.

One of the problems with this sequence of classes is that it is not linked by some natural sequential order or motivation as suggested by McHarg (1969). The main advantage of a class sequence ordered by natural processes is that data collected for one category assist in an understanding of the data in the next class. The classes proposed by Clarke, *et al.* (1987) follow each other alphabetically and do not relate to the approaches of either McHarg (1969) or De Meijere & Van de Putte (1987).

Appendix B shows the complete standard feature classification for the exchange of geo-referenced information as well as associated non-spatial attribute lists as proposed by Clarke, *et al.* (1987). Coward (1989), while commending the research and effort which went into the geo-referencing standard SWISK 45 (cf. Clarke, *et al.*, 1987), poses the question of who will draw up and maintain the definitive feature lists and classifications?

3.4 Department of Water Affairs geo-referenced data classification system

The Department of Water Affairs (DWA)(1989), in their provisional classification scheme for geo-referenced data, proposes the following highest level categories or classes:

1. Scientific and Natural.
2. Infrastructure.
3. Land and water use.
4. Social and cultural.
5. Water management.

This system is more related to the comments expressed under Section 3.3 p.127 as there is some logic to their sequence.

The complete DWA classification system is shown in Appendix C p.178.

3.5 A proposed ecological data category classification system

After reviewing other existing and proposed classification systems, it is proposed, in Appendix E, that the following data classes and categories be utilized in a classification system for ecological and other geo-referenced data:

Class 1: Natural resources data

- Category 1.1: Geology
- Category 1.2: Climate and meteorology
- Category 1.3: Geomorphology
- Category 1.4: Pedology
- Category 1.5: Hydrology and Hydrography
- Category 1.6: Vegetation
- Category 1.7: Zoology

Class 2: Land use and land cover data

Class 3: Socio-economic data

An eigth category namely oceanology could be added to Class 1 but is not dealt with in this study.

The vast number of socio-economic data categories e.g. demographic distribution, wealth distribution, cadastral data, census data, etc. are likewise not discussed in detail in this study although some of these categories occur in the proposed classification system for land use (cf. Table E8.3 p.273).

The premise of the proposed classification approach system is to have as many hierarchical levels as deemed practical to arrive at the smallest feature that can be spatially represented. The classification stops when this point is reached and the non-spatial data components or attributes are then assigned to those various spatial classes as attribute lists.

CHAPTER 6. A CONCEPTUAL LANDSCAPE PLANNING MODEL

1. INTRODUCTION

The 'landscape' represents a section of the environment and as such consists of natural entities, *inter alia*: soil, trees, land-form and water, but also various cultural entities or artifacts such as farms, recreational developments and housing (Meintjes, 1989). All these entities or artifacts have various attributes and characteristics which affect and are of use to man.

Fabos & Caswell (in Meintjes, 1989) describe landscape planning as but one of several inputs (such as economic or political planning) in the whole planning process. It articulates landscape values and presents explicit consideration of trade-off opportunities when social values are in conflict with each other.

Defined more precisely, the input of landscape planning attempts to:

* maximize the short-term and long-term positive effects of landscape resources, *inter alia*: water supplies, wildlife habitats and scenic views.
* minimize the short-term and long-term negative effects of landscape hazards, *inter alia*: flooding and unstable slopes.
* maximize natural opportunities for development, *inter alia*: well-drained and well-situated sites with little or no natural hazards.
* minimize undue long-term impact on the larger environmental/ecological system.

(Fabos & Caswell in Meintjes, 1989.)

2. WATER AS FOCUS

Water is central to many planning issues concerned with natural and altered environments. Dunne & Leopold (1978) find that water is often the focus for interdisciplinary analysis and planning and brings together specialists such as hydrologists, geologists, geomorphologists, plant ecologists and landscape architects.

Dunne & Leopold (1978) suggest that there is much to be gained from examining the catchment as a convenient unit for understanding the action of hydrological and geomorphologic processes and for appreciating the spatial linkages between different areas that affect both regional and site planning. As more and more planning is based on an understanding of all the natural processes, this is increasingly the case.

McHarg (1969) demonstrated that catchments need not be perceived only as constraints but as opportunities to be exploited with imaginative and aesthetically pleasing designs.

Ecological factors are considered as fundamental determinants in this proposed landscape planning model. That is, it is assumed that variations in ecological character will render some areas of a landscape more suitable for supporting a given human activity than others, and that the difference can be very important to environmental quality. Maaren (1989) views the water environment in a catchment as a complex natural and man-made life-support system with people as the main users.

This system is currently under stress from a rapidly increasing population, intensified land use, industrial development and expanding urbanization.

Potential conflicts between water users with regard to equitable allocation of this limited resource tend to dominate the management issues of catchments.

Maaren (1989) proposes a comprehensive hydrological research strategy, in which the priorities are, *inter alia*:

* using existing hydrological expertise to synthesize a more comprehensive picture of South African hydrology as a whole;
* ending the comparison of different hydrological models or trying to develop entirely new ones. We should select a limited number of credible, validated modelling systems and collectively build expert systems around such models; and
* developing methodology that will enable us to identify dominant hydrological processes in South Africa which in turn will help us to select modelling approaches, data gathering programmes and management strategies accordingly.

3. THE CONCEPT OF A PLANNING MODEL

3.1 The purpose of planning models

A decision-making or planning model is, according to Hewlett (1981), designed to yield useful answers to questions posed usually in an ecological, economic, managerial or planning context; the outcome affirmed not only in the states of nature, but in strategies available for influencing the outcome and also in criteria for decision-making.

The development of decision-modelling has had a profound effect on problem analysis, research planning and management of physical resources and even large organizations.

For the purpose of this study, planning models can be described as those which allow data to be displayed in some manner, presumably by means of a GIS and which then assist in decision-making on water resource related matters by calculating various alternatives.

In Figure 6.1 the steps in a planning model incorporating GIS in general, are shown.

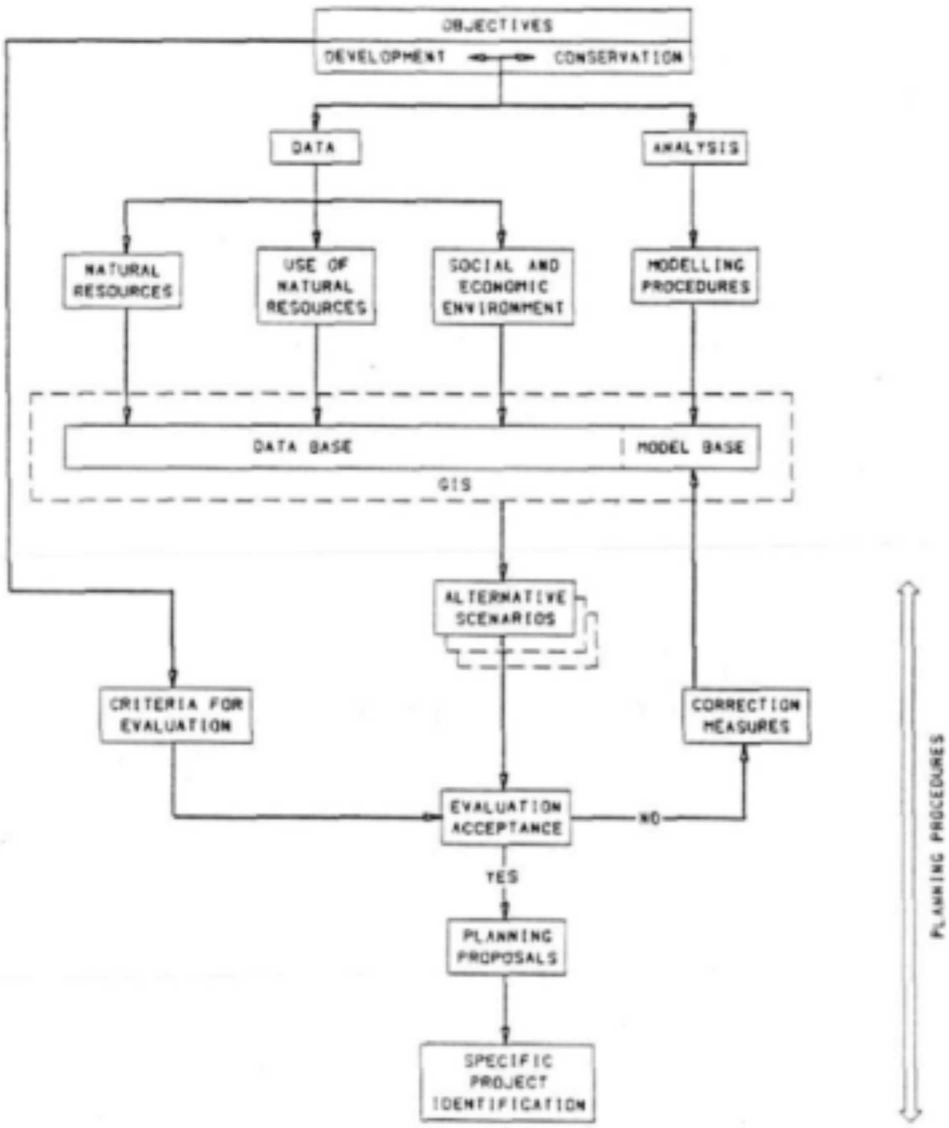


FIGURE 6.1: A PLANNING MODEL INCORPORATING GIS (FROM DE MEIJERE & VAN DE PUTTE, 1987 AND ADAPTED BY AUTHOR)

Hydrological simulation models provide ways of transferring knowledge from a measured or study area to an area where objective decisions and information are needed for planning and management.
Schulze (1985b) however, finds the following typical constraints in many existing models:

* they make too high computing demands on available expertise;
* they require levels of sophistication of input data such as climatic and soil variables which are not always available; and
* they are often single purpose models of which then a series is required to arrive at solutions for what are essentially integrated projects.

Hydrological models (and by implication landscape planning models) have to be developed in accordance with the 'systems theory' (Schulze, 1985b) in that one initially has to segregate the hydrological system into its component subsystems (e.g. atmosphere, land surface, vegetation, soil water regime, etc.) and then to recompose the subsystems by reconstructing and describing the 'broken' interconnections in order to manipulate the various data sets.

Lyle & Stutz (1987) see a landscape or land use planning model as an analysis of the interactions among three factors, namely:

* location or site;
* development actions; and
* environmental effects or impacts, or as they put it (1987: 68): 'That is, given certain developmental actions to be carried out and specified environmental effects to be controlled, we can map the most and least suitable locations for those actions'.

3.2 Decision vs. normative models

Hewlett (1981) divides decision models into normative and descriptive models. Normative models tend to prescribe what ought to be, i.e. normative models contain standards of correctness. Descriptive models on the other hand, describe facts and factual relationships. Hewlett (1981) suggests that decision models are a class of normative models and criteria for adequacy or correctness must be built in.

4. A REVIEW OF SOME EXISTING CATCHMENT MANAGEMENT MODELS AND LANDSCAPE PLANNING APPROACHES

In this study two existing catchment management models which have been validated over time are reviewed, namely: The ACRU model developed by Schulze (1985b) and the model of Van der Zel (1985) in which catchments can be managed by means of goal programming. Both models can be described as user models in contrast to the more purely research models. A major difference however, lies with the physical conceptual nature of Schulze's model when compared to the abstract concept of management goals of Van der Zel's model. The landscape planning approach of McHarg (1969) is also briefly discussed.

4.1 The ACRU model for agrohydrological decision-making

Schulze (1985b) describes the purpose of his ACRU model as providing simple decision-making options for varying levels of technological and data availability for a range of typical hydrological problems, *inter alia*: estimates of water yield, effects of land-use changes, irrigation demand and supply, dam sizing and the selection of crops.

In Figure 6.2 (p.136) the idealized structure of the ACRU model is shown and in Figure 6.3 (p.137) the general concepts as a multipurpose model are schematically shown.

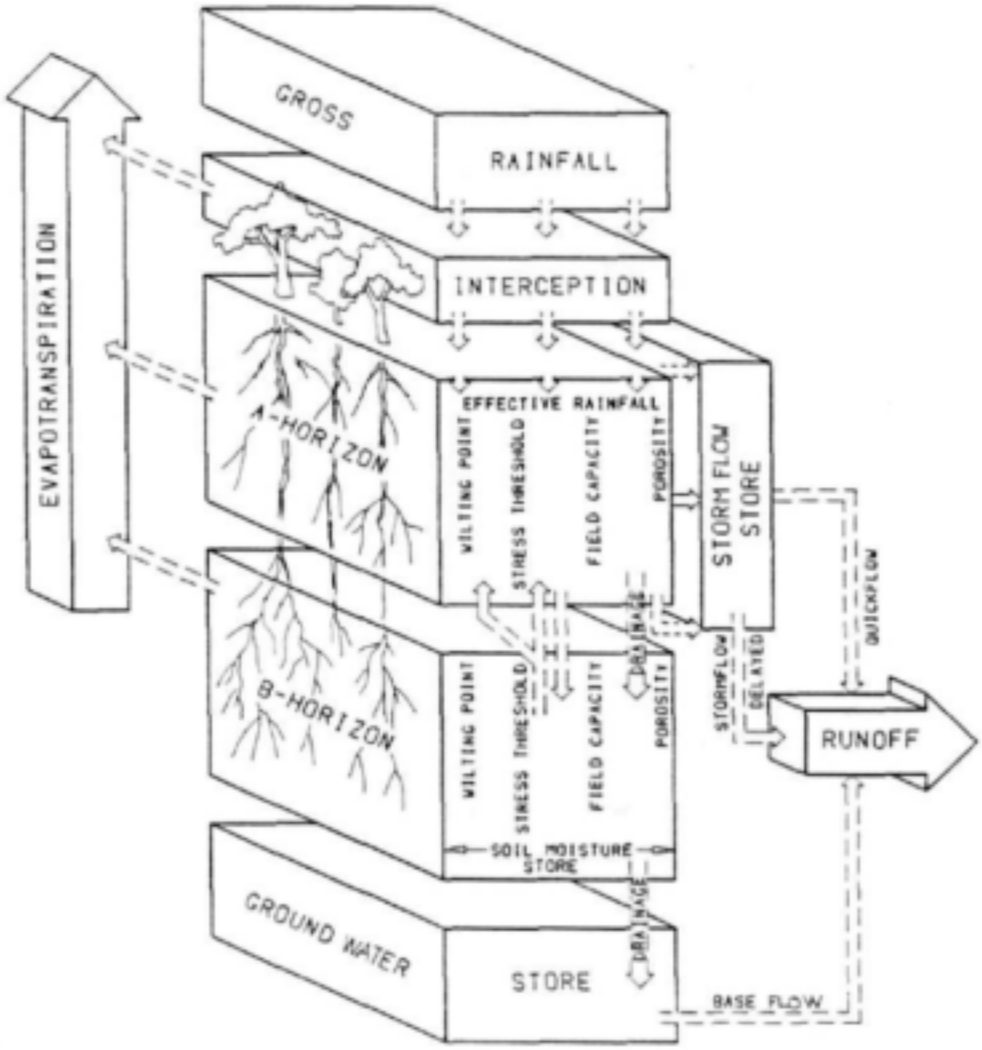


FIGURE 6.2: THE ACRU MODEL: IDEALIZED STRUCTURE
(FROM SCHULZE, 1985b)

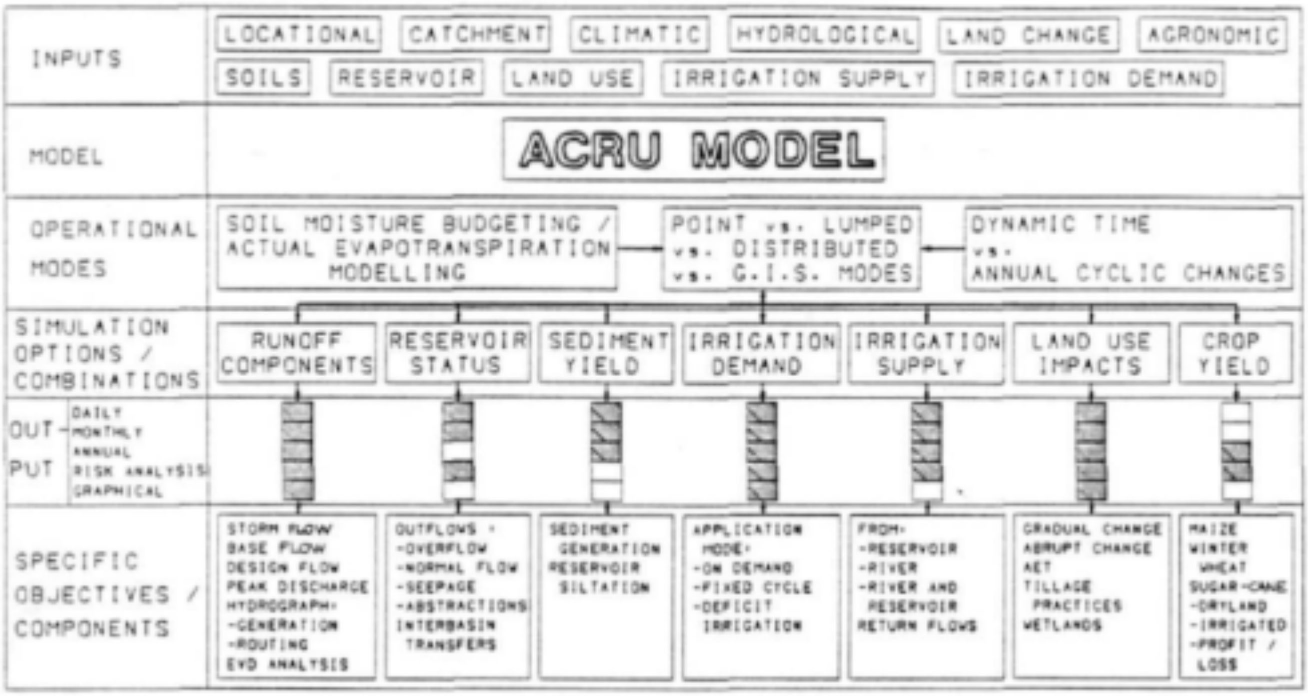


FIGURE 6.3: THE ACRU MODEL: GENERAL CONCEPTS AS A MULTIPURPOSE MODEL (FROM SCHULZE, 1985b)

The concept of the ACRU modelling system may be understood from the following description and possible uses:

It is a computerized physical conceptual modelling system which:

* is multi-purpose, with options to output, *inter alia*:
  - runoff components;
  - reservoir yield analysis;
  - sediment yield analysis;
  - soil water status and total evaporation;
  - irrigation water supply and demand; and
  - crop yield.
* uses daily time steps; and
* revolves around multi-layer soil water budgeting, making it highly sensitive to hydrological response of land use changes.
* has multiple input options to account for different levels of

sophistication of available input options; and

* accounts for changing the types of land uses over time.

Schulze (1985b) finds the ACRU model with its inherent GIS approach a powerful planning and decision-making tool especially in agrohydrological modelling. In applying his model to assess the regional runoff production in Qwa-Qwa, where the region is both physiographically and climatologically complex, the results provided answers to the 'where, how much, when and frequencies' of precipitation runoff production.

4.2 Catchment management with goal programming

In managing delineated areas such as mountain catchments, conflicts often arise between multiple simultaneous goals (Van der Zel, 1985).

Goal programming allows a system with complex, multiple and conflicting objectives to be handled through the use of priorities. In their study, they propose goal programming as an optimization programming technique which tries to achieve a set of simultaneously unattainable goals by minimizing the difference between the solution and the goals. This approach contrasts with the linear programming approach of maximizing or minimizing a single goal. In goal programming several goals can be played off against each other and solutions for different relationships (priority rankings) are produced.
Van der Zel & Walker (1988) applied their study to the Natal Midlands mountain catchment where they identified four goals, namely:

* delivery of maximum runoff;
* delivery of minimum soil loss;
* provision of maximum outdoor recreation opportunities; and
* achieving the maximum economic return.

Van Riet (1989b) however, suggests that the primary goal of any catchment management process should in the first instance be the long-term protection of the hydrological resource as a component of the ecosystem. The goals as stated by Van der Zel & Walker (1988) should be achieved without affecting this primary goal.

Van der Zel & Walker (1988) find that in goal programming a solution is found which comes as close as possible to the set goals; satisfying them in the order of priority in which they have been given. In addition, managers can attach ordinal priorities or rankings to the goals in such a way that the relative importance of these is reflected.

As goals are the desires of management and contraints the limitations set by the environment or by management, these constraints must first be satisfied before any attempt at goal achievement is made (Van der Zel & Walker, 1988).

After the modeller has assigned possible goals, decision variables, constraints, priorities and weights, the model proceeds to find the best solution for each by first satisfying the constraints, then the goal priorities, then the goals and finally expresses this solution in weighted figures.

From their study Van der Zel & Walker (1988) presented four scenarios in which each of the stated goals were allocated top priority. The results also show the emanating influence on the other three remaining goals. From these results the manager can therefore recommend particular land uses in view of specific goals and for specific catchments.

In discussing the results obtained, Van der Zel & Walker (1988: 41-44) point out the following features important to catchment planners and managers:

'(i) The analysis is objective, in the sense that it is based on the assessment of how much each homogeneous unit of land, under each type of land use, will contribute to each of the goals in question.

(ii) Once the data has been assembled, the programme can be run any number of times, varying the order of priority of the goals and imposing different constraints or levels of desired goal achievement.

(iii) The output of the analysis provides the individual levels of the goal achievement for each land use.

(iv) The output indicates what type of activity should be carried out on each unit of land (i.e. it provides a map of what should be done where for each solution).'

Van der Zel & Walker (1988) observed two problems which emerged from their study, namely:

* It requires a comprehensive and often difficult-to-obtain data set.
* The output provides a map of the final recommended pattern of land use for a given set of goals, but it does not indicate the optimum route to follow in getting from the present situation to this final pattern.

4.3 The landscape planning approach of McHarg (cf. Section 3.4.1 p.60)

Ian McHarg's 'Design with Nature' brought a systematic approach or model for land use planning using thematic map overlays to a broad audience when it was published in 1969. Examples presented in his book had the virtues of being both systematic and simple enough to be easily understood.

Lyle & Stutz (1987) find that most of the criticism on McHarg's approach were based on two issues, namely:

* his assumption of ecological determinism; and
* the equal weight that he gave to all the considered variables.

Marusic, in Lyle & Stutz (1987), describes McHarg's methods as an absolutization of values in an otherwise relative social and physical space.

McHarg's hand-drawn map overlays become virtually unmanageable if different weights are assigned to the data on each map. A computerized land use suitability mapping system (as is possible with GIS) should overcome this problem.

One of the results of McHarg's approach was a change of the previous use of maps, namely from being purely descriptive of geographic space, to using maps to spatially display appropriate and optimum landscape values and management options. Meintjes (1989) finds that this movement from descriptive to prescriptive mapping was the forerunner of revolutionary ideas in map structure, content and use.

5. A PROPOSED CONCEPTUAL LANDSCAPE PLANNING MODEL FOR CATCHMENTS

5.1 Goal

The goal of the landscape planning model is to develop a method by which proposed changes in land use in the catchment, which invariably affect the environment and thus the water resources of the basin, can be determined and evaluated.

In addition to determining the effects of land use changes, the model also aims to develop procedures for containing or eliminating detrimental effects, and to maintain ecological values which might exist. This model should therefore aid and facilitate decision-making in catchment planning and management issues.

5.2 Objectives

In view of the stated goal, the following set of objectives can be identified:

* To understand the natural processes and functions occurring in catchments. The proposed human actions in the catchment will determine whether these processes should be seen as constraints or opportunities (see Chapter 4).
* To understand the Integrated Environmental Management process (IEM, see Chapter 3) as advocated by the Council for the Environment.
* To understand the concepts behind and methods by which a computerized Geographic Information System (GIS) can be utilized as a tool to reach the stated goal (see Chapter 2).

5.3 The model

To realise the above mentioned objectives, the model is described as a flow diagram with each step in the model depicted by a block.

In Figure 6.4 p.143 the conceptual model of the actions involved in achieving the stated goal and objectives is shown. Most of these blocks will have its own flow diagram illustrating greater detail. The nine steps in this model are described as follows:

5.3.1 STEP 1: GOALS AND OBJECTIVES

In Figure 6.5 p.144 the goal and objectives of the landscape planning model are summarized. Without clear goals and objectives the model cannot function.

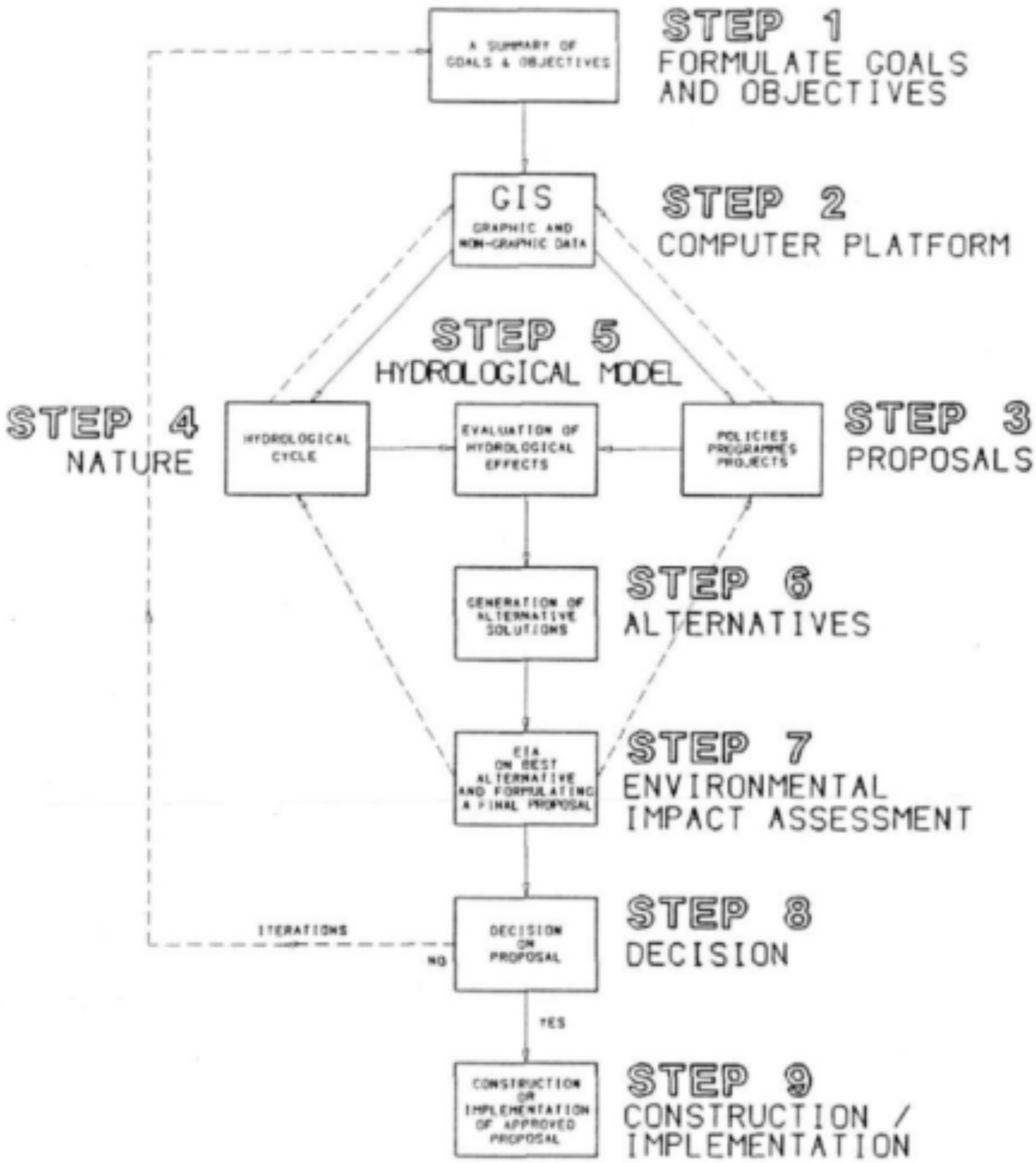


FIGURE 6.4: A CONCEPTUAL LANDSCAPE PLANNING MODEL

STEP 1

GOALS AND OBJECTIVES

GOAL: TO DEVELOP A METHOD BY WHICH ENVIRONMENTAL EFFECTS CAUSED BY ANY PROPOSED CHANGE IN LAND USE IN CATCHMENTS CAN BE IDENTIFIED AND EVALUATED

OBJECTIVES:
* UNDERSTAND THE NATURAL PROCESSES/FUNCTIONS OCCURRING IN CATCHMENTS
* UNDERSTAND THE PROPOSED IEM PROCESS
* UNDERSTAND THE CONCEPTS OF GIS AS A TOOL IN REACHING THE GOAL

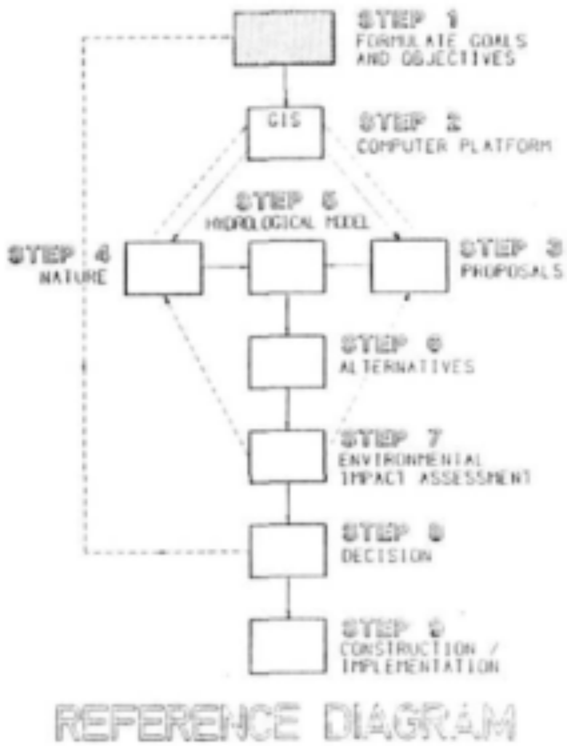


FIGURE 6.5: STEP 1 OF THE LANDSCAPE PLANNING MODEL

5.3.2 STEP 2: COMPUTER PLATFORM

In Figure 6.6 p.146 the concept of a computerized GIS as a tool to aid decision-making is set out. A GIS consists of basically two main components, namely: the graphic (lines, arcs, polygons, etc.) and non-graphic non-spatial information or data base (See Chapter 2). From the interaction of these components, overlay maps containing new information are created to determine, *inter alia*: optimum land use (shown by the newly created land facets) and areas where conflict in land use will occur.

The existing and optimum future land use determination created by the overlays, in turn influence the hydrological consequences such as the amount of water runoff, quality of water runoff and the network of hydrological features (rivers, dams, lakes, impoundments, etc.) thus established as a part of the hydrological cycle. In order to determine and evaluate these hydrological consequences through the use of GIS, a hydrological model such as the ACRU model (cf. Figure 6.2 p.136 and Figure 6.3 p.137) can be installed into the GIS programme. This is suggested in Step 5.

Finally, GIS's TIN and DTM abilities allow this network of hydrological features to be displayed, developed and manipulated in a three-dimensional way. As can be seen from Figure 6.4 p.143, the proposed landscape planning model is driven by GIS.

5.3.3 STEP 3: POLICIES, PROGRAMMES AND PROJECTS

Man's development actions, be they the formulation and execution of policies, programmes or specific projects which constitute a change in land use, have certain influences and impacts on our physical environment.

The fact that development policies also influence the environment, albeit normally over a longer term, is often forgotten when compared to the immediate visible effects of most specific development projects.

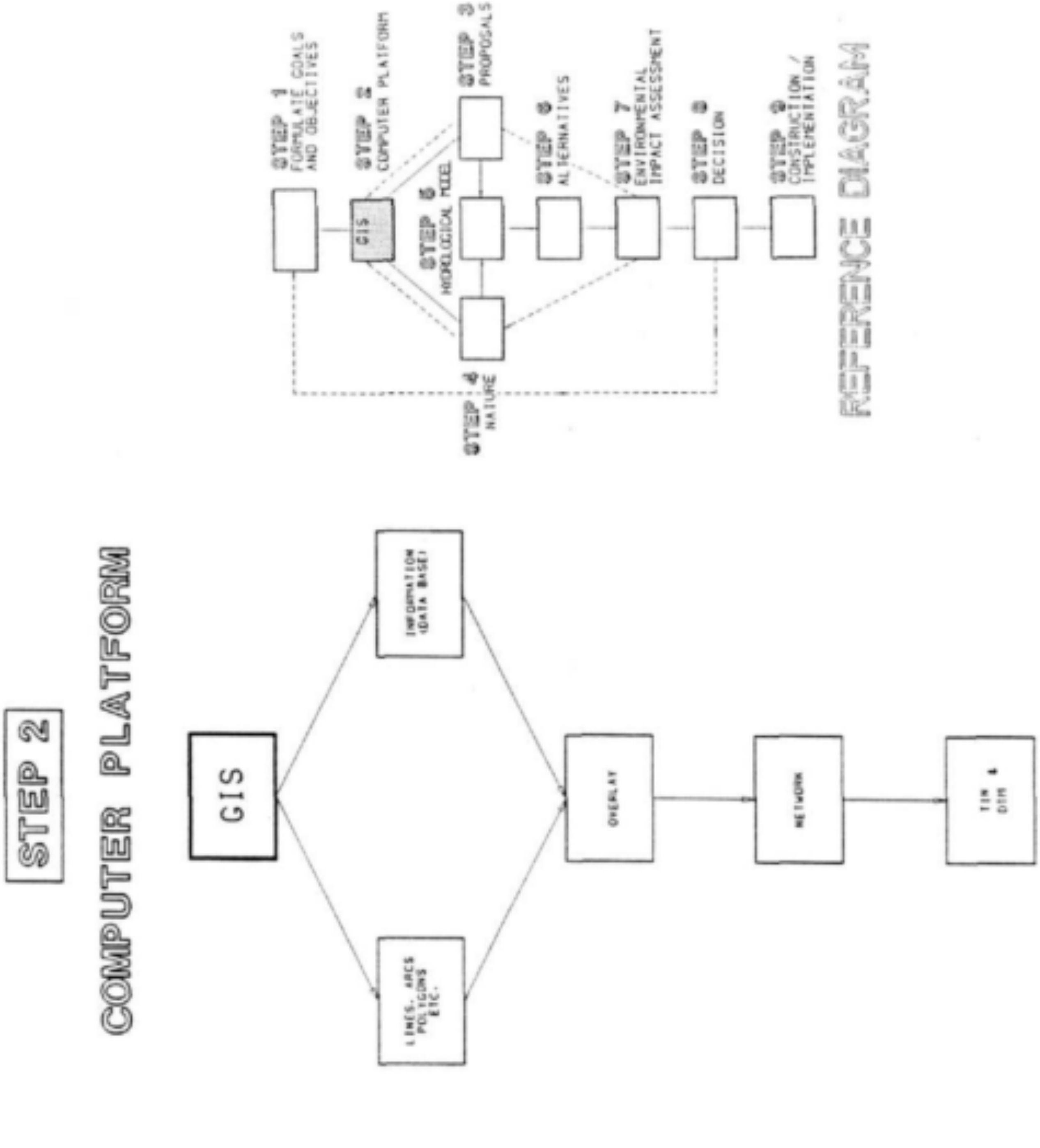


FIGURE 6.6: STEP 2 OF THE LANDSCAPE PLANNING MODEL

5.3.4 STEP 4: THE HYDROLOGICAL CYCLE

In this step the importance of understanding the nature of the hydrological cycle and component natural processes occurring in catchments is emphasized.

In Figure 6.7 p.148 this fourth step is set out schematically. Factors which affect the catchment's hydrological response can broadly be divided into five groups, namely:

* structure (the earth's geology and geomorphology);
* climate;
* cover (soil and vegetation), determined mainly by the interaction between the above two factors;
* drainage patterns; and
* land use.

Step 4 may also be seen as consisting of four phases:

* Phase 1

  The goal and objectives of this phase are to understand the hydrological cycle and the natural processes operating within that cycle in order to understand the effects caused by changes in land use.
* Phase 2

  The climate, the earth's structure (geology and geomorphology), land cover (soil and vegetation) and land use are investigated to determine the hydrological effects of land use changes.
* Phase 3

  From the Phase 2 investigation, the output or products of land use changes can be measured from the changes in water quality and quantity.

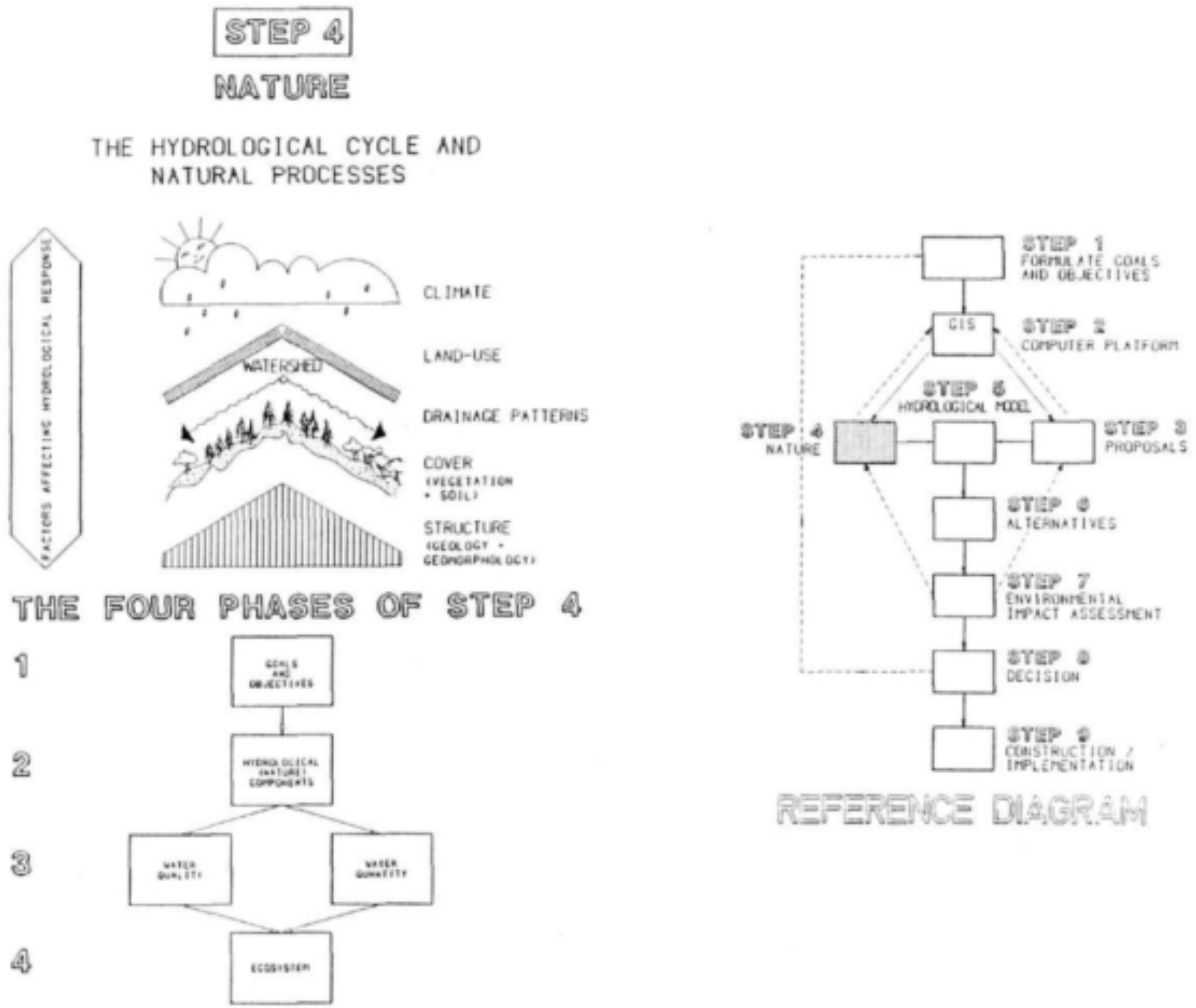


FIGURE 6.7: STEP 4 OF THE LANDSCAPE PLANNING MODEL

* Phase 4

  Changes in water quality and quantity invariably have a wider impact and thus the effects of changes in land use must also be investigated against possible effects on the ecosystem as a whole.

5.3.5 STEP 5: HYDROLOGICAL MODEL

It is only through the use of a hydrological model that the effects of policies, programmes or projects on the water resources, as illustrated by the hydrological cycle, can be determined. This model will develop the various alternative scenarios and describe the influence of man's actions on the various components of the hydrological cycle. It is proposed that a computer compatible hydrological model such as the ACRU model (cf. Figure 6.2 p.136 and Figure 6.3 p.137) be applied in this Step 5.

5.3.6 STEP 6: ALTERNATIVE SCENARIOS

From the consideration of planning policies, programmes or project proposals (Step 3) and their effect on the hydrological cycle (Step 4), various alternative scenarios for meeting the planning objectives are generated.

It is important at this stage not to discard any of the various scenarios.

This step in the procedure forms Stage 1 of the IEM process (cf. Figure 3.1 p.49) and is critical to the success of the model. Most proposals suffer from a lack of investigation into alternative scenarios and it is also one of the strong points of the GIS that alternative scenarios can be generated quickly and at relative low cost.

5.3.7 STEP 7: EIA ON THE BEST ALTERNATIVE PROPOSAL

In this step the best alternative scenarios or proposals are considered and environmental impact assessments (EIA) are done on those. In Figure 6.8 p.151 the component activities of this step are shown.

In the EIA process all impacts, be they direct physical, long-term ecological, visual or impacts on activities, are identified, described and evaluated for all the phases, such as planning, construction, monitoring and decommissioning , which will occur during the implementation of a typical development proposal.

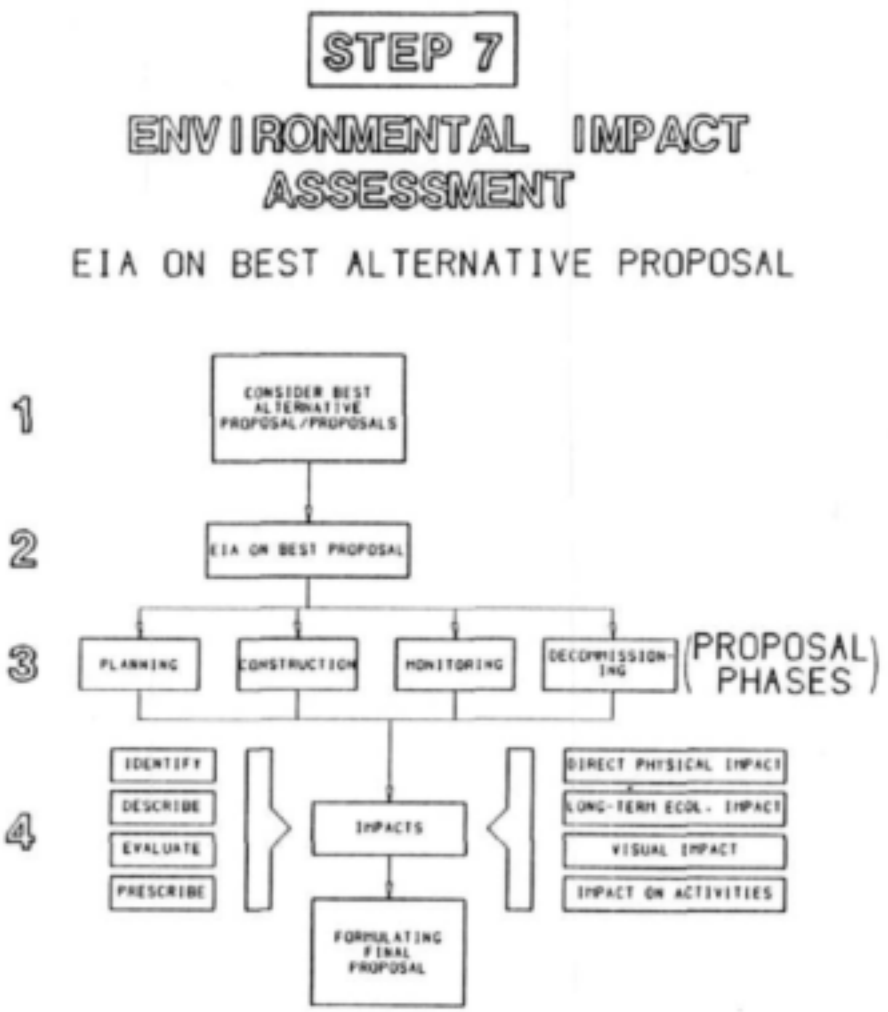
From the results of these various EIAs, the formulation of a final proposal, which should be both well considered and well motivated can be made. As is illustrated in Chapter 3, the IEM procedure involves the public opinion during this phase through the use of scoping procedures.

5.3.8 STEP 8: DECISION ON PROPOSAL

Step 8 (Figure 6.9 p.152) closely follows Stage 3 of the IEM procedure (cf. Figure 3.1 p.49).

In this step a decision is made by the authorities concerned on the final proposal generated in Step 7. If the decision is to carry on with the proposal, the conditions of approval are set and this decision is recorded.

If it is decided to turn down the proposal, this decision is also recorded and an opportunity must be given to the proposers to appeal against this decision.



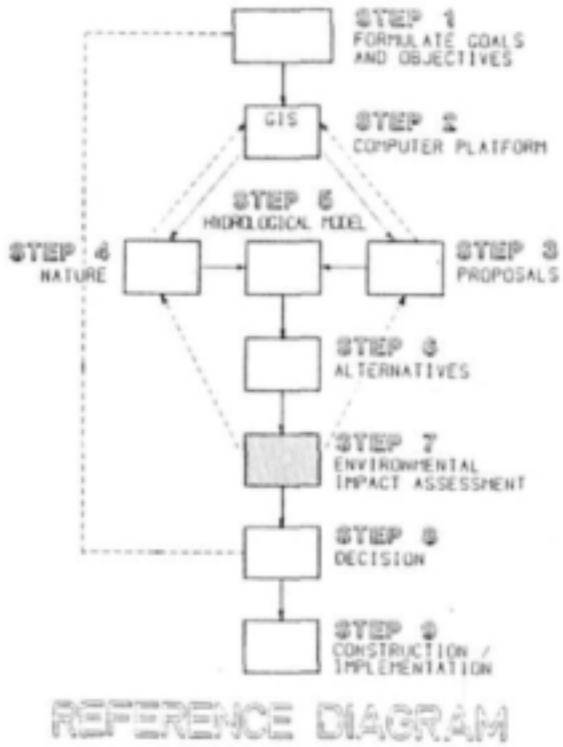


FIGURE 6.8: STEP 7 OF THE LANDSCAPE PLANNING MODEL

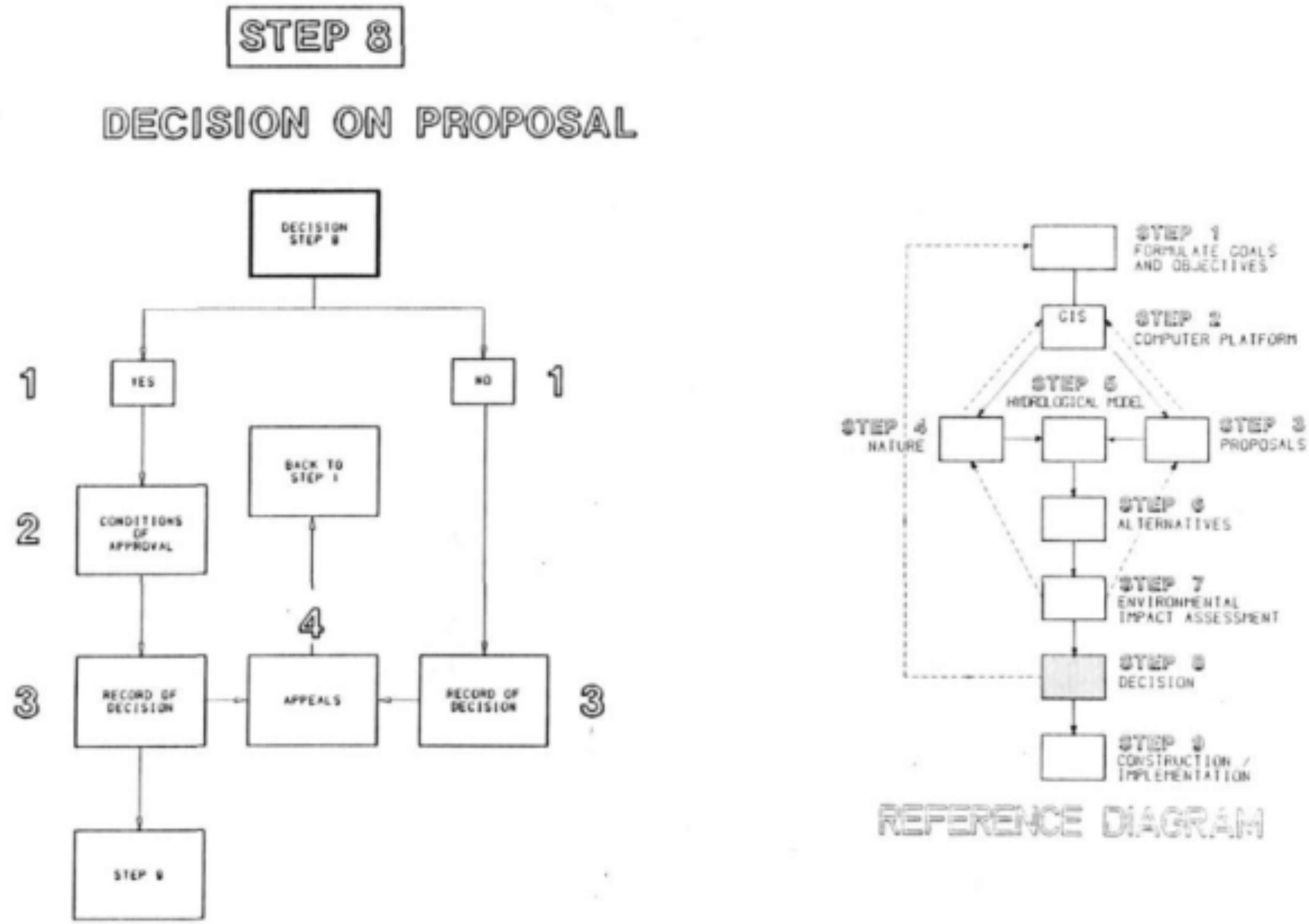


FIGURE 6.9: STEP 8 OF THE LANDSCAPE PLANNING MODEL

Opportunities to appeal against any set condition of approval must also be given, even when the proposal is approved in principle.

In those cases where the proposal is still rejected after appeal, the proposer must go back to Step 1 to reconsider the planning goals and objectives.

5.3.9 STEP 9: CONSTRUCTION OR IMPLEMENTATION

After the decision has been taken to approve the proposal, be it the construction of a specific project or the implementation of a policy or programmes, certain actions have to be taken to ensure the correct methods and compliance with the conditions of approval.

Figure 6.10 (p.154) shows these actions and it can be seen that they closely follow those described in Stage 4 of the general IEM procedure (cf. Figure 3.1 p.49).

Firstly a management plan, by which either the construction or implementation will be carried out, must be compiled and approved.

Secondly, once construction or implementation has begun, the simultaneous monitoring of these actions must be carried out as a third action.

Lastly, after the conclusion of construction activities or implementation of policies or programmes, the whole Step 9 process must be audited and feedback on lessons learnt or mistakes made during Step 9, should be made available to all concerned.

6. CONCLUSIONS

Intuitive judgement on environmental issues is changing towards rational judgement based on facts brought to the decision-maker, aided

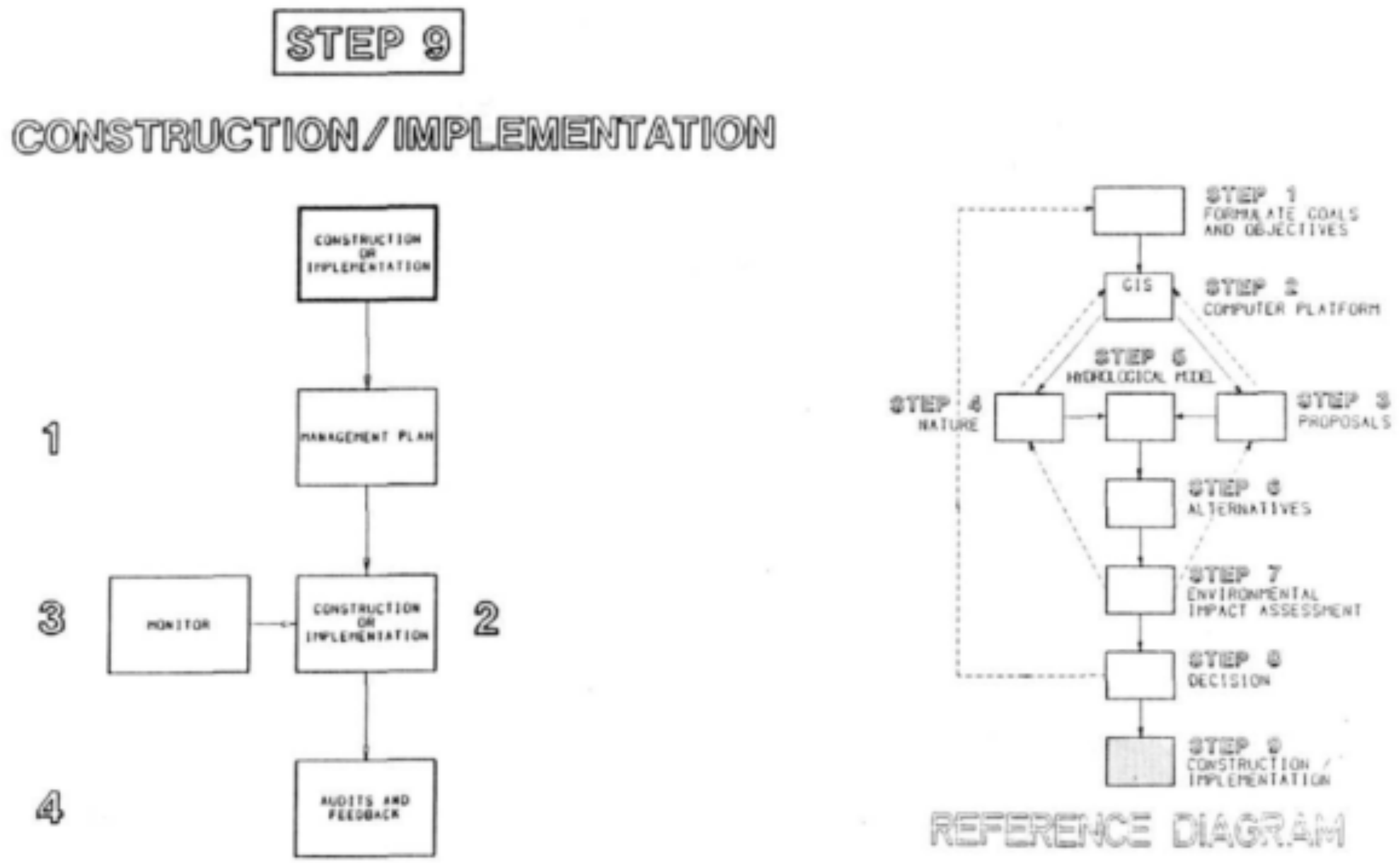


FIGURE 6.10: STEP 9 OF THE LANDSCAPE PLANNING MODEL

by recently developed decision-making tools such as GISs. Modelling (symbolically representing the functional relationships operating in a certain situation) is one of the techniques proposed in this study.

In recent times however, the immense computer capabilities have tempted holistic modellers to construct hydrological models so intricate and loaded with variables and linkages, that Hewlett (1981) comes to the conclusion that the real world is often left far behind and real solutions become very much intractable.

Conley (1989) finds that where hydrological modellers once concentrated on modelling parts of their problems and users had to try to combine them, in finding solutions, the use of a decision-aiding tool such as GIS now allows the emphasis to be put on integrating hydrological models conveniently, so encouraging the user to explore various solution possibilities.

In the proposed landscape planning model it is attempted to integrate all the issues involved in optimum landscape planning. These issues are:

* The policies, programmes or projects intended for implementation.
* The hydrological cycle occurring in nature.
* The interaction of the two issues above by means of a validated hydrological model (such as the ACRU model of Schulze, 1985b) and with the aid of a computerized GIS.
* The generating of alternative solutions for the proposed policies, programmes or projects.
* The evaluation and selection of the best alternative solution.
* The implementation or construction of the selected and approved policy, programme or project.

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APPENDIX A

A GLOSSARY OF SELECTED ABBREVIATIONS AND DEFINITIONS OF TERMS

* CDSM : Chief Directorate of Surveyor and Mapping
* CSIR : Council for Scientific and Industrial Research
* DWA : Department of Water Affairs
* ERDAS : Earth Resources Data Analysis Systems
* ESRI : Environmental Systems Research Institute
* FAO : Food and Agricultural Organization (of the UN)
* FRD : Foundation for Research Development (at the CSIR)
* HRI : Hydrological Research Institute (at the DWA)
* LULC : Land use/Land cover
* NES : National Exchange Standard (as proposed by Clarke, *et al.*, 1987)
* NPRS : National Programme for Remote Sensing (at the CSIR)
* SCS : Soil Conservation Service (of the USDA)
* TIN : Triangulated Irregular Network
* USDA : United States Department of Agriculture
* USGS : United States Geological Survey
* USLE : Universal Soil Loss Equation
* catchments: in this study the term catchment is used synonymously with drainage basin.
* chamaephytes: perennial plants, generally woody or partly, which have their perennating buds closer to the soil surface but definitely above the soil surface (Rutherford & Westfall, 1986).
* cryptophytes: perennial plants, usually herbaceous, which have their buds beneath the soil surface and which include the important geophyte group (Rutherford & Westfall, 1986).
* feature: an identifiable entity on the surface of the earth.
* hemicryptophytes: perennial plants, generally herbaceous, which have their buds at the surface of the ground (Rutherford & Westfall (1986).

* landscape architecture: Meintjes (1989: 18-19) describes landscape architecture as some action or design activity on the natural or man-made landscape which he summarizes as follows:

  * 'The wise planning of the land to create spaces to satisfy human needs and respect the environment. Landscape architecture helps create a quality environment where people live in harmony with the land;

  * each land area or site regardless of its dimensions and environs has unique characteristics which, when identified and clarified, suggests human use patterns that have maximum benefit for the client and the community; and

  * the art of design, planning or management of the land, and the arrangement of natural and man-made elements upon it, applying cultural and scientific knowledge with concern for resource conservation and stewardship to create an environment that serves a useful and enjoyable purpose.'

* phanerophytes: perennial plants usually woody, which have their bud-bearing shoots elevated and exposed to the atmosphere and are, with few exceptions, woody trees and shrubs (Rutherford & Westfall,1986).

* tessellation: a repeating pattern of either regular or irregular shapes.

* therophytes: annual plants that survive the unfavourable season in the form of seed and complete their entire life cycle in one year or less (Rutherford & Westfall, 1986).

* topology: the relationship between the spatial attributes of the same or different features (Clarke, *et al.*, 1987), or the geometrical relationships between map features.

* tuple: a related set of values.

APPENDIX B

STANDARD FEATURE CLASSIFICATION FOR THE EXCHANGE OF GEO-REFERENCED INFORMATION
(from Clarke, *et al.*, 1987: 164-181)

It is imperative that the standard feature classification scheme together with the feature coding scheme and list of non-spatial attributes be maintained centrally by a national co-ordinating body.

B.1 Standard feature classification scheme - version 1.0

The standard feature classification scheme is represented by a variable level hierarchical structure in list form. The different levels are shown by indentations. For example:

COMMUNICATION NETWORK	LEVEL 1
ROAD	LEVEL 11
ROADS	LEVEL 111
FOOTPATH	LEVEL 111
PASS	LEVEL 111
INTERSECTION	LEVEL 111
TOLLGATE	LEVEL 111
RAIL	LEVEL 11
RAILWAY	LEVEL 111
STATION	LEVEL 111
PIPELINE	LEVEL 11
TELECOMMUNICATION	LEVEL 11
GEOMORPHOLOGY	LEVEL 1

Level 1 is the major class, with subsequent breakdown to sublevels until the level that identifies the feature class (feature level) is reached. The path to identify the feature class 'RAILWAY' is 'COMMUNICATION NETWORK/RAIL/RAILWAY'. Its path length is 2 and it is at level 3.

Level 1 is divided into twelve major classes, which can be extended when the need arises. The twelve Level 1 classes are:

BIOLOGY
BUILDING AND STRUCTURE
CLIMATOLOGY AND METEOROLOGY
COMMUNICATION NETWORK
CONTROL SURVEYS
GEOLOGY AND GEOPHYSICS
GEOMORPHOLOGY
HYDROLOGY AND HYDROGRAPHY
LAND USE
OCEANOLOGY
PEDOLOGY
SOCIAL AND CULTURAL

A feature class appears once and only once in the feature classification scheme. Each feature class has been inserted into the scheme in its most probable position. However, some users may find it more convenient for their application to have certain feature classes in a different position, that is, under a different 'parent'. In these cases, the user's interface to the national standard classification must provide the link to associate the feature class with the new parent. For example, the feature class 'CANAL' is given in the standard feature classification as 'BUILDING AND STRUCTURE/CANAL' whereas in an application it might be viewed as a conveyor of water and be classified as 'COMMUNICATION NETWORK/CANAL'. The link can be done by the use of identical data but different feature code dictionaries to allow the translation to the respective feature classifications.

B.2 Feature coding scheme - version 1.0

A feature is identified by its feature class, which in turn has to be identified by its full path name in the feature classification scheme. For the sake of brevity, it is sometimes desirable to represent the feature class path name by a coding scheme.

Human readable codes are desirable if direct human interpretation is required. A mnemonic coding scheme is often used in these cases. In a mnemonic coding scheme a unique mnemonic code is assigned to abbreviate the feature class path name. However, in a large classification scheme it becomes difficult to find a unique mnemonic code that adequately represents the feature class path name.

The feature coding scheme used here is based on computer-readable codes. These codes are taken from the set of natural numbers and are arbitrarily allocated to the feature classes. A feature code dictionary is used to translate from the feature path name to the numeric code, and vice versa.

The advantages of this coding scheme are:

- Very short codes are used (directly related to the number of feature classes in the classification scheme).
- No 'renumbering' of codes is necessary as the 'next number' is allocated to a new feature class.
- Computer-readable codes mean more efficient computer handling.
- The codes are not of fixed length codes.
- These codes are not used at the human interface level and are completely transparent to the user, but can easily be translated into human readable feature class path names.

B.3 Non-spatial attribute lists for each class - version 1.0

The non-spatial attributes of a feature class are given in a non-spatial attribute list. Each feature class has a unique non-spatial attribute list. The name of a non-spatial attribute may appear in the non-spatial attribute list of another feature class, possibly with another definition. It is not necessary for all the attributes to be given to a particular feature. In this case the characteristics of the feature described by the omitted non-spatial attributes are unknown or undefined. The non-spatial attribute list can be an empty (null) list, implying that no information is available to describe the characteristics of that feature.

A non-spatial attribute attached to a 'parent' feature class implies that all the 'children' (lower level) feature classes have that non-spatial attribute. In this case the inherited non-spatial attribute does not have to be explicitly given in the non-spatial attribute list for the 'child' feature classes.

A non-spatial attribute is further described by assigning an attribute value. The attribute value can be one of a set of predefined values or a variable (numeric or string). For example, a bridge with a status of 'IN USE', a width of 10 metres and a name 'CONNAUGHT BRIDGE' would have the following values:

STATUS	= IN USE	: predefined value
WIDTH	= 10	: numeric value
NAME	= CONNAUGHT BRIDGE	: string value

The relation in the standard structure of a data set for the exchange of non-spatial attributes requires the attribute values to be atomic, that is, only one value for each non-spatial attribute. If a non-spatial attribute has more than one value, then the relation must be repeated for each value.

STANDARD FEATURE CLASSIFICATION VERSION 1.0			FEATURE CODE VERSION 1.0	NON-SPATIAL ATTRIBUTE LIST VERSION 1.0
LEVEL 1	11	111		(* Compulsory attribute)
BIOLOGY			10	REFERENCE, ALIAS
	SPECIES OBSERVATION POINT		11	TAXON*,OBSERVATION NUMBER*,TYPE, DATE,TIME,NUMBERS
	SPECIES POPULATION AREA		12	TAXON*,POPULATION NUMBER*,SURVEY NUMBER*,TYPE,DATE,TIME,DEMOGRAPHY CLASS, DEMOGRAPHY TOTAL, DEMOGRAPHY STATUS,CONSERVATION MANAGEMENT STATUS,CONSERVATION THREAT STATUS, CONSERVATION GENETIC STATUS
	SPECIES RANGE		13	TAXON*,REGION*,RANGE NUMBER*,TYPE, DATE,TIME,POPULATION NUMBER,INDIVIDUAL NUMBER
	BIOLOGICAL SURVEY SITE		14	SYSTEM,SURVEY SERIES,SITE NUMBER, SAMPLE NUMBER,DATE,TIME
	NATURAL COMMUNITY AREA		15	SYSTEM,COMMUNITY TYPE,COMMUNITY BLOCK,COMMUNITY OCCURENCE,DATE, TIME
	BIOME-TYPE AREA		16	SYSTEM,BIOME TYPE,BIOME BLOCK, BIOME OCCURENCE
	BIOGEOGRAPHICAL REGION		17	SYSTEM,REGION TYPE,REGION BLOCK, REGION OCCURENCE
BUILDING AND STRUCTURE			18	NAME,CONSTRUCTION
	BUILDING		19	CATEGORY,USE,NUMBER OF FLOORS, HEIGHT
	BRIDGE		20	CATEGORY,FEATURE CLASS CARRIED, FEATURE CLASS CROSSED,STATUS, CLEARANCE HEIGHT,LENGTH,WIDTH, LOAD RATING
	TUNNEL		21	FEATURE CLASS CARRIED,LENGTH, WIDTH,CLEARANCE HEIGHT,LINING, STATUS
	WINDMILL		22	HEIGHT,WHEEL DIAMETER,FUNCTION
	CANAL		23	WIDTH,DEPTH,CAPACITY,GRADIENT
	TOWER		24	FUNCTION,LIGHTED,HEIGHT
	TELEPHONE/TELEGRAPH POLE		25	HEIGHT,REFERENCE NUMBER
	BARRIER		26	TYPE,HEIGHT,WIDTH
	DAM WALL		27	LENGTH,WIDTH,HEIGHT
	JETTY		28	LENGTH,WIDTH
	WHARF		29	FRONTAGE,WIDTH
	RESERVOIR		30	TYPE,DIAMETER,CAPACITY,HEIGHT
	MINE HEADGEAR		31	FUNCTION,LOAD RATING
	SILO		32	TYPE
	STORAGE TANK		33	SUBSTANCE STORED
	BREAKWATER		34	LENGTH
	CHIMNEY		35	HEIGHT,LIGHTED
	CUTTING		36	
	EMBANKMENT		37	
	CRANE		38	TYPE,LOAD RATING
	PLATFORM		39	FUNCTION,LENGTH

STANDARD FEATURE CLASSIFICATION VERSION 1.0			FEATURE CODE VERSION 1.0	NON-SPATIAL ATTRIBUTE LIST VERSION 1.0
LEVEL				
1	11	111		(* Compulsory attribute)
CLIMATOLOGY AND METEOROLOGY			**40**	
COMMUNICATION NETWORK			41	
	ROAD		42	NAME
		ROADS	43	CLASS,ROUTE NUMBER,NUMBER OF CARRIAGEWAYS,NUMBER OF LANES, SURFACE,USE,ACCESS,STATUS
		FOOTPATH	44	
		PASS	45	GRADIENT
		INTERSECTION	46	TYPE
		TOLLGATE	47	NUMBER OF GATES,TOLL
	RAIL		48	
		RAILWAY	49	NUMBER OF LINES,GAUGE,USE,STATUS, GRADIENT,ELECTRIFIED
		STATION	50	NAME,TYPE
	AIR		51	
		AIRPORT	52	NAME,TYPE,ELEVATION
		RUNWAY	53	LENGTH,WIDTH,ORIENTATION,NUMBER, SURFACE,STATUS
		HELIPAD	54	DIAMETER,ELEVATION,SURFACE,STATUS
		CONTROLLED FLYING AREA	55	MINIMUM ALTITUDE,TYPE OF CONTROL
		NAVIGATION/FLYING AID	56	TYPE
	SEA AND INLAND WATER		57	
		FERRY	58	TYPE,CAPACITY
		HARBOUR	59	NAME
		ANCHORAGE AREA	60	MINIMUM DRAUGHT,BOTTOM TYPE
		DOCK	61	MINIMUM DRAUGHT,NAME,HANDLING CAPACITY
		CHANNEL	62	MINIMUM DRAUGHT,NAME
		MARINE NAVIGATION AID	63	TYPE
	PIPELINE		64	FUNCTION,DIAMETER,CONSTRUCTION, CAPACITY,SURFACE
	TELECOMMUNICATION		65	FREQUENCY,POWER,DIRECTION,SPREAD ANGLE
	ELECTRIC TRANSMISSION		66	RATING
		POWERLINE	67	TYPE
		CABLE	68	
	AERIAL CABLEWAY		69	FUNCTION,LOAD RATING
	CONVEYOR BELT		70	LOAD RATING
CONTROL SURVEYS			71	REFERENCE,NUMBER
	TRIGONOMETRICAL BEACON		72	NAME,TYPE,HEIGHT OF BEACON,HEIGHT OF PLATFORM,HEIGHT OF SIGNAL, WITNESS MARK,STATUS,ELEVATION
	TOWN SURVEY MARK		73	REFERENCE,NUMBER,STATUS,ELEVATION
	BENCH MARK		74	ROUTE,ELEVATION,STATUS
	STANDARDISATION BASE		75	NUMBER OF LEGS,LEG NUMBER, DISTANCE

STANDARD FEATURE CLASSIFICATION VERSION 1.0			FEATURE CODE VERSION 1.0	NON-SPATIAL ATTRIBUTE LIST VERSION 1.0
LEVEL				
1	11	111		(* Compulsory attribute)
	PHOTO CONTROL		76	TYPE
	TIDE GAUGE		77	TYPE, STATUS
GEOLOGY AND GEOPHYSICS			78	
	GRAVITY STATION		79	REFERENCE, NAME, TYPE, ELEVATION, G-VALUE
	GRAVITY POINT		80	G-VALUE
	GRAVITY ANOMALY CONTOUR		81	G-VALUE
	MAGNETIC STATION		82	REFERENCE, NAME, TYPE, MAGNETIC DECLINATION, DATE
	MAGNETIC POINT		83	MAGNETIC DECLINATION, DATE
	ISOGONIC LINE		84	MAGNETIC DECLINATION
	CONTACT		85	TYPE, LITHOLOGICAL UNIT SEPARATED
	JOINT		86	TYPE, ORIENTATION
	FAULT		87	TYPE, RELATIVE DIRECTION OF MOVE-MENT, LITHOLOGICAL UNIT LEFT, LITHOLOGICAL UNIT RIGHT, NAME
	LINEATION		88	TYPE, DIRECTION
	YOUNGING		89	DIRECTION
	DIP AND STRIKE		90	DIRECTION, ANGLE, STATUS
	FOLD AXIS		91	TYPE, NAME, DIRECTION, ANGLE
	MINERAL DEPOSIT		92	MINERAL, NAME, STATUS
	LITHOLOGICAL UNIT		93	NAME, ROCK TYPE, AGE, MINERAL COMPOSITION
	RADIOMETRIC AGE		94	VALUE, METHOD
GEOMORPHOLOGY			95	
	RELIEF		96	ELEVATION, TYPE
		CONTOUR	97	
		SPOT HEIGHT	98	
		DEPTH SOUNDING	99	DEPTH
LANDFORM			100	NAME
	ALLUVIAL FAN		101	
	CAPE		102	
	BAY		103	
	BEACH		104	
	COASTLINE		105	
	CAVE		106	
	CLIFF		107	
	DONGA		108	
	DELTA		109	
	DEPRESSION		110	
	ESCARPMENT		111	
	ESTUARY		112	
	FLOOD PLAIN		113	
	GORGE		114	
	HILL		115	
	HEADLAND		116	
	ISLAND		117	
	ISTHMUS		118	

STANDARD FEATURE CLASSIFICATION VERSION 1.0			FEATURE CODE VERSION 1.0	NON-SPATIAL ATTRIBUTE LIST VERSION 1.0
LEVEL				
1	11	111		(* Compulsory attribute)
	LANDSLIDE		119	
	MARSH		120	
	MOUNTAIN RANGE		121	
	MUD FLAT		122	
	OLD RIVER COURSE		123	
	PLAIN		124	
	PLATEAU		125	
	PENINSULA		126	
	POORT		127	
	PEAK		128	
	POTHOLE		129	
	RIVER TERRACE		130	
	RIVER MEANDER		131	
	RIDGE		132	
	REEF		133	
	ROCK OUTCROP		134	
	RAPIDS		135	
	SAND BAR		136	
	SAND BANK		137	
	SAND DUNE		138	
	SEA ARCH		139	
	STACK		140	
	SADDLE		141	
	SINKHOLE		142	
	VALLEY		143	
	VLEI		144	
	WATERFALL		145	
	WATERSHED		146	
	ERODED AREA		147	
HYDROLOGY AND HYDROGRAPHY			148	NAME,MINERAL COMPOSITION
	RIVER		149	TYPE,FLOW CAPACITY
	DAM		150	CAPACITY
	LAKE		151	
	LAGOON		152	
	PAN		153	TYPE
	WATER POINT SOURCE		154	STRENGTH,TYPE
	SUBTERRANEAN WATER		155	
	DRAINAGE BASIN		156	
LAND USE			157	
	INDUSTRIAL		158	ACTIVITY
	COMMERCIAL		159	ACTIVITY
	RESIDENTIAL		160	TYPE
	RECREATION		161	TYPE
	CULTURAL		162	TYPE
	AGRICULTURAL		163	
		CULTIVATED LAND	164	TYPE,YIELD,IRRIGATION
		VINEYARD	165	TYPE,YIELD,IRRIGATION
		ORCHARD	166	TYPE,YIELD,IRRIGATION
		PLANTATION	167	TYPE

STANDARD FEATURE CLASSIFICATION VERSION 1.0			FEATURE CODE VERSION 1.0	NON-SPATIAL ATTRIBUTE LIST VERSION 1.0
LEVEL 1	11	111		(* Compulsory attribute)
		STOCK	168	TYPE
		POULTRY	169	
		GARDEN	170	COVERED
	MINING		171	
		OPENCAST	172	TYPE,YIELD STATUS
		UNDERGROUND	173	TYPE,YIELD,STATUS
		PROSPECTING	174	
		DUMP	175	
		MINE SHAFT	176	
		SLIMES DAM	177	
	MILITARY		178	
	RELIGION		179	TYPE
	EDUCATION		180	TYPE
	GOVERNMENT		181	
	MEDICAL		182	TYPE
	COMMUNICATION		183	TYPE
	UTILITY		184	TYPE
	CONSERVATION AREA		185	TYPE,NAME
OCEANOLOGY			186	NAME
	OCEAN		187	
	SEA		188	
	CURRENT		189	FLOW DIRECTION,SPEED
PEDOLOGY			190	
SOCIAL AND CULTURAL			191	
	CADASTRAL		192	
		CADASTRAL BEACON	193	DESCRIPTION
		CADASTRAL BOUNDARY	194	TYPE,DESCRIPTION
		LAND PARCEL	195	TYPE,DESIGNATION,SITUATION,DEED NUMBER,PARENT DEED NUMBER,LEGAL AREA,SIDE,DIRECTION,CO-ORDINATES, OWNER,STREET ADDRESS
		SERVITUDE	196	TYPE,DESCRIPTION,OWNER
		SECOND PARTY LEGAL RIGHTS	197	TYPE,OWNER
		ADMIN/REGISTRATION-DISTRICT	198	
	ADMINISTRATIVE AREA		199	NAME
		INTERNATIONAL	200	
		PROVINCIAL	201	
		MAGISTERIAL DISTRICT	202	
		LOCAL AUTHORITY	203	TYPE
		REGIONAL SERVICES COUNCIL	204	
		PROCLAIMED RESTRICTION	205	TYPE
		STATE FOREST	206	
		NATURE RESERVE	207	TYPE

STANDARD FEATURE CLASSIFICATION VERSION 1.0			**FEATURE CODE** VERSION 1.0	**NON-SPATIAL ATTRIBUTE LIST** VERSION 1.0
LEVEL				
1	11	111		(* Compulsory attribute)
	SOCIAL STATISTICAL		208	NAME
		ELECTORAL DIVISION	209	
		POLLING DISTRICT	210	
		DEMOGRAPHIC ENUMERATION AREA	211	STATISTICS
		STATISTICAL REGION	212	STATISTICS
		DEVELOPMENT REGION	213	STATISTICS

APPENDIX C

DEPARTMENT OF WATER AFFAIRS

Directorate of Strategic Planning

PROVISIONAL CLASSIFICATION SCHEME FOR GEO-REFERENCED DATA
(from the Department of Water Affairs, 1989).

1. SCIENTIFIC AND NATURAL

1.1 Hydrology

Catchment area
Rivers
Flow gauge
Rain gauge
Evaporation gauge
Water quality gauge
Isohyets
Water quality isolines
Flood zone
Hydrological zone
Geohydrological zone
Evaporation zone
Mean annual rainfall zone
Rainfall zone

1.2 Geology

Minerals zone
Geological zone
Boreholes - geotechnical

1.3 Meteorology

Temperature gauge
Humidity gauge
Wind speed gauge
Sunlight gauge
Isobars
Isotherms
Climatic zone
Lightning zone

1.4 Pedology

Sediment production zone
Soil type zone

1.5 Biology

Veld type zone
Vegetation zone

1.6 Agronomy

Irrigation potential zone
Afforestation potential zone

1.7 Geomorphology

Contours
Constant slope isolines

2. INFRASTRUCTURE

2.1 Distribution Network

- Scheme
- Water transportation media/hydraulic structures
  - Pipelines
  - Canals
- Transport/communication media
  - Roads
  - Railway lines
  - Power lines
  - Telephone lines
  - Servitudes
  - Stand taps
- Municipal
  - Water
  - Gas
  - Electricity
  - Sewerage
  - Stormwater
  - Streets

2.2 Structure

- Hydraulic
  - Tunnels
  - Aquaducts
  - Siphons
  - Rejects
  - Radial gates
- Transport/Communication
  - Bridges
  - Tunnels
- Pumps
  - Windmills
  - Diesel pump
  - Electric pump

2.3 Water source

- Dams
- Pans
- Water outfall points
  - Mine outfall
  - Industry outfall
  - Purification works
- Diffuse water source
- Water boreholes

3. LAND AND WATER USE

3.1 Consumers

- Point users

Mines
Industries
Power stations
Towns/cities/metropoles/conurbations
Fisheries
Municipalities
Ecology

3.2 Industry

Waste disposal site

3.3 Agriculture

Agriculture: irrigation
Agriculture: dry-land
Agriculture: livestock

3.4 Forestry

- Forest
  - Indigenous
  - Commercial
  - State
  - Other
- Fire-break
- Fire lookout

3.5 Recreation

- Sensitive areas
  - Scenic area

3.6 Conservation

- Sensitive areas
  - Archaelogical area
  - Ecological area
  - Wetlands area
  - Endangered species area
  - Breeding area
  - Coastal dunes
  - Streams and lakes
  - Shorelands
  - Estuaries
  - Riverine area
- Conservation areas
  - National Park (RSA)
  - National Park (Independent states)
- Nature reserve
  - State nature reserve
  - Provincial nature reserve
  - Independent state nature reserve
  - SADF nature reserve
  - Private nature reserve
  - Local nature reserve
  - National Botanical garden
  - Nature Area
  - Marine Island

4. SOCIAL AND CULTURAL

4.1 Administrative area

Neighbouring State
Independent state (TBVC)
Self-governing region
Trust land
Land ceded
Land to be ceded
Land to be returned to RSA
Province
Local Authorities
- RDACs
- RSCs
- Magisterial districts
- Municipalities

4.2 Cadastral

Farm/Registered property

4.3 Social Statistical

Enumeration district

5. WATER MANAGEMENT

Government Water Control Areas
Water Board
Irrigation Board
River Basin Authority

APPENDIX D

A 4-LEVEL HIERARCHICAL CLASSIFICATION SYSTEM OF LAND-USE/LAND COVER CATEGORIES. AS AN EXAMPLE THE CATEGORY: URBAN AND BUILT-UP - RESIDENTIAL IS SHOWN.
(from Anderson, *et al.*, 1976 and the Urban Renewal Administration, 1965)

SLUC (Standard Land Use Coding Manual) codes refer to those issued by the Urban Renewal Administration (1965)).

1. URBAN AND BUILT-UP

Urban and built-up land comprises areas of intensive use with much of the land covered by structures. Included in this category are cities, towns, villages, strip developments along highways, transportation, power, and communication facilities, and such isolated units as mills, mines, and quarries, shopping centers, and institutions.

As development progresses, small blocks of land of less intensive or non-conforming use may be isolated in the midst of built-up areas and will generally be included in the (1) caregory. Agricultural, forest, or water areas on the fringe of urban and built-up areas will not be included except where they are part of low-density urban development. The urban and built-up land category takes precedence over others when the criteria for more than one category are met. Thus, residential areas that have sufficient tree cover to meet forest land criteria will be placed in the residential category.

11 RESIDENTIAL

Residential land uses range from high density, represented by the multiple-unit structures of urban cores, to low density, where houses are on lots of more than an acre, on the periphery of urban expansion. Linear residential developments along transportation routes extending outward from urban areas should be included as residential appendages to urban centers, but care must be taken to distinguish them from commercial strips in the same locality. Residential development along shorelines is also linear and sometimes extends back only one residential parcel from the shoreline to the first road.

Areas of sparse residential land use will be included under another category. In some places, the boundary will be clear where new housing developments abut against intensively used agricultural areas, but the boundary may be vague and difficult to discern when residential development is sporadic, or occurs in small isolated units over an extended period of time in areas of mixed or less intensive uses. A careful evaluation of density and the overall relation of the area to the total urban complex must be made.

Residential sections may also be included in other use categories where they are integral parts of the other use. Housing on military bases, at colleges and universities, living quarters for labourers near a work base, or lodging for employees of agricultural field operations or resorts are often difficult to identify and may be placed within the institutional, industrial, agricultural, or commercial categories.

111 MULTI-FAMILY, MEDIUM- TO HIGH-RISE

Includes all multi-family and apartment structures of 4 or more stories. Included are apartments, condominiums, and the like, whether in complexes or as single structures. It is inclusive of lawns, parking areas, any small-area recreational facilities. These areas should also be included under categories 112, 113, 114 and 115.

1111 HIGH DENSITY

Development containing an average gross density of 35 or more dwelling units per acre.

1112 MEDIUM DWELLING

Development containing an average gross density of more than 20 dwelling units per acre, but less than 35 dwelling units per acre.

1113 LOW DENSITY

Development containing an average gross density of 20 or less dwelling units per acre.

112 MULTI-FAMILY, LOW-RISE

Similar to 111 except that it is for structures of 3 or less stories. Duplexes are not included, but townhouses are.

1121 HIGH DENSITY, APARTMENT

Apartment development containing an average gross density of 18 or more dwelling units per acre.

1122 MEDIUM DENSITY, APARTMENT

Apartment development containing an average gross density of more than 12 dwelling units per acre but less than 18 dwelling units per acre.

1123 LOW DENSITY, APARTMENT

Apartment development containing an average gross density of 12 or less dwelling units per acre.

1124 HIGH DENSITY, TOWNHOUSE

Townhouse development containing an average gross density of 12 or more dwelling units per acre.

1125 MEDIUM DENSITY, TOWNHOUSE

Townhouse development containing an average gross density of more than 8 dwelling units per acre, but less than 12 dwelling units per acre.

1126 LOW DENSITY, TOWNHOUSE

Townhouse development containing an average gross density of 8 or less dwelling units per acre.

113 SINGLE-FAMILY/DUPLEX

This category includes areas having detached single and two-family structures used as a permanent dwelling more than two rows wide except for those strip developments connected to larger residential areas. Associated structures may include tool sheds, garages, garden sheds, etc.

1131 HIGH DENSITY

Development or grouping containing an average gross density of 6 or more dwelling units per acre.

1132 MEDIUM DENSITY

A development or grouping containing an average gross density of more than 3 dwelling units per acre, but less than 6 dwelling units per acre.

1133 LOW DENSITY

A development or grouping containing an average gross density of 3 or less dwelling units per acre.

1134 NON-FARM RESIDENCE

A dwelling located in a rural or urban-rural fringe area and occupied by a non-farming family.

1135 MOBILE HOME

Single or several mobile homes not located in a mobile home park.

1136 SEASONAL DWELLING

A dwelling occupied only during a specific season of the year.

1139 OTHER

Any single family or duplex structure not covered above.

114 STRIP RESIDENTIAL

Predominantly residential development located in a linear pattern along a shoreline or road containing a minimum of 5 or more structures and not more than two rows wide. Land use directly behind the strip itself should be unrelated to residential land use.

1141 HIGH DENSITY, SHORELINE

Continuous strip residential grouping wherein are located 8 or more structures per 1000 linear feet .

1142 MEDIUM DENSITY, SHORELINE

Continuous strip residential grouping wherein are located more than 2 structures per 1000 linear feet, but less than 8 structures per 1000 linear feet.

1143 LOW DENSITY, SHORELINE

Continuous strip residential grouping wherein are located 2 or less structures per 1000 linear feet .

1144 HIGH DENSITY, ROADSIDE

Continuous strip residential grouping wherein are located 8 or more structures per 1000 linear feet.

1145 MEDIUM DENSITY, ROADSIDE

Continuous strip residential grouping wherein are located more than 2 structures per 1000 linear feet, but less than 8 structures per 1000 linear feet.

1146 LOW DENSITY, ROADSIDE

A continuous strip residential grouping wherein are located 2 or less structures per 1000 linear feet.

115 MOBILE HOME PARKS (SLUC 140)

Area of land used for a grouping of mobile homes shall be classed into this category. Usually these areas will include mobile homes in numbers over three. Related services and recreational spaces are to be included. Single mobile homes will be classed as of 113.

1151 HIGH DENSITY

A development or grouping containing an average gross density of 12 or more dwelling units per acre.

1152 MEDIUM DENSITY

A development or grouping containing an average gross density of 12 or more dwelling units per acre.

1153 LOW DENSITY

A development or grouping containing an average gross density of 6 or less dwelling units per acre.

116 GROUP AND TRANSIENT QUARTERS

A structure which is used for housing, whether permanent or temporary, of a number of unrelated individuals. This differs from apartments in that residents tend to interact with each other for meals, care, etc. All of these quarters could also logically go under other uses (i.e., hotels - commercial, dormitory - educational), but they are classed here because all have predominantly residential characteristics in common.

1161 ROOMING AND BOARDING HOUSES

Generally operated on a commercial basis, renting rooms to five or more persons not related to the proprietor, with or without board. (SLUC 121)

1162 MEMBERSHIP LODGING

Includes organizational private hotels, organizational lodging houses and membership residence dormitories. Does not refer to religious organizational facilities. (SLUC 122)

1163 RESIDENCE HALLS AND DORMITORIES

Buildings containing nurses and students residential facilities, including adjacent lawn and parking. (SLUC 123)

1164 RETIREMENT HOMES AND ORPHANAGES

Includes residential facilities for the aged, orphaned, or indigent. (SLUC 124)

1165 RELIGIOUS QUARTERS

Includes convents, monasteries, abbeys, rectories, parish houses and parsonages. (SLUC 125)

1166 RESIDENTIAL HOTELS

Non-organizational residential or apartment hotels operated as a facility wherein guests reside on a semi-permanent basis. (SLUC 130)

1167 HOTELS, TOURIST COURTS, MOTELS

Transient lodging facilities operated on a commercial basis, by day or week. (SLUC 151)

1168 MIGRANT QUARTERS

Season dwellings used for housing seasonal workers.

1169 OTHER

Group and transient uses not covered above. (SLUC 190)

119 OTHER RESIDENTIAL

All other obviously residential land uses not covered above.

APPENDIX E

A PROPOSED GEO-REFERENCED DATA CATEGORY CLASSIFICATION SYSTEM

The following data classes and categories are portrayed in this study:

Class 1: Natural resources data

Category 1.1: Geology

Category 1.2: Climate and meteorology

Category 1.3: Geomorphology

Category 1.4: Pedology

Category 1.5: Hydrology and Hydrography

Category 1.6: Vegetation

Category 1.7: Zoology

Class 2: Land use data

CLASS 1 NATURAL RESOURCES DATA

Category 1.1: Geology

1.1.1 INTRODUCTION

Bosch, *et al*. (1986) find the precise influence that the geology of a catchment has on the hydrological response of that catchment difficult to define. Nevertheless, the hydrological function of the catchments' underlying lithology is its potential to control water transmission and storage. This potential is determined, according to Bosch, *et al*. (1986), by the hydraulic conductivity and porosity of the rock matrix and by structural features such as fissures, cracks and joints.

Variation in these properties will influence, *inter alia*:

* the seasonal flow patterns of rivers;
* a river's individual storm flow characteristics;
* sub-surface flow patterns;
* water quality; and
* erosion and sediment yield.

During the early 1970s the National Committee for Geological Sciences decided to assemble the South African Committee for Stratigraphy (SACS) and task it, *inter alia*, with classifying and mapping southern African geology from a stratigraphic perspective.

SACS (1980: 643) defines stratigraphy as ' ... the descriptive science of strata, (which) deals with the form, arrangement, distribution, chronologic succession, classification, nomenclature and relationships of rock strata and other related rock bodies with respect to any or all of the properties which rocks may possess.'

'The main objective of stratigraphy is to construct a stratigraphic column representing a systematic and geochronologic picture of the succession of events which occurred during the earth's history.' (SACS, 1980: 644)

1.1.2 GEOLOGICAL CLASSIFICATION SYSTEMS

Three major classification categories are proposed by SACS (1980), namely:

* Lithostratigraphic classification

  The units are comprised of a dominant rock type or consist of a few rock types or a characteristic combination of rock types or possess other significant unifying lithological features.

* Biostratigraphic classification

  The units are each unified with respect to adjacent strata by its fossil content or palaentologic character (SACS, 1980).

* Chronostratigraphic classification

  The units of this classification show a uniformity with regard to the 'geologic time' interval in which they are formed.

In Table E1.1 (p.191) a summary is shown of these three categories of classification and their terms is shown.

1.1.3 SACS LITHOSTRATIGRAPHIC CLASSIFICATION SYSTEM

1.1.3.1 Hierarchy of the lithostratigraphic classification system

For the purpose of this study, the hierarchy of the lithostratigraphic classification system needs to be explained in more detail.

* Bed

  This, the lowest ranking formal lithostratigraphic unit is a named, distinctive rock layer within a member or formation. It's thickness may vary from a few millimeters to a few meters. Usually only very

TABLE E1.1: THE SACS GEOLOGICAL CLASSIFICATION SYSTEM: SUMMARY OF CATEGORIES AND UNIT TERMS IN STRATIGRAPHIC CLASSIFICATION. PREFIXES SUB- AND SUPER- MAY BE USED WITH UNIT TERMS, WHEN APPROPRIATE, IF ADDITIONAL RANKS ARE NEEDED. (FROM SACS, 1980)

CATEGORIES	PRINCIPAL UNIT TERMS	
LITHOSTRATIGRAPHIC	GROUP	
	FORMATION	
	MEMBER	
	BED	
BIOSTRATIGRAPHIC	BIOSTRATIGRAPHIC ZONES (BIOZONES)	
	ASSEMBLAGE ZONE	
	RANGE ZONE (VARIOUS KINDS)	
	ACME ZONE	
	OTHER KINDS OF BIOZONES	
CHRONOSTRATIGRAPHIC		EQUIVALENT GEOCHRONOLOGIC UNITS
	(EONOTHEM)	EON
	ERATHEM	ERA
	SYSTEM	PERIOD
	SERIES	EPOCH
	STAGE	AGE
	CHRONOZONE	CHRON
OTHER STRATIGRAPHIC CATEGORIES	ZONE (WITH APPROPRIATE PREFIX, E.G. MAGNITITE ZONE)	
(MINERALOGIC, METAMORPHIC, ENVIRONMENTAL, SEISMIC, MAGNETIC, TECTONO-STRATIGRAPHIC ETC.)	SEQUENCE/SYNTHEM (FOR TECTONOSTRATIGRAPHIC UNITS)	

distinctive beds (known as marker beds and particularly useful for stratigraphic purposes) are formally named (SACS, 1980).

* Member

  A member is usually distinguished by lithologic properties which differ from adjacent parts within a certain formation. Members are thus always part of formations, although formations need not necessarily be divided into members.

* Formation

  Formations are the fundamental formal units in lithostratigraphic classification. It is also the only unit used to divide the entire stratigraphic column into named units. 'The establishment of different formations may depend on the complexity of the geology of a region and the detail needed to portray its rock framework satisfactorily.' (SACS, 1980: 648). SACS (1980) adds that because it is impossible to lay down universal rules for the establishment of distinct formations, the dimensions of formations follow no standard. As a practical rule, the 'ability to depict a unit on 1:50 000 scale maps should give an indication of the minimum size of units which can be accorded formation status' (SACS, 1980: 648).

* Group

  Groups are combinations or assemblages of two or more successive formations with significant unifying lithologic features in common (SACS, 1980).

  'The term supergroup is used when there is need to refer to several successive associated groups, or groups and formations, with significant lithologic features in common' (SACS, 1980: 649). The term subgroup is used 'when there is a need to distinguish an assemblage of successive formations from the rest of an already established group' (SACS, 1980: 649).

  In Figure E1.1 (p.193) an imaginary succession of the formal lithostratigraphic units are shown.

1.1.3.2 Other lithostratigraphic units

* Complex

  'A rock unit composed of diverse types of any classes of rocks, (igneous, metamorphic or even sedimentary) and characterized by a complicated structure...' (SACS, 1980: 650).

* Suite

  SACS (1980) recognizes suites as the fundamental units in terrains where intrusive igneous and high-grade metamorphic rocks occur. Suites are comparable to the lithostratigraphic groups.

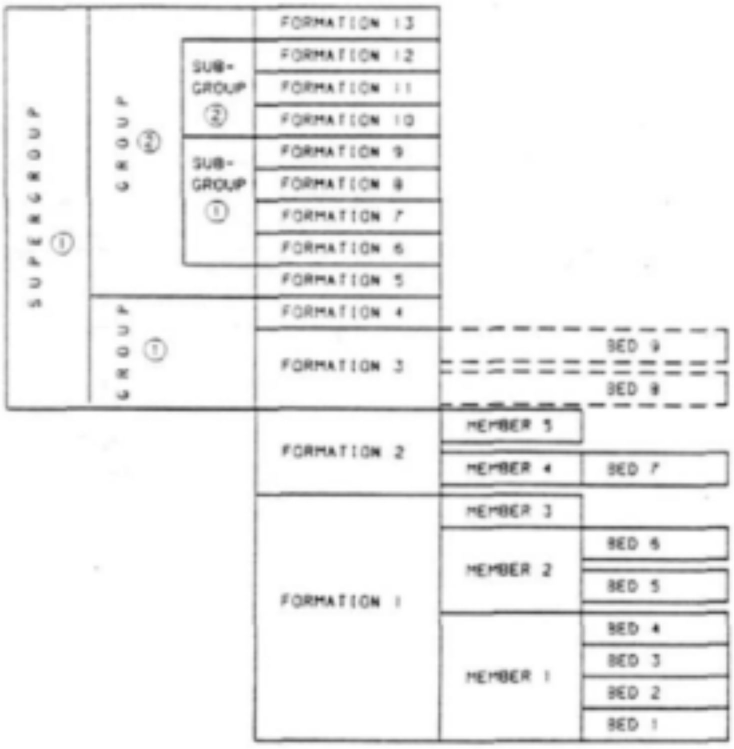


FIGURE E1.1: AN IMAGINARY SUCCESSION OF THE FORMAL LITHOSTRATIGRAPHIC UNITS
THE ONLY ESSENTIAL REQUIREMENT IS THAT THE ENTIRE SUCCESSION BE SUBDIVIDED INTO FORMATIONS. WHERE APPROPRIATE, THESE MAY BE FORMED INTO GROUPS. IN RELATION TO ESTABLISHED GROUPS, CIRCUMSTANCES MAY SUGGEST THE SUITABILITY OF ERECTING SUPERGROUPS AND/OR SUBGROUPS. THE WHOLE OR PORTIONS OF FORMATIONS MAY BE SUBDIVIDED INTO MEMBERS, AND SIMILARLY MEMBERS INTO BEDS. NOTE THAT BEDS MAY ALSO BE ESTABLISHED DIRECTLY WITHIN FORMATIONS. (VAN EYSINGA AND TAKEN FROM SACS, 1980)

A suite consists of related lithologic units, characterized by distinctive lithologic, mineralogic, textural or chemical features (SACS, 1980).

1.1.3.3 Other units

* Sequence

Though not a lithostratigraphic unit, the term sequence is used to describe a collection of formations, groups and even supergroups normally bounded by major unconformities. A sequence, one of the tectonostratigraphic units, usually displays 'a broad cyclic development reflecting the tectonic and sedimentary history of the sedimentary basin and surrounding provenance areas.' (SACS, 1980: 663).

1.1.4 GEOLOGICAL MAPS

SACS, under the auspices of the Geological Survey Office of the Department of Mineral and Energy Affairs, publishes three main series of geological maps, namely: the 1:1 000 000, the 1:250 000 and the 1:50 000 scale series. The latter two series currently do not cover the whole of South Africa. In the case of the 1:250 000 scale series, approximately 43% and in the 1:50 000 scale series less than 1% of the total South African areas are mapped. A small number of 1:125 000 scale maps (produced during previous surveys) are also still available.

The 1:50 000 scale series is mapped and annotated according to the chronostratigraphic classification whereas both the 1:250 000 and 1:1 000 000 series are mapped according to the lithostratigraphic classification system.

Because of the divergent mapping units on the various geological maps, ranging from groups, sub-groups, formations, complexes and suites on lithostratigraphic maps to stages, series, units and complexes on chronostratigraphic maps, it is not possible to hierarchically classify the various geological units on the three level spatial feature system as proposed in the NES (Clarke, *et al.*, 1987).

They propose (1987: 173) that the various lithological units (both lithostratigraphic and chronostratigraphic) be accommodated as level II classifications with the name, rock type, age and mineral composition as non-spatial attributes. Clarke, *et al.* (1987) furthermore propose that other geological information, mostly point or linear features such as dykes, faults, lineaments, beds, dips and strikes and contact lines, also be accommodated at a level II classification. They combine geophysical information, such as gravity points, gravity anomaly contours and isogonic lines under the level I classification named, 'Geology and Geophysics'.

1.1.5 CONCLUSIONS AND PROPOSAL

Due to varying formats in which geological information is presented on available maps, it is difficult to integrate a formal hierarchy of geological units with a system suitable for GIS as proposed by Clarke, *et al.* (1987).

In Table E1.2 (p.196) a proposal is made on how to classify spatial geological and geophysical features in a multi-level hierarchy and with associated non-spatial attributes. For the purpose of this study, attention is given only to the two most frequently used lithological classifications namely the lithostratigraphic and chronostratigraphic systems but other recognized systems such as the biostratigraphic, tectonostratigraphic systems as well as equivalent geochronologic unit terms can be added to the proposed classification.

TABLE E1.2 A proposed classification system for geology and geophysics
(Clarke, *et al.*, 1987 and adapted by author)

FEATURES LEVELS I II III IV V VI VII	NON-SPATIAL ATTRIBUTES
Natural resources data	
Geology and Geophysics	
Geophysics	
Gravity station	Name,reference,type,elevation,G-value
Gravity point	G-value
Gravity anomaly contour	G-value
Magnetic station	Name,reference,type,magnetic declination,date
Magnetic point	Magnetic declination,date
Isogonic line	Magnetic declination
Geology	
Lithological unit, e.g. group	Name,reference,rock type,mineral composition,age,lithological classification system used, e.g. lithostratigraphic
Lithological unit, e.g. formation	
Lithological unit, e.g. member	
Lithological unit, e.g. bed	
Lithological unit, e.g. Erathem	Name,reference,rock type,mineral composition,age,lithological classification system used, e.g. chronostratigraphic
Lithological unit, e.g. System	
Lithological unit, e.g. Series	
Lithological unit, e.g. Stage	
Mineral deposit	Mineral,name,status
Radiometric age	Value,method
Fault	Type,relative direction of movement,lithological units left and right,name,exposed/concealed
Diatremes	Type,reference
Strike and dip	Direction,status,degrees of dip
Fold axis	Type,name,direction,angle
Lineament	Type,direction
Beds	Horizontal/vertical
Springs	Temperature,yield,name
Contact	Exposed,concealed,lithological units separated

CLASS 1 NATURAL RESOURCES DATA

Category 1.2: Climate and meteorology

1.2.1 INTRODUCTION

The climate at any location is mainly controlled by latitude, position relative to the distribution of land and sea, height above sea level, general circulation of the atmosphere, influence of ocean currents and it's position relative to hills, mountains and rivers (Schulze, 1965).

Schulze (1965) found that South Africa's climate is almost entirely determined by the westerly circulation of air masses (to a lesser extent in summer than in winter), and that it can be said that weather changes in this country are largely dominated by perturbations in the southern hemisphere's westerly circulation which appear on the surface as a succession of cyclones or anticyclones moving around the coast or across the country from a westerly point.

As Rutherford & Westfall (1986) point out, any analysis and climate classification system proposal on an extensive spatial basis (e.g. the extent of the RSA), necessarily tend to lose the precise information and parameters available for a detailed locality.

They also state that it is generally accepted that heat and water relations form the most important habitat and environmental factors in any bioclassification of the geosphere. They quote various authors who found that plant form and vegetative structure are determined primarily by air temperature and the climatic water balance. Schulze & McGee (1978) also see climatic restrictions as the most important restraint for biogeographical and ecological studies on a sub-continental scale. Of these climatic factors, Schulze & McGee (1978) recognize light, air temperature and moisture as of the greatest importance to the biota.

1.2.2 CLIMATIC FACTORS

For the purpose of this study, attention is given to climatic factors which are spatially representable on a map and which have been mapped by experts in the particular fields of study. Among these factors are:

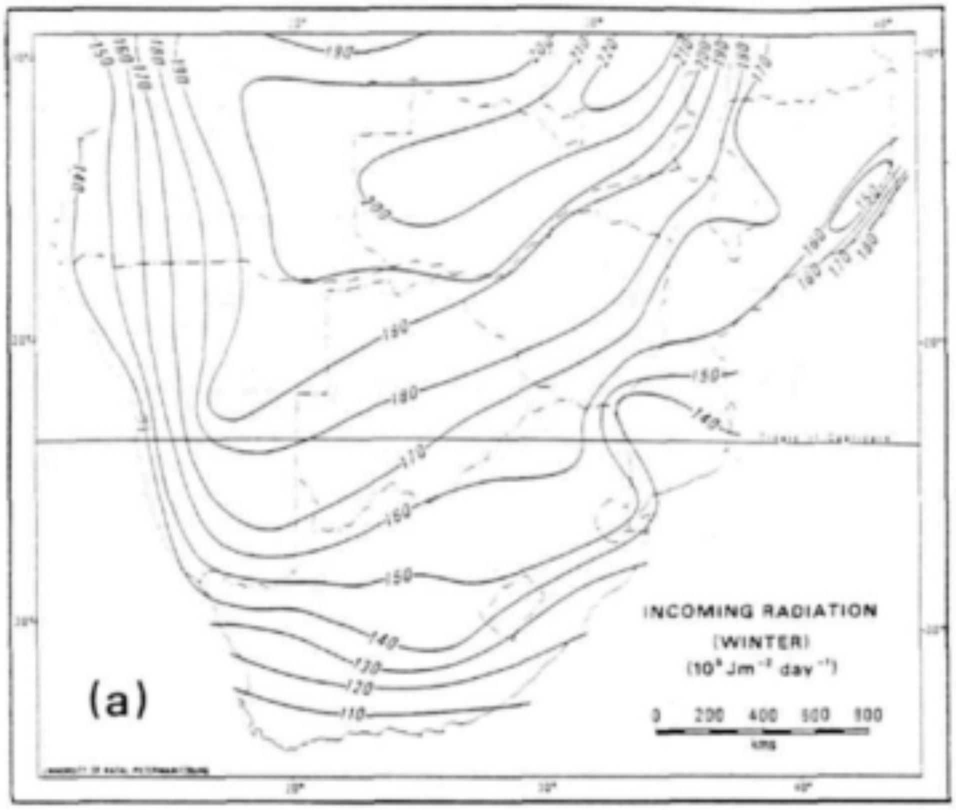
* solar radiation in the form of light;
* air temperature;
* moisture (various sources of precipitation); and
* wind.

1.2.2.1 Light

Schulze & McGee (1978: 21) point out that the 'energy resources of all ecosystems are ultimately dependent upon the quantity of incoming solar radiation intercepted'. The visible light portion of the solar radiation spectrum activates biological processes such as photosynthesis, photoperiodism, phototropism and vertical zonation of plant groupings.

The amount of solar radiation received at a particular location can, despite what is indicated on incoming radiation maps such as Figures E2.1(a) and E2.1(b)(p.199) be affected by local circumstances such as altitude, sunshine duration, atmospheric moisture, cloud cover and atmospheric dust content.

According to Schulze & McGee (1978) the main factor determining the winter radiation patterns in southern Africa (Figure E2.1(a)) is the increase in cloudiness south of 30°S.



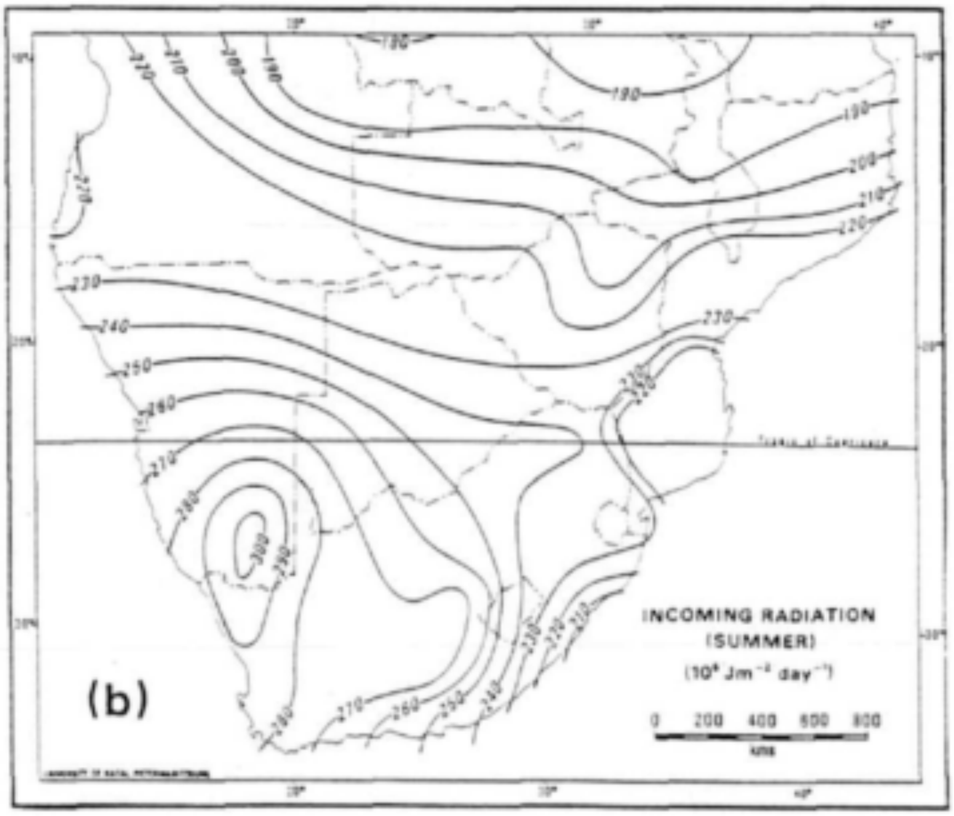


FIGURE E2.1: INCOMING RADIATION PATTERNS
(FROM SCHULZE & MCGEE, 1978)

In the summer, with the sun in its southernmost position, the zone of maximum radiation moves southwards from its winter position. In Figure E2.1(b) this movement, compared to Figure E2.1(a), can be seen.

The topography of the land influences the amount of incoming solar radiation to a marked degree. Schulze & McGee (1978) quote various authors whose work confirm the following general observations:

* Radiation increases with latitude for north, northeast/northwest and east/west aspects.
* There is little variation with latitude on southeast/southwest slopes.
* Radiation decreases with increasing latitude on south aspects, especially on the steeper slopes.
* The influence of latitude on incoming radiation fluxes on slopes is most noticeable in mid-winter.
* Topographically induced radiation, and consequently water balance differences, account to a large degree for vegetation successional changes.

Schulze (1965) gives statistics on a month to month basis of the annual march of total and diffuse radiation for 11 major southern African cities. The duration of average monthly and annual sunshine hours for 84 southern African locations are also given in this work.

1.2.2.2 Air temperature

Although, according to Schulze & McGee (1978), air temperature alone is not a significant factor in determining major regional vegetation formations, it does play a major role in determining floristic variations on a meso- or micro-scale.

Air temperature does influence among others, rates of plant growth, plant stature, seed germination, time of flowering and maturing of plant tissues.

Schulze & McGee (1978) perceive critical air temperature, that of summer maxima and winter minima (and associated frosts) of more significance to plant distribution than temperature means.

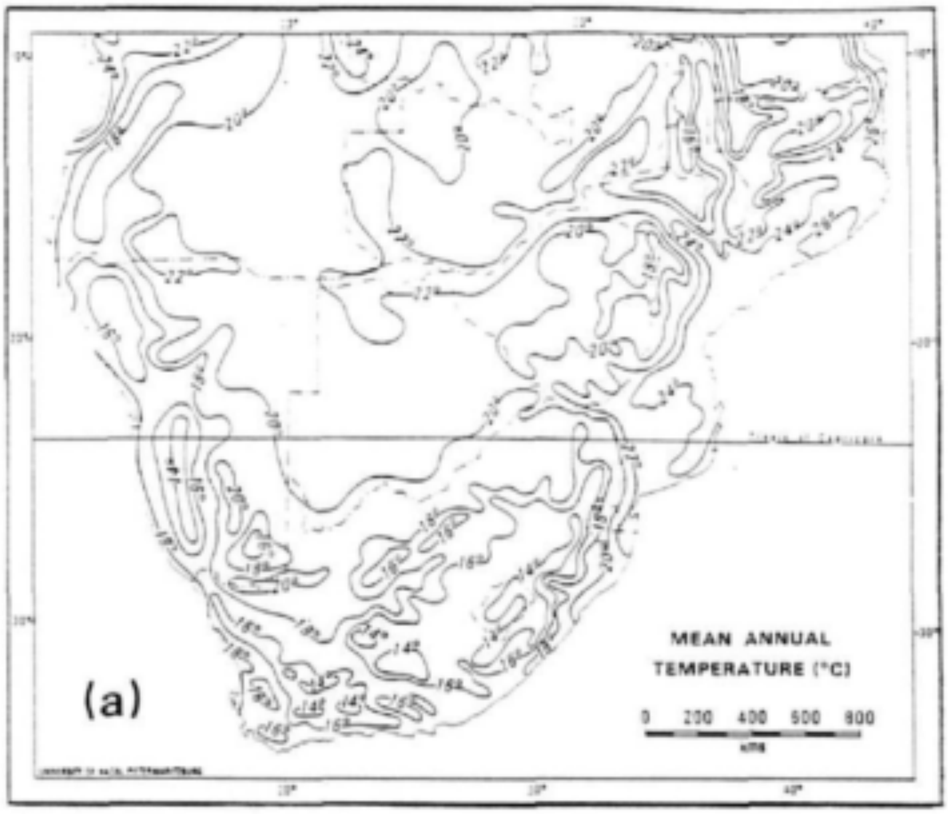
In Figures E2.2(a) and E2.2(b)(p.202) the mean annual isotherms and mean annual range of temperatures for southern Africa are mapped. In the last figure it can be seen that the smallest temperature range occurs towards the equator and that the biggest temperature range occurs over southern Kalahari and northern Karoo where the ameliorating effect of cloud cover is generally absent (Schulze & McGee, 1978).

Schulze (1965) found the distribution of mean air temperature for January and July as very similar, except that the air temperature is on the whole slightly lower over the southern African subcontinent than on adjoining sea-surfaces at the same latitudes.

In Figure E2.3(a)(p.203) the mean daily maximum temperature for January (middle of summer) is shown. Figure E2.3(b)(p.203) shows mean minimum temperature for July (middle of winter) for southern Africa. The critical zero isotherm encompasses most of Lesotho, the interior plateau above 1800 m as well as the Karoo regions.

At the more detailed level, Schulze (1965: 86-91) presents diagrams of the following monthly temperature marches, taken over a year, for 58 southern African locations:

* mean daily temperature;



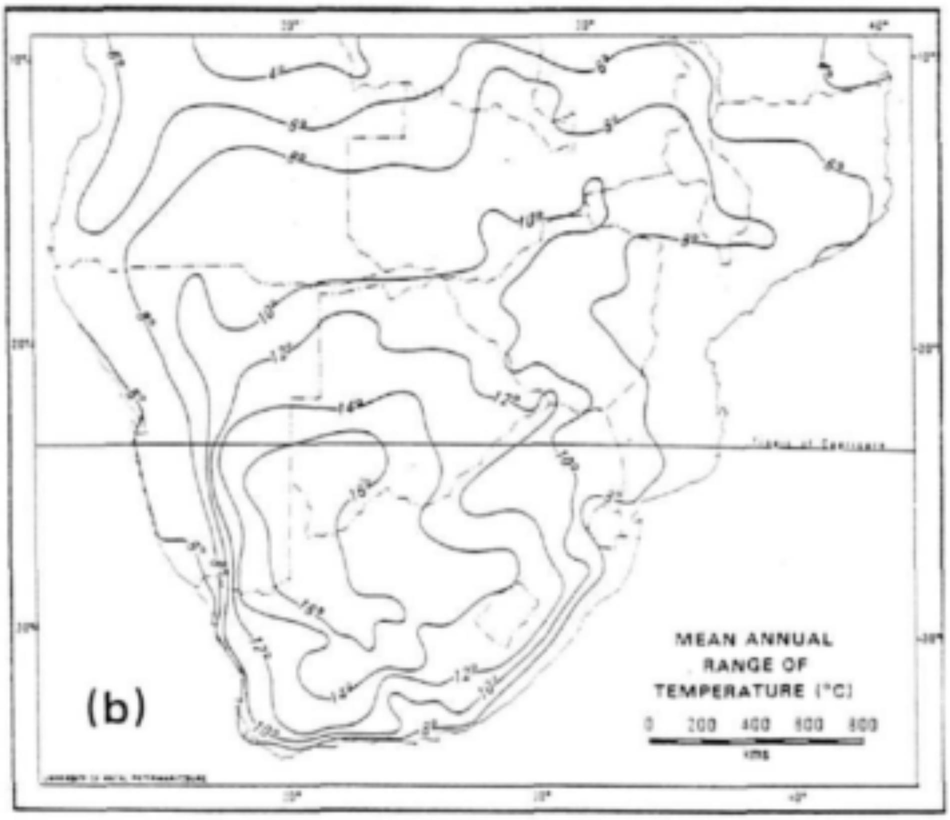
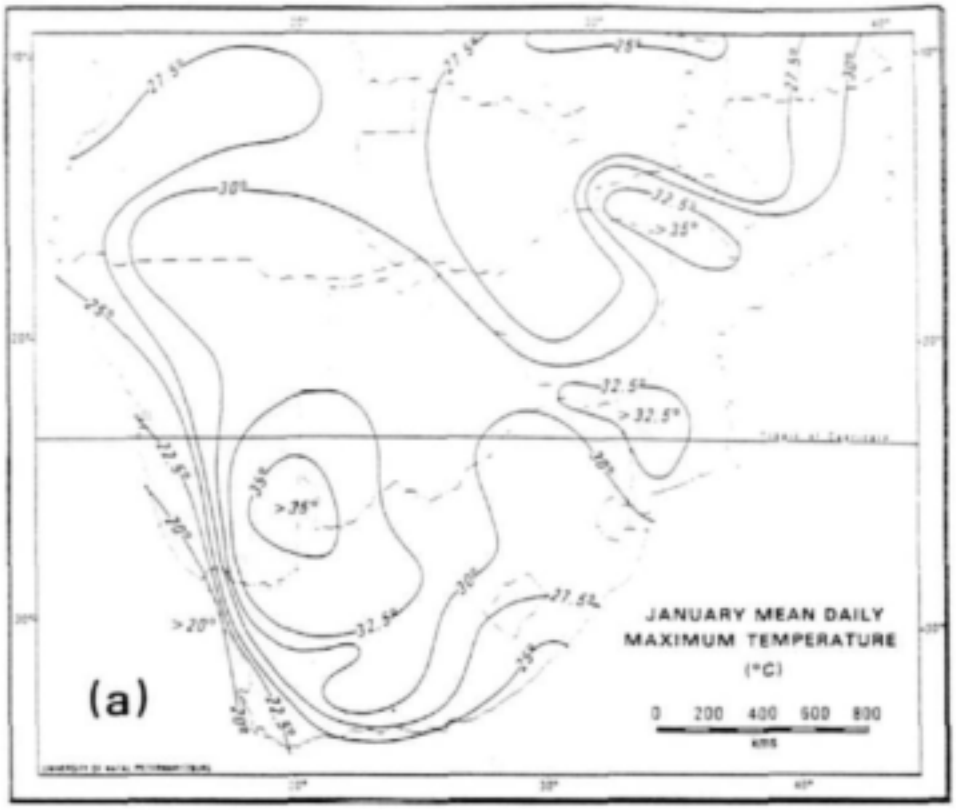


FIGURE E2.2:
(a) MEAN ANNUAL TEMPERATURE
(b) MEAN ANNUAL RANGE OF TEMPERATURE
(KNOCH & SCHULZE AND TAKEN FROM SCHULZE & MCGEE, 1978)



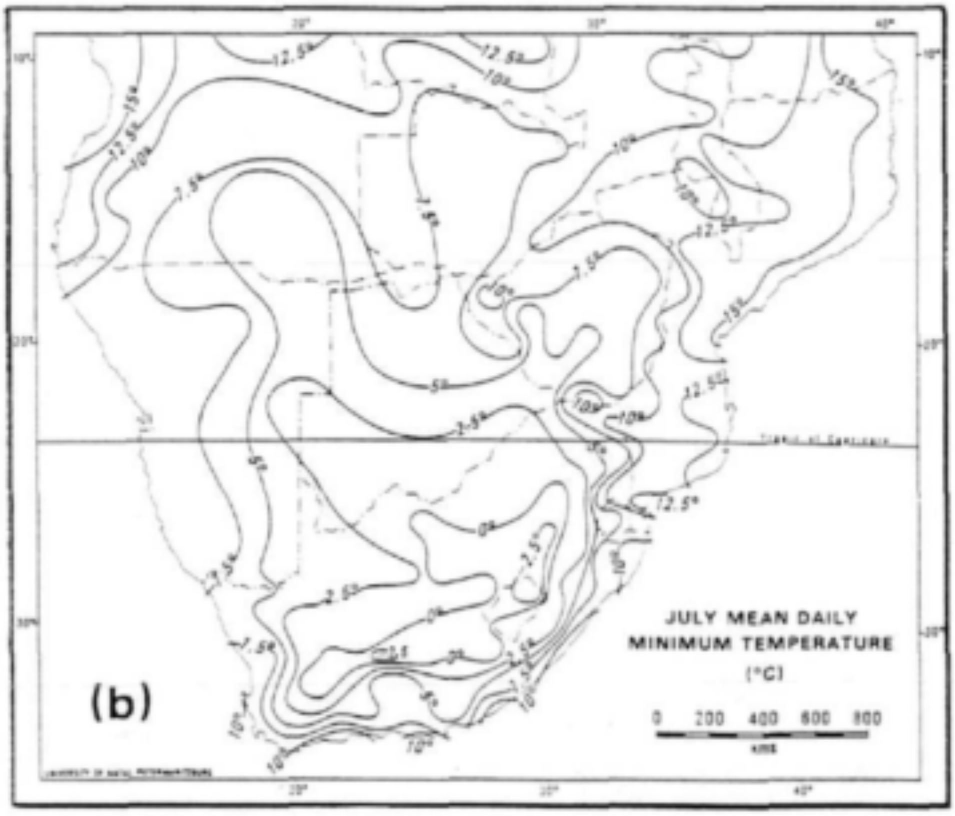


FIGURE E2.3:
(a) MEAN DAILY JANUARY MAXIMUM TEMPERATURE
(b) MEAN DAILY JULY MINIMUM TEMPERATURE
(THOMPSON AND TAKEN FROM SCHULZE & MCGEE, 1978)

* mean daily maximum temperature;
* mean daily minimum temperature;
* mean monthly maximum temperature;
* mean monthly minimum temperature;
* absolute maximum temperature; and
* absolute minimum temperature.

It is suggested that these data be used as attributes of the particular spatial locations.

1.2.2.3 Earth temperature

The surface of the earth is subject to large changes of temperature which are mainly periodic in character and due to seasonal and diurnal changes in insolation and terrestrial radiation, though conduction from overlaying air also plays some part in changing the temperature of the earth's surface (Schulze, 1965). When the surface temperature increases, due mainly to insolation, heat is conducted downwards into the earth's crust and vice versa when the surface temperature decreases due to terrestrial radiation. Schulze (1965) found that the soil temperatures at various depths are dependant on the amount of incoming /outgoing radiation, the nature and colour of the surface and the texture of the soil with regard to reflectivity and conductivity.

The earth temperature, aside from being important to agriculture, also determines to some extent the climate of the overlaying surface air. Schulze (1965) gives statistics on soil temperature at various depths under various covers, and at various times for a number of South African locations.

1.2.2.4 Moisture

One of the major driving forces of the hydrological cycle is precipitation (Bosch, *et al.*, 1986). Both the quantity and quality of of precipitation can be influenced by airborne pollutants such as atmospheric dust caused by ploughing, smoke generated by burning of vegetation and atmospheric sulphur, phosphorus and nitrogen oxides originating from industrial processes.

Among the various individual climatic parameters which influence the vegetation differences on earth, Schulze & McGee (1978) consider water to be the most important.

Land plants draw water from soil moisture which, in turn, is derived mainly from rainfall, fog and snow. In this country the latter is not considered of the same importance as rain and fog.

In Figure E2.4(p.206) the mean annual precipitation over southern Africa is mapped. The most significant feature of this map is the relatively uniform decrease in precipitation westwards from the escarpment across the plateau.

Because rainfall maxima occur in December/January (mid-summer) over almost the entire southern Africa, the map of mean January precipitation (Figure E2.5(a)p.207) shows a big correspondence with that of the mean annual precipitation (Figure E2.4 p.206.) Only portions of the south-west Cape receive an average of 50 mm or more of rainfall during the mid-winter (July). This can be seen on Figure E2.5(b)p.207.

Schulze & McGee, (1978) quote various authors whose research indicate that precipitation is intercepted by vegetation as follows:

* mature exotic forest: 8 - 12% loss of mean annual precipitation;
* tall grassveld: 11,6% loss of mean annual precipitation; and
* mixed bushveld/open savanna: 16 - 30% loss during a shower of 15 mm.

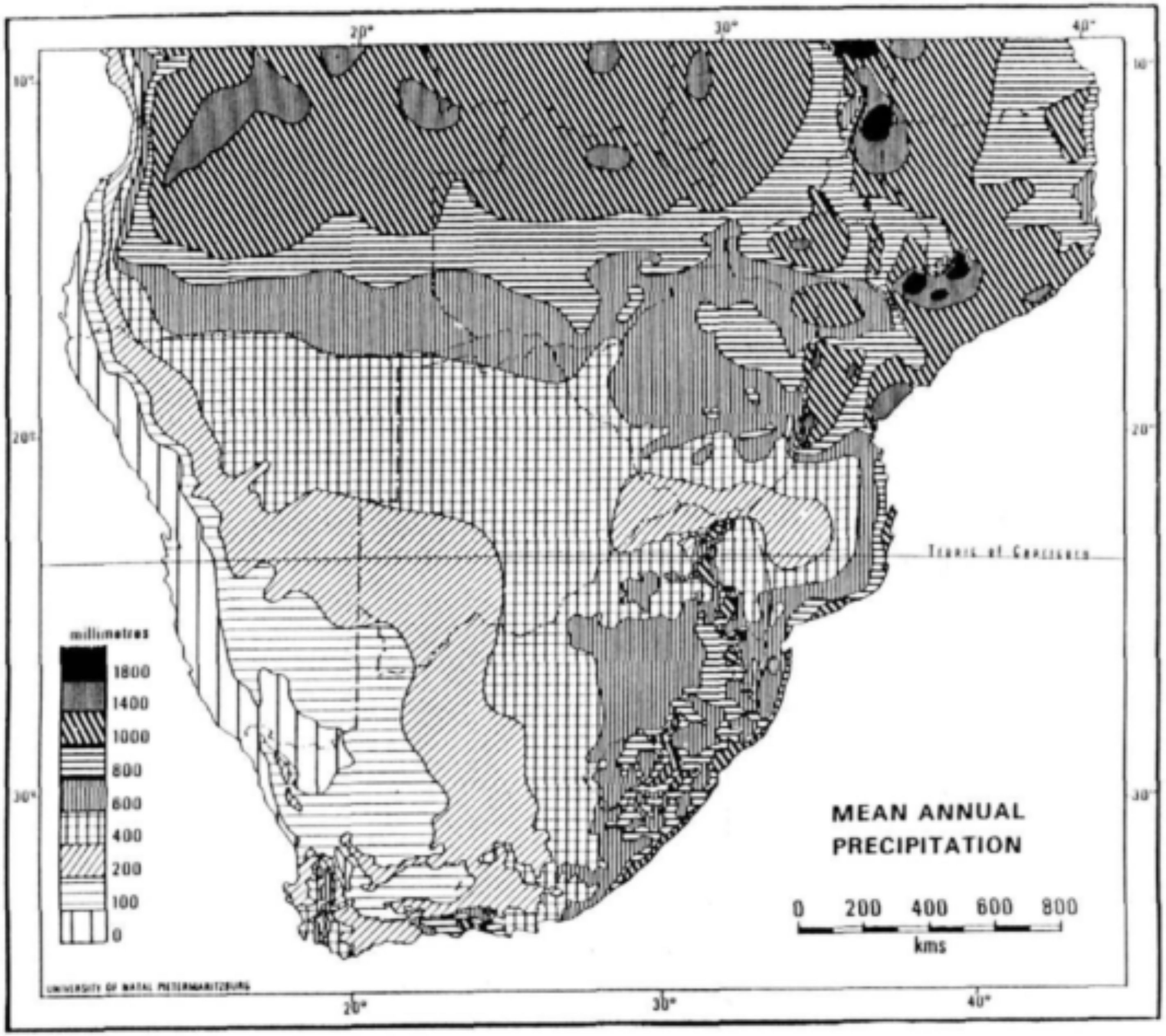
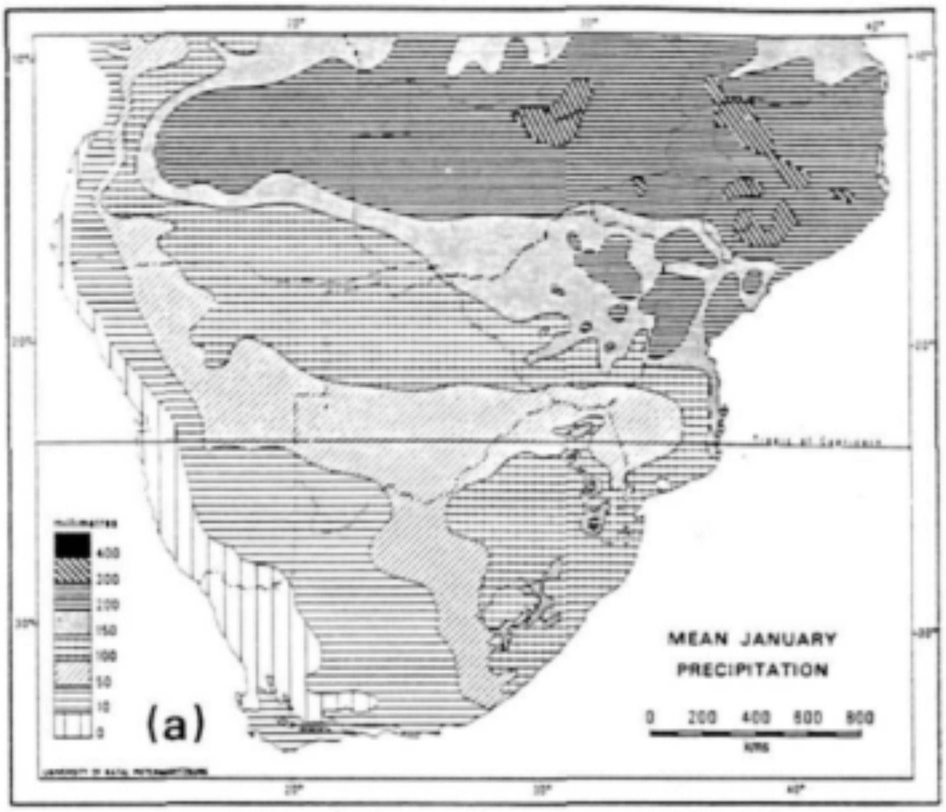


FIGURE E2.4: MEAN ANNUAL PRECIPITATION
(FROM JACKSON AND TAKEN FROM SCHULZE & MCGEE, 1978)



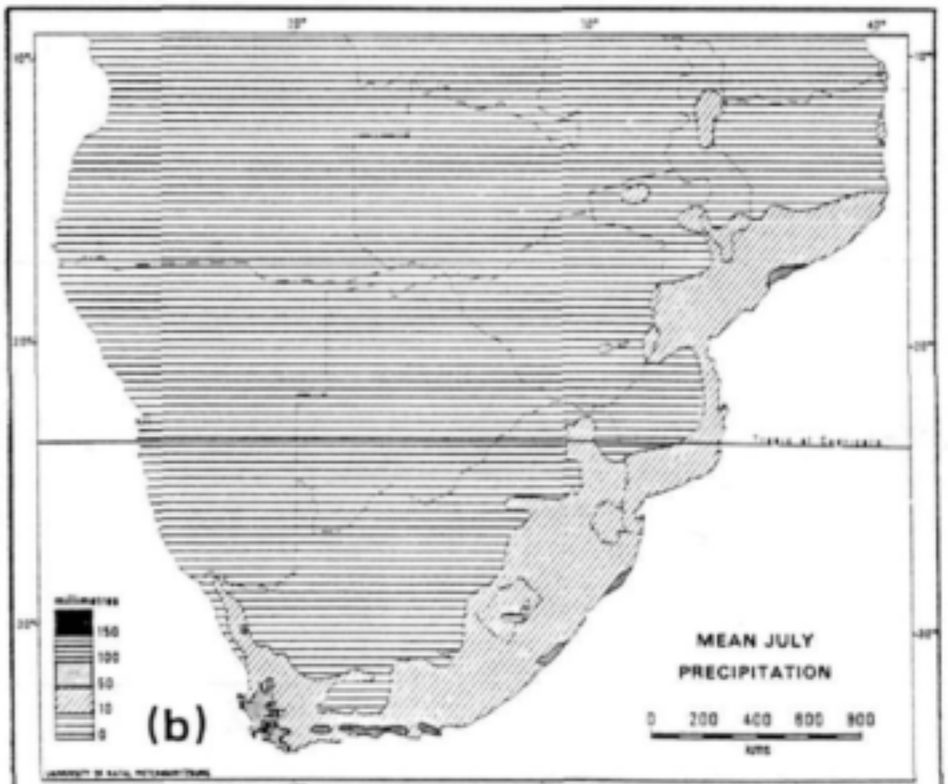


FIGURE E2.5:
(a) MEAN JANUARY PRECIPITATION
(b) MEAN JULY PRECIPITATION
(JACKSON AND TAKEN FROM SCHULZE & MCGEE, 1978)

Precipitation interception can be interpreted as a function of vegetation volume per unit area and the number of wetting cycles, i.e. the number of rain days (Schulze & McGee, 1978).

In areas where fog or advective sea fog is prevalent, moisture may be intercepted by the vegetation even though standard rain gauges do not necessarily record any precipitation during the same period.

Schulze & McGee, (1978) found that since the amount of fog is directly proportional to the liquid water content of the air, fog frequencies and amounts in the winter rainfall regions of South Africa are highest in winter. Conversely, summer fog predominates in the summer rainfall areas. Nagel, quoted in Schulze & McGee, (1978) found that on Table Mountain the amount of fog intercepted per annum over a five year period was as high as 5664 mm, which is three times as high as the annual rainfall. He also found that the amount of fog intercepted in Swakopmund in 1958 was equivalent to 130 mm of rainfall - more than seven times the annual rainfall.

These statistics underline the importance of fog as an ecological agent. Considerable amounts of moisture not recorded conventionally may in fact be intercepted and utilized, directly or indirectly, by vegetation cover.

Snow, while occurring most often from June to August on the higher mountains along the Drakensberg escarpment and on south-west ranges in the Cape Province, is of such spasmodic occurrence that Schulze & McGee, (1978) consider the ecological effects in southern Africa minimal.

Evaporation data is a climatic indicator often needed in water related environmental planning. Schulze (1965) gives data on average monthly and annual evaporation from both the standard Class 'A' and Symons evaporation pans for a number of southern African stations. From the maps of evaporation isolines (Schulze, 1965: 228-229) it becomes evident that average annual evaporation reaches a maximum over southern Namibia and North-west Cape and decreases to a minimum over the southern Cape coast, eastern escarpment and the mist belt of Natal.

1.2.2.5 Wind

Schulze (1965: 233-260) provides comprehensive data on surface winds over southern Africa. For the purpose of this study it suffices to note that the summer and winter windroses provided by Schulze (1965: 235-238) for 23 locations could be registered as non-spatial attributes of those mappable locations.

1.2.3 CLIMATIC INDICES

1.2.3.1 Introduction

Over the years various authors have put forward proposals for climatic indices ranging in extent for either large generalized areas to small localized areas such as specific cropland areas.

Various combinations of environmental parameters, *inter alia*, annual precipitation, annual mean temperatures, solar radiation, potential evapotranspiration, evaporation, duration of dry conditions, average annual water surplus and average annual water deficiency have been used.

Rutherford & Westfall (1986) see, as a basic difficulty with most of these indices, the non-availability of suitable simultaneous data for a sufficient number of stations over a long enough period. Another difficulty they perceive is the apparent random employment of different indices with little regard for the existence of other indices or for practical application.

The number of stations where precipitation and temperature are recorded, although long established, provide insufficient data for both long enough periods and for certain areas in which distinctive vegetation transitions take place. In many instances the particular location of a station, affected by large microclimatic differences, renders some of the obtained data unrepresentative for the region (Rutherford & Westfall, 1986).

1.2.3.2 The Köppen climates of southern Africa

The useful and practical climate classification developed by Köppen around the turn of the twentieth century has, over time, been applied and modified by various authors in southern Africa such as Coetzee, Werger, Schulze, Buys and Jansen (Schulze & McGee, 1978).

A map of Köppen's classification with accompanying explanation of symbols is shown in Figures E2.6 (p.211) and E2.7 (p.212).

Köppen used only mean annual precipitation and air temperature as criteria and this led to an extensive BSh climatic province, a feature which Schulze & McGee, (1978) find disturbing as this 'province' groups together areas such as the eastern Transvaal Lowveld, the interior of Mocambique, the Kalahari, northern Cape and northern Namibia. The Köppen classification shows only broad term agreement with the Acocks' (1988) vegetation map.

FIGURE E2.6: CLIMATES OF SOUTHERN AFRICA ACCORDING TO KÖPPEN
(AFTER SCHULZE & OTHERS AND TAKEN FROM SCHULZE & MCGEE, 1978)

1st LETTER	2nd LETTER	3rd LETTER
A, C, D SUFFICIENT HEAT AND PRECIPITATION FOR FOREST VEGETATION	——	——
A EQUATORIAL CLIMATES MEAN TEMPERATURE ABOVE 18 °C FOR ALL MONTHS	f SUFFICIENT PRECIPITATION DURING ALL MONTHS m MONSOON CLIMATE (FOREST-VEGETATION DESPITE DRY SEASON) w WINTER DRY SEASON	——
B ARID ZONES SEE BELOW FOR LIMITS	S STEPPE CLIMATE W DESERT CLIMATE SEE BELOW FOR LIMITS	h DRY-HOT, MEAN ANNUAL TEMPERATURE OVER 18 °C k DRY-HOT, MEAN ANNUAL TEMPERATURE BELOW 18 °C
C WARM TEMPERATE CLIMATES COLDEST MONTH 18 °C TO -3 °C	s SUMMER DRY SEASON w WINTER DRY SEASON f SUFFICIENT PRECIPITATION DURING ALL MONTHS	a WARMEST MONTH OVER 22 °C b WARMEST MONTH BELOW 22 °C BUT AT LEAST 4 MONTHS ABOVE 10 °C

LIMITS OF ARID ZONES .

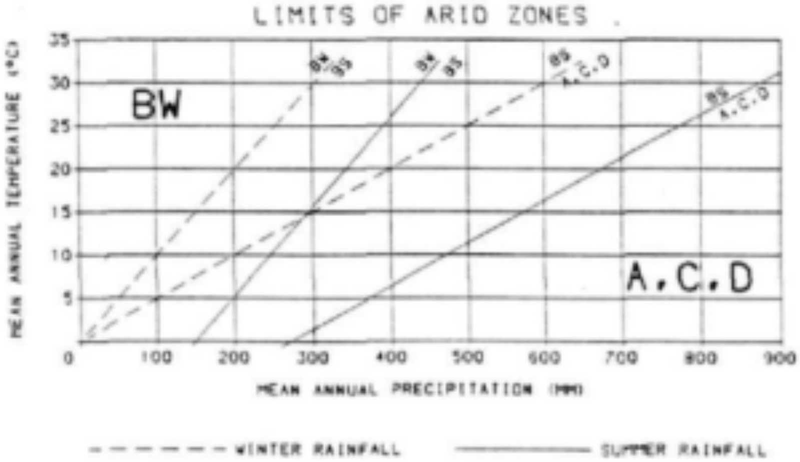


FIGURE E2.7: A SIMPLIFIED KÖPPEN CLASSIFICATION RELEVANT TO SOUTHERN AFRICA
(KÖPPEN & GEIGER AND TAKEN FROM SCHULZE & MCGEE, 1978)
(READ WITH FIGURE E2.6)

1.2.3.3 The Thornthwaite climatic indices

Other classification systems relating climate to vegetation distribution include the Holdridge Life Zone System and that of Thornthwaite (Schulze & McGee, 1978), having as its basis, the climatic water budget, i.e. water surplusses and deficiencies.

The thermal and moisture regions as derived by Poynton (1971) and which are based on the work of Thornthwaite, justify closer attention, because according to Schulze & McGee, (1978: 49) ' ... little doubt exists as to the potential usefulness of these indices in bio-geographical research on a subcontinental scale'.

In Figure E2.8 (p.214) thermal regions for southern Africa are shown. The Thermal Efficiency Index which is referred to in column 3 of Figure E2.8 reflects the optimum water need of plants. This relates in turn to potential evaporation which Thornthwaite derived empirically from temperature and day length. This index is not merely a growth index but expresses growth in terms of the water needed for growth (Schulze & McGee, 1978). Given in the same units as precipitation, it relates thermal efficiency to precipitation effectiveness.

In Figure E2.9 (p.215) moisture regions for southern Africa are shown.

Moisture Index is defined as:

$$Im = Ih - Ia,$$

where
Im = moisture index
Ih = humidity index calculated from $Ih = 100(S/PE)$
Ia = aridity index calculated from $Ia = 100(D/PE)$
S = relative annual surplus of water in mm
D = relative annual deficiency of water in mm
PE = potential evaporation

(Poynton in Schulze & McGee, 1978)

ZONE	CLIMATIC TYPE	THERMAL EFFICIENCY INDEX	FROST	APPROXIMATE MEAN MONTHLY MINIMUM TEMPERATURE FOR THE COLDEST MONTH
1	TROPICAL (MEGATHERMAL)	>1140 mm	NONE	———
2	SUB-TROPICAL (MESOTHERMAL)	997 TO 1140 mm	OCCASIONAL	5° TO 10°C
3	WARMER-TEMPERATE (MESOTHERMAL)	570 TO 997 mm	VERY LIGHT	5° TO 10°C
4		570 TO 997 mm	LIGHT	0° TO 5°C
5	COOLER-TEMPERATE (MESOTHERMAL)	570 TO 997 mm	MODERATE	-5° TO 0°C
6		570 TO 997 mm	SEVERE	<-5°C
7	SUB-ALPINE (MICROTHERMAL)	427 TO 570 mm	VERY SEVERE	<-5°C

FIGURE E2.8: THERMAL REGIONS
(AFTER POYNTON AND TAKEN
FROM SCHULZE & MCGEE, 1978)

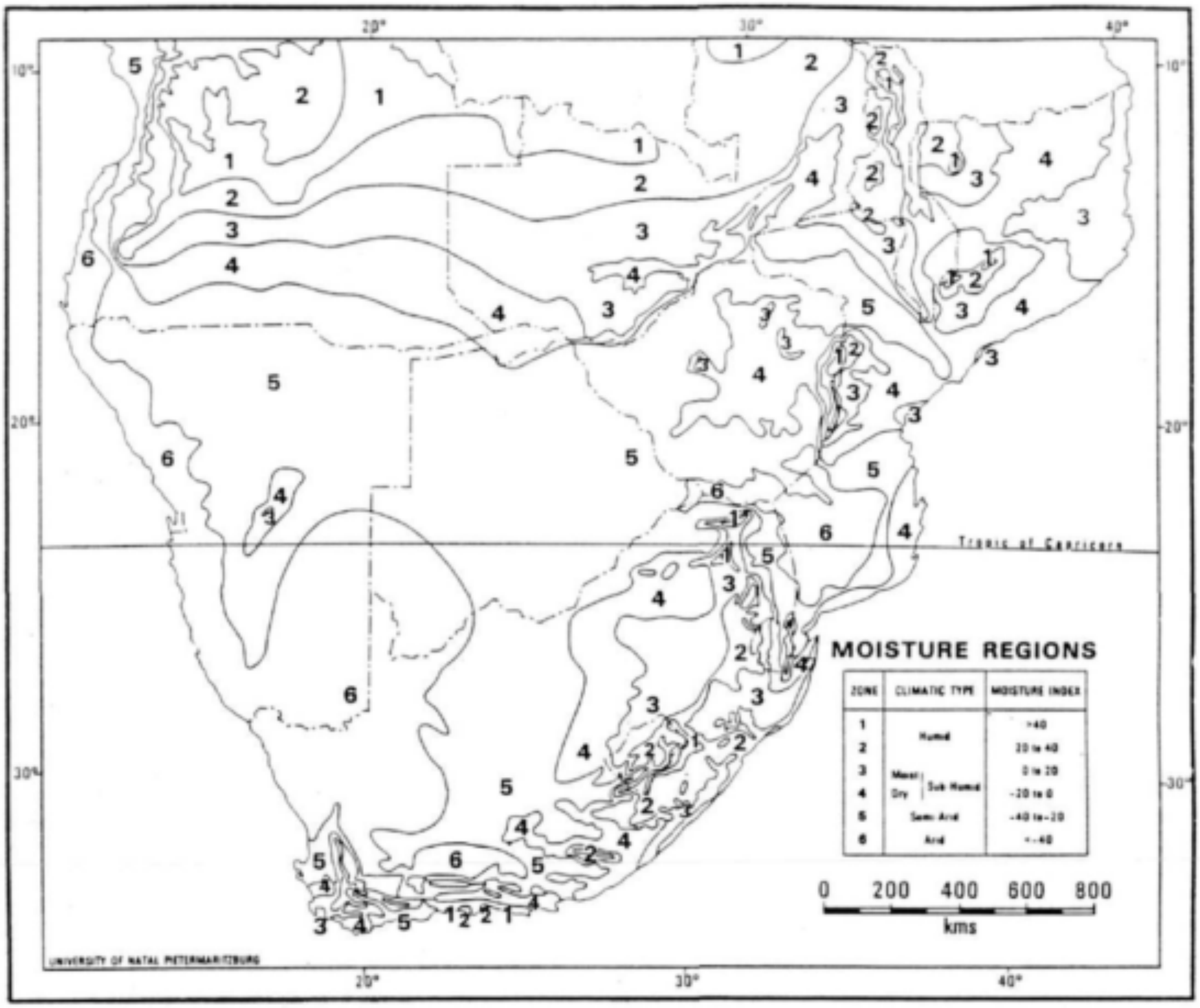


FIGURE E2.9: MOISTURE REGIONS (AFTER POYNTON AND TAKEN FROM SCHULZE & MCGEE, 1978)

1.2.3.4 The Weather Bureau climatic regions

For practical purposes the South African Weather Bureau (Schulze, 1965) partitioned South Africa into 15 climatic regions. This division into regions is based firstly on geographic considerations, more particularly the prominent mountain ranges, rivers and also political boundaries. On the interior plateau of the RSA, use has been made of the change from BW to BS and from BS to C climates according to the Köppen classification (cf. Figures E2.6 p.211 and E2.7 p.212).

Each Weather Bureau climatic region is described according to the following climate indicators and their temporal, quantitative variability:

* precipitation (rain and snow);
* air temperature;
* winds; and
* sunshine.

1.2.4 CONCLUSIONS AND PROPOSAL

Climate influences vegetation, both directly through factors such as radiation, temperature and moisture and indirectly through the influence on soil conditions and competing biotic associations (Schulze & McGee, 1978).

Reciprocally, vegetation influences the microclimate of an area. Climatic factors in this study have been investigated both as individual parameters (temperature, radiation, precipitation, and wind) and as combined, interrelated climatic indices. The effects of winds have not been dealt with in much detail because Schulze & McGee (1978) consider them to be largely of local nature. They conclude that, for any biogeographical study in southern Africa, no one climatic factor or index should be used to the exclusion of others.

In Table E2.1 (p.217) a proposal is made of classifying climate in terms of a hierarchical spatial feature and an associated non-spatial attribute system.

TABLE E2.1 A proposed classification system for climate and meteorology

FEATURES LEVELS I	II	III	IV	NON-SPATIAL ATTRIBUTES
Natural resources data				
	Climate and Meteorology			
		Solar radiation		
			Winter radiation isohels	Value in $10^5 Jm^{-2}day^{-1}$
			Summer radiation isohels	Value in $10^5 Jm^{-2}day^{-1}$
			Specific locations	Radiation data (from Schulze,1965)
		Air temperature		
			Mean daily maximum summer isotherms	Value in °C
			Mean daily minimum winter isotherms	Value in °C
			Annual isotheres and isochimenals	Value in °C
			Mean annual range of temperatures	Value in °C
			Specific locations	Temperature data (from Schulze, 1965)
		Earth temperature		
			Specific locations	Temperature data (from Schulze, 1965)
		Moisture		
			Mean annual isohyets	Value in mm
			Mean July isohyets	Value in mm
			Mean January isohyets	Value in mm
			Average annual evaporation isolines	Value in mm (from Schulze, 1965)
		Wind		
			Specific locations	Windrose data (from Schulze, 1965)
		Köppen Climatic Index		
			Climatic areas	Each area described by criteria such as precipitation nature, temperature groupings. (Köppen, in Schulze & McGee, 1978)
		Thornthwaite Climatic Index		
			Thermal regions	Each region described by climatic type, thermal efficiency index, occurrence of frost, mean monthly minimum temperature in winter. (Poynton, in Schulze & McGee, 1978)
			Moisture regions	Each region described by climatic type and moisture index (Poynton, in Schulze & McGee, 1978)
		Weather Bureau Climatic Regions		Each region described by four climatic factors, *viz.:* precipitation, air temperature, winds, sunshine. (Schulze, 1965)

CLASS 1 NATURAL RESOURCES DATA

Category 1.3: Geomorphology

1.3.1 INTRODUCTION

Geomorphology is primarily a reflection of the underlying geological formations and the climate, with vegetation also playing an important role (Bosch, *et al.*, 1986).

Geomorphology has been defined by Cooks (1987) as the systematic study of earth's crust relief or land-forms. It can therefore be described as the science of landscape, the processes and history of the development of land-forms and the relation of geologic material to surface features.

In describing geomorphological systems, it is attempted to define the interrelationship between the physical components of the landscape, in this sense also the earth's surface. The questions asked in this process typically include 'What occurs in nature?' and 'Why does it occur?'

Whereas geomorphology has over time developed from a science describing the land-forms to one wherein the reasons for land-form change are investigated, for the purposes of this study it is only necessary to identify, describe and classify spatial geomorphological features.

In this regard relief, land-form and relatively homogeneous geomorphological areas, called 'geomorphological provinces' by King (1967), are described.

1.3.2 RELIEF

Relief, in this sense, is seen as a quantifiable feature such as a contour line, a spot height or a depth-sounding.

1.3.3 LAND-FORM

Cooks (1987) distinguishes a three order land-form hierarchy which enables us to better understand the interrelationship between land-forms.

As a first order relief, he recognizes continental platforms and ocean basins. However, he sounds a cautionary note in this regard because the existing distinction between land and sea does not represent a true reflection, on a broad scale, of the extent of continents and true ocean basins. The continental shelf, which can vary considerably in width, and which is covered by relatively shallow water, must be regarded as 'part' of the continent.

On a second order relief level, Cooks (1987) distinguishes three basic components of the continental platforms, namely: continental shields, stable platforms or cratons and folded belts. The African continental shield is made up from low relief, complex cristalline rock structures called cratons, normally covered by a layer of sedimentary rocks and mostly undisturbed by intensive folding.

They are thus seen as stable platforms. In Figure E3.1 (p.220) the position of cratons in southern Africa can be seen. The stable platforms are separated by mobile belts.

In these areas of instability, normally manifestated by folded mountains such as the Cape folded mountain belt, lateral and vertical movements caused vast changes to the appearance of the landscape.

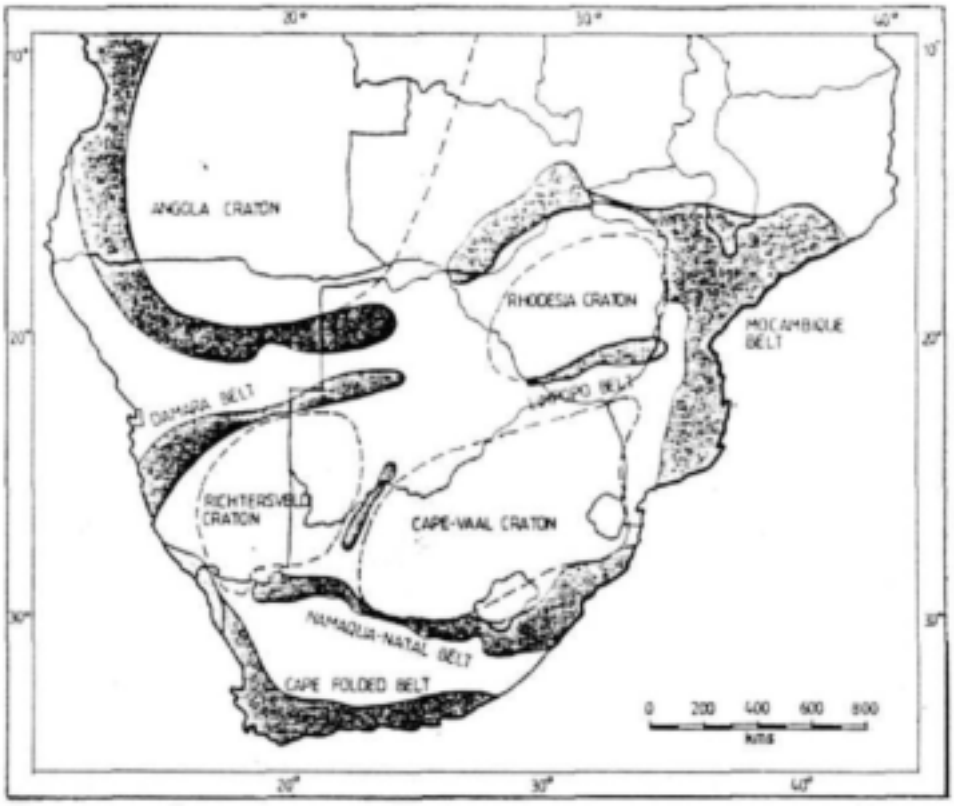


FIGURE E3.1:
CRATONS AND MOBILE BELTS IN SOUTHERN AFRICA
(AFTER TRUSSWEL AND TAKEN FROM COOKS, 1987)

Third order relief is understood to encompass smaller variations of landscape features. These landforms typically include descriptions such as alluvial fans, cliffs, escarpment, floodplain, etc. These descriptions therefore represent the detail of the landscape (Cooks, 1987).

1.3.4 GEOMORPHOLOGICAL PROVINCES

In order to divide the country into more manageable, identifiable areas, King (1967) describes 18 'provinces', each of relatively uniform physiography.

He employed, in a general way, geomorphological history, geological structure, climate, location and altitude as criteria in distinguishing these 'provinces'. Of these, King (1967) finds geomorphological history as the most significant.

In Figure E3.2 17 of these the geomorphological provinces of southern Africa are shown.

1.3.5 CONCLUSIONS AND PROPOSAL

Both relief and landforms are detail features recognized and classified by Clarke, *et al.*(1987) in the NES. It is suggested however, that a broader scaled description and classification of geomorphological feature are necessary for implementation in a GIS.

In Table E3.1 (p.222) a proposal is therefore made to classify geomorphological features in a system commensurate with that proposed by Clarke, *et al.* (1987).

FIGURE E3.2: GEOMORPHOLOGIC PROVINCES OF SOUTH AFRICA
(PARTLY AFTER WELLINGTON AND FROM KING, 1967)

TABLE E3.1 A proposed classification system for geomorphology
(After Clarke, *et al.*, 1987; King, 1967 and adapted by the author)

FEATURES LEVELS I II III IV	NON-SPATIAL ATTRIBUTES
Natural resources data	
Geomorphology	
Relief	
Contour	Elevation, type
Constant slope isolines	Value
Spot height	Elevation, type
Depth-sounding	Depth, type
Landform e.g.	
Alluvial fan	
Cape	
Bay	
Beach	
Butte etc. (Clarke, *et al.* 1987 recognize 49 landforms)	
Geomorphological provinces e.g.	Certain essential attributes e.g.: climate, vegetation, altitude, nature of transition zones, broad geologic structure (after King, 1967)
Highveld	
Lesotho highlands	
Bushveld basin	
Northern Tvl	
Cape plateau etc. (King,1967 recognizes 18 geomorphological provinces)	

CLASS 1 NATURAL RESOURCES DATA

Category 1.4: Pedology

1.4.1 INTRODUCTION

Soil, water, plants, energy and atmosphere are man's basic natural resources. Soils form the denominator as well as the basis of the other associated renewable resources such as agricultural production, building materials and as a source of water supply.

Soils formation (or pedogenesis) 'does not depend only on climate and vegetation but on several other important factors including geology, topography and past climate patterns, so that strong links between soils and biomes remain unlikely' (Rutherford & Westfall, 1986: 64).

1.4.2 CLASSIFICATION AND MAPPING OF SOILS

Soil maps have always been made for practical purposes. The main objective of soil surveys is to produce maps and associated memoirs designed to aid the planning and management of land use. Originally the prime emphasis was on the needs of agriculture but, according to Davidson (1982), the trend is now towards a much broader spectrum of applications. The aim of encouraging the use of soil survey data in planning and management can only be achieved if this information is in a form appropriate for the specific users. As Davidson (1982: G2.40) points out: 'consideration has to be given to interpretation of soil survey data in order to ensure its use'.

Classification and mapping of soils are done for a variety of purposes and these determine the description and scale at which the mapping units are shown. In South Africa the Soil and Irrigation Research Institute (at the Department of Agriculture and Water Supply), makes two series of maps available:

1.4.2.1 Land-type Map Series

The first, namely the Land-types series, (of which approximately 60% of total South Africa is already available) mapped at 1:250 000, indicate Land-type units which show uniformity with regard to terrain form, soil pattern and climate. The above criteria led to the decision to identify broad soil patterns for the purpose of constructing a common legend for the Land-type maps (Land Type Survey Staff, 1985).

These broad soil patterns of which nine classes were formed, with their associated borders and colours on the map series have a restricted function, namely:

* to improve the readability of the maps; and
* to give the reader an indication of the soils of the area (Land Type Survey Staff, 1985).

1.4.2.2 Soil map series

The Soil and Irrigation Research Institute (SIRI) is also currently engaged in mapping soils at a scale of 1:50 000. On these maps, of which 21 are already available and which cover the PWV Complex, and certain other metropolitan centres, soil series are indicated. Groupings of soil series into soil forms (Macvicar, *et al.*, 1977) are normally not shown on these maps. Factors that restrict soil depth such as rock and calcrete are however indicated.
Due to the potential extent of a common legend showing all possibilities of mappable units, each 1:50 000 scale map has its own legend. SIRI is, however, aiming to publish a single accompanying memoir or report to be read with the maps.

1.4.2.3 Soil classification of the Soil Classification Working Group (SCWG)

A soil series, recognized by Macvicar, *et al.* (1977) as being the lowest level of soil classification unit, can be described as a collection of soil individuals essentially similar with regard to certain discernible properties and arrangement of horizons. 501 soil series are currently distinguished. Soil phase differentiation, based on properties such as slope, rockiness, nature of tilled A-horizon and depth to rockbed and which are not essentially part of the pedogenetic profile, can however be used to describe various soil capabilities or soil behaviour within a soil series. A soil form, consisting of two or more essentially similar soil series, is based on the most important factors involved in pedogenesis. Macvicar, *et al.* (1977) recognized 41 soil forms which they believed cover most of the soil patterns to be found in South Africa. This binomial soil classification (soil series and forms) of Macvicar, *et al.* (1977) corresponds in varying degrees with both the FAO/UNESCO system of the United Nations and that of the United States Department of Agriculture Soil Conservation Service (USDA-SCS).

The SCWG (1989) however, is currently engaged in revising the first edition of the soil classification system of Macvicar, *et al.* (1977).

The SCWG (1989) observes that during the writing of their first edition (Macvicar, *et al.*,1977), the amount and detail of soil information required to classically define soil series was available for few South African soils. In the light thereof it was then decided to present simplified soil series classes based primarily on clay-content and sand grade.

The SCWG (1989) proposes that, because the information required to define the soil series in the classic manner is even now still lacking, a new soil class namely soil family be introduced with the proposed 2nd Edition. A soil family is seen as a more specific concept than soil form. Each form is subdivided into two or more families. They suggest that the soil family be used as the lowest class in this 2nd Edition.

Their intention is that the current level of soil knowledge be accommodated and represented in this family class and that a structure is also hereby created to eventually cater for a more comprehensive soil series as they are identified and described. By recognizing additional diagnostic soil horizons and materials the SCWG (1989) has increased the number of soil forms from 41 to 73.

Soil texture is not used as a differentiating criterium but will be described with forms and families, e.g. Hutton fine sand loam. The hierarchy of this taxonomic soil classification (SCWG, 1989) can therefore schematically be described as follows:

Level 1 : Soil form (specific sequence of diagnostic horizons).

Level 2 : Soil family.

Level 3 : Soil series (with soil phase descriptions such as slope, depth, topographic position, water table and parent material as non-spatial attributes).

The SCWG (1989) feels that the proposed soil families will contain, either directly or through co-variance, most of the information required for land suitability interpretations.

At this stage the SCWG has classified 398 soil families (Idema,

1989. pers. comm.) and it is anticipated that soil families will eventually be mapped at a scale of 1:10 000. Detailed soil surveys on series level will in the future lead to soil series maps at a scale of not smaller than 1:5 000. (Idema, 1989. pers.comm.)

1.4.2.4 FAO soil classification

Soil maps of the world at a scale of 1:5 000 000 were produced by the World Soil Resources Office of the FAO in 1973. The definitions of the mapped soil units were drawn up by Dudal and others in 1968 (Von M. Harmse, 1978). In South Africa, Von M. Harmse (1978) produced a schematic soil map of southern Africa south of latitude 16° 30' S. The definitions, descriptions and mapped units correspond with those proposed by the FAO. Von M. Harmse (1978) chose a schematic approach to soil classification because of the varied nature and composition of the soil mantle of a region as large as southern Africa. Von M. Harmse (1978) used available data on soils, geology, geomorphology and climate to compile his map from mapping units in the form of associations of soils. He states (1978: 73) that the legend for his map 'had primarily been designed to group the major soils of the area into categories which not only would have relevance to the distribution of the natural vegetation, but would also reflect the genetic factors of soil formation'. This approach led him to ten level IV soil 'associations', each consisting of between two and seven level V smaller mapping 'units'. The criterion used for differentiation between 'associations' and 'units' is mainly the degree of alteration of the original parent material.

The ten soil 'associations' recognized by Von M. Harmse (1978) in his study area are:

* ferrallitic soils;
* fersiallitic soils;
* black and red montmorrillonitic clays;
* solonetzic and planosolic soils;
* halomorphic soils;
* arenosols;
* alluvial and other soils of low lying areas;
* weakly developed shallow soils;
* weakly developed shallow soils of arid regions; and
* lithosols.

It should be noted that Macvicar, *et al.* (1977) provide a correlation between mainly the soil forms (occasionally also the soil series) and the soil categories of both the FAO and the USDA Soil Survey Staff.

1.4.3 SOIL SUITABILITY

A suitability map assesses the ability of each increment of land under study to support a given cause.

The mapping of soils and land types are exercises in land classification but are not *sensu stricto* projects of land evaluation though the collected data can contribute to such an analysis (Davidson, 1982).

A soil suitability survey, culminating in a soil suitability map, implies a subjective assessment of soil types for a predefined purpose or purposes.

The mapped units in a soil suitability map each normally comprise an association, a combination or simplification of soil series for the purpose at hand.

The grouping of soils into suitability classes can therefore be seen as an interpretation action (or evaluation) to determine the soil's relative suitability or capability or even susceptability with regard to, *inter alia*:

* specified agricultural uses;
* urban developments;
* irrigation projects;
* sylviculture;
* road networks;
* erosion potential; and
* recreational potential.

Davidson (1982: G2.3), while describing the factors which led, during the 1930s, to the formation of the USDA Soil Conservation Service, defines the principle of grading areas into capability classes as 'land uses (which) can be pursued on a sustained basis without environmental degradation'.

Eight capability classes ranging from Class I (few limitations which restrict their use) to Class VIII (soils and land-forms with limitations that preclude their use for commercial plant production and restrict it to recreation, wildlife, water supply or aesthetic purposes) are specified. In Table E4.1 (p.230) this classification is shown.

The intensity with which each land capability class can be used with safety is shown in Figure E4.1 p.231.

The regional offices of the Department of Agriculture and Water Supply undertake the compilation of soil suitability maps, albeit on a local detailed scale, for a specific land owner (the information therefore is confidential) and primarily with agricultural purposes in mind.

TABLE E4.1: LAND CAPABILITY CLASSIFICATION DEVELOPED BY THE U.S. DEPARTMENT OF AGRICULTURE (CLASSES I-IV ARE SUITABLE FOR CROP CULTIVATION; CLASSES V-VIII ARE SUITABLE ONLY FOR GRAZING, FORESTRY, OR WILD LIFE HABITAT. THE CLASSIFICATION CAN BE APPLIED TO OTHER USES, SUCH AS URBANIZATION, WITH ONLY MINOR MODIFICATION) (KLINGEBIEL & MONTGOMERY AND TAKEN FROM DUNNE & LEOPOLD, 1978)

CLASS	DESCRIPTION
I	FEW LIMITATIONS ON LAND USE. LOW GRADIENTS; SOILS DEEP, WELL DRAINED, FERTILE, AND EASILY WORKED. OVERLAND FLOW ABSENT OR VERY RARE.
II	MODERATE LIMITATIONS ON USE AND MODERATE RISKS OF DAMAGE; NEEDS CAREFUL SOIL MANAGEMENT TO PREVENT DETERIORATION, BUT PRACTICES ARE EASY TO APPLY. LIMITATIONS DUE TO ONE OR A COMBINATION OF: GENTLE GRADIENTS, MODERATE SUSCEPTIBILITY TO EROSION, LESS THAN IDEAL SOIL DEPTH, SLIGHTLY UNFAVORABLE SOIL STRUCTURE, SLIGHT SALINITY PROBLEMS, OCCASIONAL DAMAGING OVERLAND FLOW, SOIL WETNESS.
III	SEVERE LIMITATIONS ON USE OR RISKS OF DAMAGE. REGULAR CULTIVATION REQUIRES CAREFUL SOIL CONSERVATION PRACTICES. LIMITATIONS DUE TO ONE OR A COMBINATION OF: MODERATELY STEEP SLOPES, HIGH SOIL ERODIBILITY, FREQUENT OVERLAND FLOW, VERY SLOW PERMEABILITY OF SUBSOIL, WATER-LOGGING, SHALLOW SOIL, LOW WATER-HOLDING CAPACITY, LOW FERTILITY, MODERATE SALINITY.
IV	VERY SEVERE LIMITATIONS ON USE OR RISKS OF DAMAGE THAT RESTRICT THE CHOICE OF PLANTS AND REQUIRE VERY CAREFUL SOIL CONSERVATION PRACTICES WHICH ARE DIFFICULT TO APPLY AND MAINTAIN. HAVE THE LIMITATIONS OF CLASS III BUT IN A MORE EXTREME FORM.
V	NO EROSION HAZARD BUT HAVE LIMITATIONS OF WETNESS, STONINESS, FLOODING.
VI	SEVERE LIMITATIONS DUE TO GRADIENT, EROSION HAZARD, EFFECTS OF PAST EROSION, STONINESS, SHALLOW DEPTH, WETNESS, LOW WATER-HOLDING CAPACITY, OR SALINITY.
VII	VERY SEVERE LIMITATIONS EVEN FOR GRAZING AND FORESTRY. SAME CHARACTERISTICS AS CLASS VI BUT IN A MORE EXTREME FORM.
VIII	EXTREME LIMITATIONS ON ANY KIND OF LAND USE EXCEPT WILDLIFE HABITAT AND WILDERNESS AREAS. CHARACTERISTICS OF CLASS VI IN EXTREME FORM.

The process entails two phases (Ludick, 1989. pers. comm.), namely:

* Resources survey: Using a mosaic of 1:10 000 aerial photographs, an overlay is produced indicating soil form, soil series, effective soil depth, percentage clay of the A and B horizons, terrain form, geology, slope, aspect, erosion condition and current uses.
* Production potential map: Using the above information a prediction is made with regard to the suitability of certain crops and the potential yield. Of the total 11 500 00 ha of the Highveld Region of the Department of Agriculture and Water Supply, resource survey maps (phase I) have been completed of approximately 500 000 ha. Of this number, production potential maps have been drawn of approximately 300 000 ha (Ludick, 1989. pers. comm.).

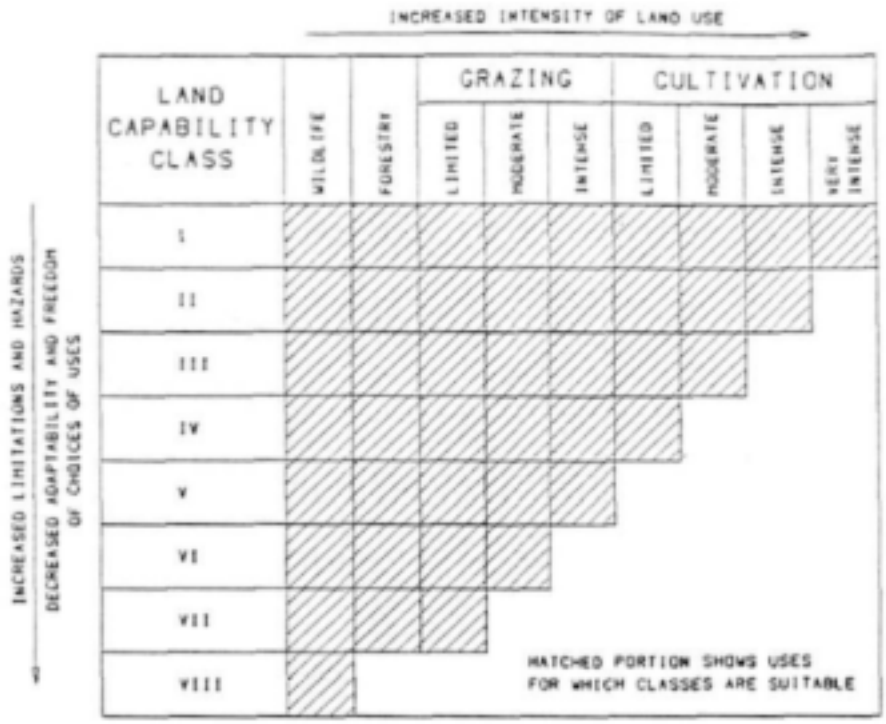


FIGURE E4.1: INTENSITY WITH WHICH EACH LAND CAPABILITY CLASS CAN BE USED WITH SAFETY
(NOTE THE INCREASING LIMITATIONS ON THE USES TO WHICH THE LAND CAN SAFELY BE PUT AS ONE MOVES FROM CLASS I TO CLASS VIII)
(BRADY, AND TAKEN FROM DAVIDSON, 1982)

In conclusion, it should be emphasized that the analysis of a soil profile has in the past and will still in the future form the basis on which soils are classified, correlated and mapped and from which their suitability, capability or potential is assessed.

1.4.4 HYDROLOGICAL CHARACTERISTICS OF SOILS

From a hydrological sense, soils affect a catchment's response to rainfall through characteristics such as soil depth, water holding capacity and infiltration rates (Hydrological Research Institute, 1985).

Schulze (1985a: 121) concurs by adding: 'Indeed, it is the capacity of soil to absorb, retain and release/redistribute water, that is a prime regulator of the response of a catchment, and the soil is the medium in/through which the other hydrological processes can operate'.

It is therefore clear that these soil characteristics need also be fully examined in any study concerned with the planning and management of water resources in catchment areas.

To this end Schulze (1985a) investigated the 501 soil series described by Macvicar, *et al.*(1977) in terms of the following criteria:

1.4.4.1 Runoff potential

The amount of runoff reaching the rivers is closely related to the infiltration factor. In turn infiltration is governed by, *inter alia*: soil structure and vegetation cover which is dependant on land management and farming practices.

Using the USDA-SCS System of classifying runoff potential of soils in four groups (Groups A to D) ranging from low to moderate to moderately high to high runoff potential (see Table E4.2 p.233), Schulze (1985a) found these classes too coarse for the wide spectrum of soils found in southern Africa. He proposes three additional intermediate groups (A/B, B/C and C/D) to comprehensively cover the variance of soil run-off potentials in this country.

1.4.4.2 Selected physical and chemical properties that effect the hydrological character of soils

The texture of the A-horizon, degree of leaching (dystrophic or eutrophic), position of the water table, degree of crusting of both A and B-horizons, soil depth, amount of surface sealing, topographic position and parent material are recognized by Schulze (1985a) to influence the runoff potential.

TABLE E4.2 Classification of soils according to their hydrological properties (USDA-SCS and taken from Dunne & Leopold, 1978)

Classification	Type of Soil
A (low runoff potential)	Soils with high infiltration capacities, even when thoroughly wetted. Chiefly sands and gravels, deep and well drained
B	Soils with moderate infiltration rates when thoroughly wetted. Moderately deep to deep, moderately well to well drained, with moderately fine to moderately coarse textures
C	Soils with slow infiltration rates when thoroughly wetted. Usually have a layer that impedes vertical drainage, or have a moderately fine to fine texture
D (high runoff potential)	Soils with very slow infiltration rates when thoroughly wetted, mainly clays with a high swelling potential; soils with a high permanent water table; soils with a clay layer at or near the surface; shallow soils over nearly impervious materials

He assigned certain relative values to these soil properties which then finally determined into which SCS grouping each soil series is placed.

1.4.4.3 Soil erodibility

Scotney (Dept. A.T.S., 1976) rated selected South African soils for their erodibility. Certain soil series (cf. Macvicar, *et al.*, 1977) were classified as being very highly, moderately, low or very low erodable. Each class was allocated approximate K-values according to the USLE (cf. Chapter 4 section 3.4 p.90).

1.4.4.4 Interflow potential

Schulze (1985a: 124) states: 'The potential for interflow is not just a simple matter of association with soil form and series however, because the process is dependant largely on slope, on topographic position inducing a convergence of soil water, as well as on soil depth, and in addition also on the degree of transmissivity which can take place through an impeding layer and which can be highly variable.'

Using the the characteristics of different diagnostic horizons, Schulze (1985a) attempts to group soils according to their potential for interflow into three classes, namely:

* interflow unlikely;
* some/low interflow potential; and
* high interflow potential.

Soil interflow potential is an important determinant in any catchment study and these characteristics should be noted as attributes of soil series. Schulze (1985a) stresses that his grouping of soil should be seen as an indicator of possible interflow potential but that in situ examination of soil conditions should be undertaken because of the number of variables.

1.4.4.5 Soil water retention potential

Schulze, Hutson & Cass (1985) investigated the soil water retention potential of the soils (at both soil form and soils series level) in terms of the three soil water retention constants, namely: porosity, field capacity and wilting point. While equations for the latter two are expressed in terms of clay content only and with the binomial system of soil classification for southern Africa (Macvicar, *et al.*,

1977) specifying clay content classes, Schulze, *et al.* (1985) propose a system of five clay distribution models to enable water retention constants to be estimated. In Figure E4.2 these schematic models are shown.

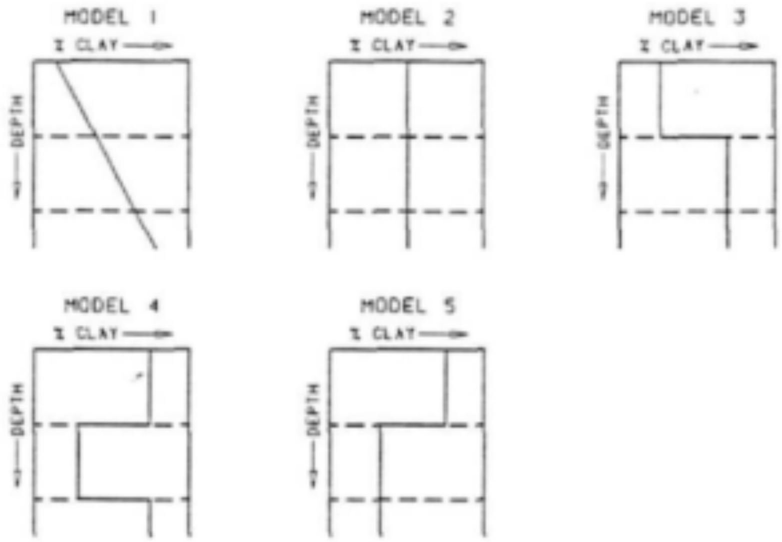


FIGURE E4.2: CLAY DISTRIBUTION MODELS FOR SOUTHERN AFRICA (FROM SCHULZE, HUTSON & CASS, 1985)

To these five clay distribution models are added the five classes of clay content of the B21 horizon (Macvicar, *et al.*,1977), namely:

a: 0 - 6% clay (called sands or loamy sands);

b: 6 - 15% clay (called sandy loams);

c: 15 - 35% clay (called sandy clay loams);

d: 35 - 55% clay (called sandy clays);

e: $>$ 55% clay (called clays).

The association of the three soil water constants with physical soil properties (clay distribution) by means of generally accepted and applicable equations, led Schulze, *et al.* (1985) to estimates of soil water content at both field capacity and wilting point.

This information, noted as attributes of both soil forms and soil series, can be extremely usefull when making generalized deductions.

1.4.5 CONCLUSIONS AND PROPOSAL

As can be deducted from the extent of published maps and memoirs and from the changes still being proposed to a South African Soil Classification Scheme, the comprehensive analysis, classification and mapping of soils, for various purposes, are still at an early stage. Dohse (1989, pers. comm.) attempted, in Table E4.3, to align the issues of soil classification and mapping with the hierarchical feature classification system as proposed by Clarke, *et al.* (1987).

The lack of additional mappable feature levels in the soil survey section (Dohse, 1989. pers. comm.) other than Level II: soil survey and Level III: soil unit, does not allow sufficient detail to be mapped and described.

The work of Von M. Harmse (1978) in producing a soil map based on the FAO categories is also accommodated in the proposed soil classification system.

TABLE E4.3 The classification of soils in terms of the format proposed by Clarke, *et al.* (1987) by Dohse (1989. pers. comm.)

FEATURES LEVELS I	II	III	NON-SPATIAL ATTRIBUTES
Pedology			
	Land-type survey		
		Land-types	Soil pattern, number, area
		Land-type boundary	Type, land-types separated
		Modal profiles	Soil profile number, soil form, soil Series, latitude, longitude
	Soil survey		
		Soil unit	Symbol, type, description, area
		Soil unit boundary	Soil units separated, edge of survey
		Soil profiles	Soil profile number, soil form, soil series, latitude, longitude
	Suitability mapping		
		Suitability classes	Symbol, description, area
		Class boundary	Classes separated

The various non-spatial soil characteristics discussed, namely runoff potential, interflow potential, water retention potential and soil phase properties are registered against the applicable spatial unit as attributes in the proposal in Table E4.4 (p.238).

It is therefore proposed in Table E4.4 that six mappable feature levels be recognized to accommodate the characteristics of soils and soil classification approaches to date.

TABLE E4.4 A proposed classification system for soils
(Dohse, 1989. pers. comm. and adapted by author)

FEATURES LEVELS I II III IV V VI	NON-SPATIAL ATTRIBUTES
Natural resources data	
Pedology	
Land-type	
Surveys	
Land-types	Soil pattern, number, total areas
Land-type boundary	Type boundary, land-types separated
Modal profile	Soil profile number, soil form, soil family, soil series, latitude and longitude
Soil survey (SCWG system)	
Soil form	Name, diagnostic horizon description, selected hydrological properties (Schulze, *et al.*, 1985)
Soil family	Name, code, diagnostic horizon description and certain selected soil characteristics (SCWG, 1989)
Soil series	Name, code, texture, hydrological properties, *viz.*: run-off potential, interflow potential, water retention potential, soil phase properties, *viz.*: slope, depth, topographic position, aspect, water table, erodibility (Dept. A.T.S., 1976) and parent material
Soil survey (FAO system adapted by Von M. Harmse (1978))	
Soil associations	Name, critical climatic parameters, geomorphology, geologic parent material
Soil unit	Degree of clay formation, horizon descriptions, colour, C.E.C. status, salinity status, amount of organic material
Soil profile samples	Number, soil form, family and series, latitude and longitude, date, elevation, vegetation, date described
Suitability mapping *	
Suitability classes	Description, symbol, date described (cf. Davidson, 1982)

* In the USDA Soil Conservation Service System the terms 'capability mapping' and 'capability classes' are preferred.

CLASS 1 NATURAL RESOURCES DATA

Category 1.5: Hydrology and Hydrography

1.5.1 INTRODUCTION

The major part of southern Africa south of 20° S is predominantly arid with the potential evaporation rate in excess of annual precipitation. Ferrar, O'Keeffe & Davies (1988) estimate that in the RSA perennial rivers occur only over 25% of the land surface and rivers that flow only periodically are found over a further 25% of the landscape. In the remaining 50%, mainly the western and southern interior, rivers flow only after infrequent storms. They therefore stress that all rivers carrying useable quantities of water will have to be intensively managed for human benefit.

In Figure E5.1 (p.240) the principal drainage systems in the RSA and their contribution to total mean annual runoff are shown.

1.5.2 CLASSIFICATION OF RIVERS

In the past various attempts have been made to classify rivers. Allanson (In O'Keeffe, 1986a) commented that all South African rivers are geologically young and could be assigned to one of the following categories:

* coastal rivers with mountain sources;
* coastal rivers without mountain sources; and
* rivers of the elevated central plateau.

Noble and Hemens (In O'Keeffe, 1986a) have extended this to seven categories, combining geological, chemical and zoological characteristics:

* Cape clear acid rivers (e.g. Olifants, Berg and Breede).
* South Cape dark acid rivers (e.g. Kaaimans, Groot, Storms and

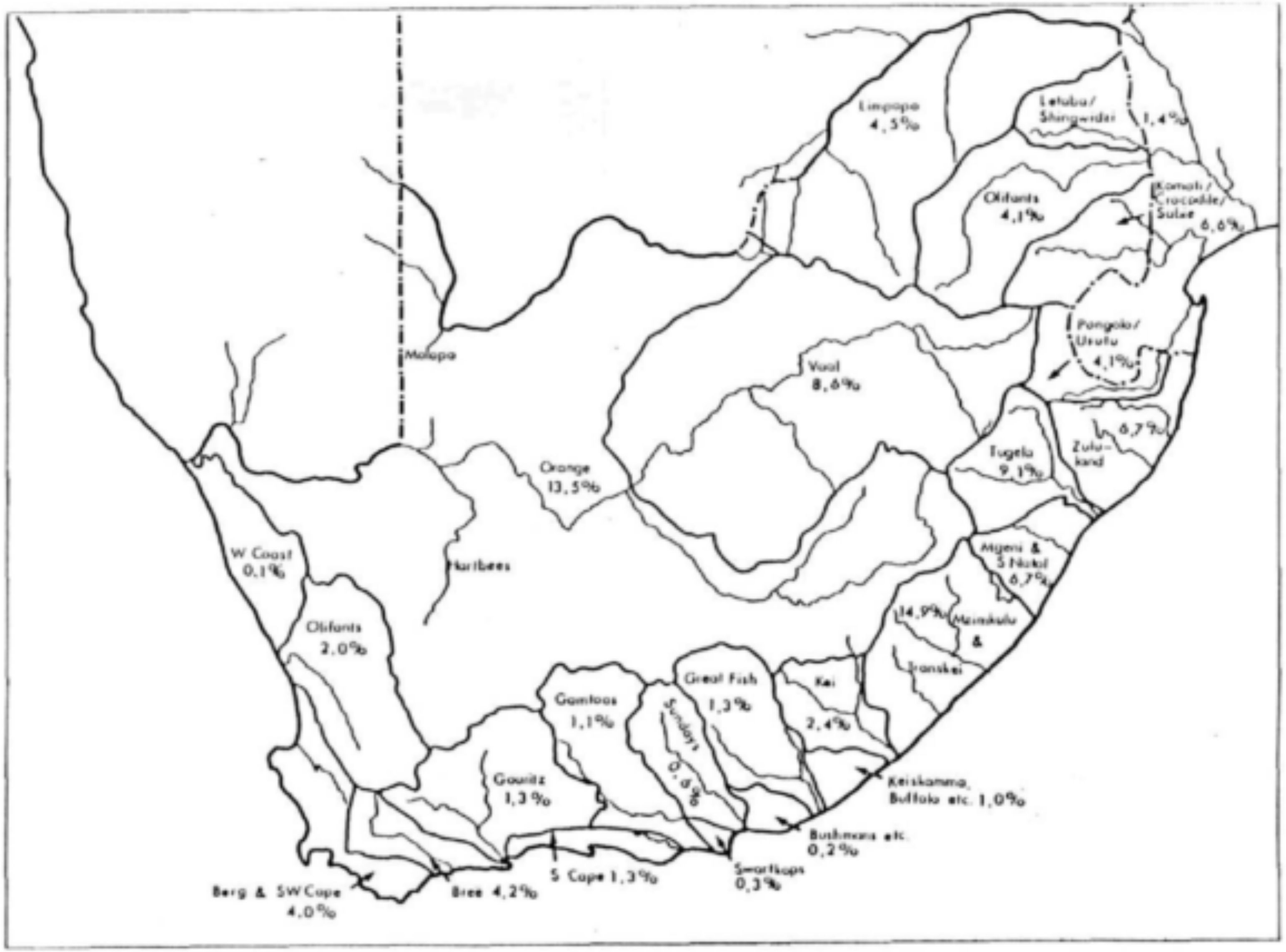


FIGURE E5.1: PRINCIPAL DRAINAGE SYSTEMS AND THEIR CONTRIBUTIONS TO TOTAL MEAN ANNUAL RUNOFF
(FROM FERRAR, O'KEEFFE & DAVIES, 1988)

Bloukrans).

* Southern Karoo turbid rivers (e.g. Gouritz, Gamtoos and Sundays).
* Transkei and Natal degrading rivers (e.g. Buffalo, Great Kei, Mkomazi, Mgeni and Tugela).
* Escarpment floodplain rivers (e.g. Crocodile/Limpopo, Letaba, Olifants, Mfolozi, Mkuze and the Pongola/Usutu).
* Central plateau catchment (Vaal).
* Orange.

A hydrobiological classification of river regions based on earlier hydrobiological surveys was started with by J.D. Agnew and A.D. Harrison in the 1950s. They suggest (in O'Keeffe, 1986a) the following regions:

(read in conjunction with Figure E5.2 p.242)

A. The Cape System Region:
   1. Streams from Table Mountain Sandstone:
      a. dark acid rivers; and
      b. clear acid rivers.
   2. Streams from Bokkeveld and Witteberg Series geology (e.g. the Hex River).
   3. Two large rivers, the Gouritz and the Gamtoos.
   4. Streams from Malmesbury series geology.

B. Recent Limestone Region near Bredasdorp (southern Cape).

C. Central Arid Region.

D. Eastern Cape Region.

E. South-east Coastal Region:
   1. Streams originating in the Drakensberg Mountain region (F).
   2. Streams originating in the foothills and outliers of the Drakensberg.

FIGURE E5.2: HYDROBIOLOGICAL RIVER REGIONS
(AFTER HARRISON AND FROM O'KEEFFE, 1986b)

F. Drakensberg Mountain Region.

G. Highveld Region.

H. Eastern Escarpment Region.

J. Transvaal Mountain Region.

K. Lowveld Subtropical Region.

L. Middle Transvaal Veld Region (e.g. middle Olifants River).

M. Tropical Arid Region (e.g. Palala River).

1.5.3 CONCLUSIONS AND PROPOSAL

Some hydrological features to be mapped cannot effectively be displayed in a two-dimensional manner. A three-dimensional modelling method is required to display features such as aquifer bottoms, position and thickness of aquifer-confining rock strata.

Time-dependant data such as ground water level, water temperature, water quality and water flow velocity cannot efficiently be managed in a spatial relational data base system (Fürst, Haider & Nachtnebel, 1987). They suggest a separate hydrological data base containing the time series of the hydrological variables mentioned above. This data base must be seen as a non-spatial attribute of certain spatial hydrological entities and must allow analysis, interpolation and display of data on a temporal basis and which can be related to spatial entities such as gauging stations and observation points.

In Table E5.1 (p.244) a proposal is made to classify hydrological and hydrographical entities in a hierachical spatial feature and associated non-spatial attribute system. It should be noted however that some of the level IV features under level III 'Natural hydrological features' would probably also occur in the geomorphology classification.

TABLE E5.1 A proposed classification system for hydrology and hydrography.

FEATURES LEVEL I	II	III	IV	NON -SPATIAL ATTRIBUTES
Natural resources data				
	Hydrology			
		Geohydrology		
			Borehole/well	Identification, depth, construction, yield characteristics, ground water level, water quality
			Ground water level isolines	Value
			Aquifer	Type, storage capacity, permeability, thickness, water quality
			Spring	Type, yield characteristics, water quality
		Hydraulic constructions		
			Dam	Name, construction, capacity, owner/authority, pipe/valve sizes and capacity, gales
			Canal	Name, construction, flow capacity, owner/controlling authority
			Pipeline	Name, type, flow capacity, owner/controlling authority
			Tunnel	Name, construction, flow capacity, owner/controlling authority
			Water purification works	Name, type, construction, capacity, owner/controlling authority
			Reservoir	Name, type, construction, capacity, owner/contolling authority
			Other	Name, type, construction
		Water management		
			Water board	Name, purpose, permits, quotas, proclamations, controlling authority
			Irrigation Board	Name, farm names and nos. involved, water sources, controlling authority, cost/tariffs
			Government Water Control Area	Name, purpose, proclamation, controlling authority
			Gauging station	Name, number, river name, flow data, water quality, catchment area, period of record
		Water pollution control		
			Effluent discharge point	Permit volume, permit quality, actual volume and quality
			Waste disposal point	Leachate quality, nature of waste
			Water quality isolines	Value

TABLE E5.1 continued

FEATURES LEVEL I	II	III	IV	NON -SPATIAL ATTRIBUTES
		Natural hydrological features/processes		
			Catchment	Name, number, order, % mean annual runoff, sediment produced per year, max. flood discharge
			River	Name, flow statistics, water quality, perennial/intermittent, order, sediment produced per year, conservation status, aquatic zoological and floral taxa
			Dam	Name, capacity, flow statistics, water quality, aquatic zoological and floral taxa
			Lake	Name, water quality, aquatic zoological and floral taxa
			Lagoon	Name, water quality, aquatic zoological and floral taxa
			Pan	Name, water quality, perennial/ intermittent, aquatic zoological and floral taxa
			Marsh/vlei	Name, water quality, perennial/ intermittent, aquatic zoological and floral taxa
			Flood zone	Frequency of flooding
			Evaporation isolines	Value, pan employed
			River regions	Name, names of rivers occurring in region, hydrobiological attributes of region according to Agnew & Harrison (O'Keeffe, 1986a)

CLASS 1 NATURAL RESOURCES DATA

Category 1.6: Vegetation

1.6.1 INTRODUCTION

Detailed local vegetation classifications can lead to a prolific number of different vegetation mapping units, and therefore Mueller-Dombois & Ellenberg (1974) consider it useful to maintain an unsystematic status for all the abstract vegetation communities in cases where the emphasis is on intensive local vegetation studies.

Coetzee (1983) however, maintains that a comprehensive hierarchical classification scheme becomes desirable when looking at developing a vegetation synopsis at a more extensive geographical scale.

For purposes of description, communication and understanding, definition and classification of vegetation are necessary, bearing in mind the often forgotten corollary that classifications (and by implication mapping of the classified units) are abstractions in which a certain range of internal class variation (heterogeneity) is found dependant on the classifactory level and fineness of resolution that is intended (Edwards, 1983). Scheepers (1987) finds that vegetation maps could provide useful indications of areas of degradation, erosion, invasion and ecologically sensitive conditions.

Acocks (1988) draws attention to the dynamic nature of the ecology in southern Africa and points out the fact that vegetation types tend to migrate into wetter rather than drier habitats.

The natural migration of plants take place over millions of years, yet Acocks (1988) demonstrated that startling changes have taken place in southern Africa over the past 600 years.

Vegetation changes are accelerated by the way it is treated by man. There is little or no vegetation in South Africa which is in its original condition and Acocks (1988) feels that this has not been made sufficiently clear in previous accounts of our vegetation. The environment in which vegetation occurs contains many variable factors, some of which include grazing animals, birds, insects, light, heat and most important of all, water (Acocks, 1988). These variations lead to variations in vegetation. Acocks (1988) sees the problem as grouping these infinite variations of vegetation into manageable units and to separate the natural variations from the man-made ones.

1.6.2 SOME CLASSIFICATION SYSTEMS IN USE IN SOUTH AFRICA

Classification systems of vegetation can be done on several bases. The properties of the vegetation itself or vegetation systems which are also based on various environmental factors and which lead to an ecological classification, can be used. Three main groupings can reasonably be made, namely: classification systems based on floristic community properties, structural classification systems and thirdly, habitat, biome or ecological systems. As will be shown, the biome approach is essentially an extension of the floristic community approach; only the scale of the different approaches vary.

Within biome parameters, Scheepers (1987) found that three criteria for vegetation classification can be used, namely: floristic, quantitative and structural. His study of the grassland biome indicates that structural criteria alone do not offer enough scope for differentiation. He furthermore adds (1987: 3) that 'Quantitative attributes have invariably led to difficulties of reconciliation between the results of different workers who have imposed arbitrary distinctions as criteria for classifications'. Scheepers (1987) therefore concludes that researchers tend to fall back on floristic composition to provide the criteria for classification.

For the purpose of this study, classification of vegetation implies that at some stage the classified vegetation units will be mapped in some form and at some scale. In Table E6.1 the general relationships between scale of study, scale of mapping and scale of remote-sensing products using visual interpretation techniques are shown.

TABLE E6.1: GENERAL RELATIONSHIPS BETWEEN SCALE OF STUDY, SCALE OF MAPPING AND SCALE OF REMOTE-SENSING PRODUCTS USING VISUAL INTERPRETATION TECHNIQUES (FROM EDWARDS & JARMAN, 1972)

SCALE OF SURVEY	AIM	FINAL MAP PRODUCT SCALE	APPROPRIATE AIR PHOTO	APPROPRIATE FIELD SAMPLING PROCEDURES
GENERAL AND GENERAL RECONNAISSANCE	ASCERTAIN MAJOR CLASSES OF VEGETATION AT REGIONAL AND SUB-REGIONAL LANDSCAPE LEVELS	1:1 000 000 OR SMALLER	1:500 000 - 1:1 000 000	DESCRIPTIVE, NON-DEFINED, NON-REGULAR SAMPLES USUALLY RECORDING PHYSIOGNOMIC TYPES
RECONNAISSANCE	DETERMINE THE MAIN PLANT COMMUNITIES/ECOLOGICAL RELATIONS WITHIN REGIONS OR SUB-REGIONS	1:50 000 - 1:1 000 000	1:40 000 - 1:500 000	NON-REGULAR SAMPLES, LOW DENSITY OF PLOT SAMPLES RECORDING STRUCTURAL TYPES AND DOMINANT FLORISTICS
SEMI-DETAILED	INVESTIGATION OF PHYSIOGNOMIC / STRUCTURAL AND FLORISTIC STRUCTURE OF COMMUNITIES AND HABITAT RELATIONS	1:10 000 - 1:50 000	1:5 000 - 1:20 000	DEFINED SAMPLES, MODERATELY HIGH DENSITY, RECORDING STRUCTURAL TYPES AND TOTAL FLORISTICS
DETAILED	STUDY OF STRUCTURE AND FUNCTION OF COMMUNITY OR PART OF COMMUNITY	1:500 - 1:10 000	1:5 000 OR LARGER	INTENSIVE QUANTITATIVE SAMPLING ON DEFINED PLOTS
ULTRA-DETAILED	STUDY WITHIN COMMUNITY SPECIES / SPECIES GROUP / HABITAT RELATIONS	1:500 OR LARGER	1:500 OR LARGER	INTENSIVE QUANTITATIVE SAMPLING ON DEFINED PLOTS / SPECIES

1.6.2.1 Floristic uniform plant communities

Vegetation forms an integral part of an ecosystem and Bredenkamp & Theron (1976) found that individual plant species are excellent indicators of environmental conditions.

In 1953 Acocks published his 'Veld Types of South Africa'. This work, republished in 1975 and 1988 and edited by D.J.B. Killick, formed the basis of the majority of ecological studies carried out in South Africa (Werger, 1974).

Acocks (1988) recognizes 70 veld types and 75 variations, based on a floristic comparison of stand data (Werger, 1974). The basis of Acocks' (1988: 1) classification system is the 'Veld type' which he defines as 'a unit of vegetation whose range of variation is small enough to permit the whole of it to have the same farming potential'. Because of the number of flowering plant species and the extent of their distribution over the country, Acocks selected relatively few species which serve as indicators of the different kinds of vegetation and of changes in vegetation.

Acocks (1988) grouped his 70 Veld Types into seven main classes, namely:

1. Coastal Tropical Forest types.
11. Inland Tropical Forest types.
111. Tropical Bush and Savanna types (including 'False bushveld' types).
1V. Karoo and Karroid types (including 'False Karoo' types).
V. Temperate and transitional Forest and Scrub types.
V1. Grassveld types (including the 'False Grassveld' types).
V11. Sclerophyllous Bush types (including the 'False Sclerophyllous' bush types).

Bredenkamp (1989. pers. comm.) suggests that for local level investigations, e.g. for farms, nature reservations and recreation resorts, a floristic approach to the classification and mapping of vegetation (using the Braun-Blanquet vegetation survey method), could be of more value. This approach could eventually lead to the identification of ecologically founded vegetation units (or ecosystems) which should act as basis for the development of such areas. In this approach rare and endangered species and ecologically sensitive habitats are also identified.

1.6.2.2 Physiognomic and structural classifications

The term 'vegetation structure' refers to and includes the primary elements, namely growth-form, stratification and coverage. Bredenkamp & Theron (1985) note that although the concept of the floristically uniform plant community (association) originally also implied a structural uniformity, various authors since 1978 found that extreme environmental conditions such as overgrazing, severe trampling and veld burning cause considerable structural heterogeneity within floristically homogeneous plant communities.

Beard (quoted in Bredenkamp & Theron, 1985: 45) suggests that a desirable goal for the future should be 'the marrying of the two approaches into a single system of classification wherein floristic units are combined by their structure into physiognomic units'.

Dansereau (in Rutherford & Westfall, 1986) describes vegetation structure as the organization in space of the individuals that form a stand, and by extension a vegetation type or a plant association.

This description is used in the study of Edwards (1983) as a working definition of vegetation that includes both spatial and morphological features but excludes purely floristic features.

Fosberg (1967: 75) describes physiognomy as 'the appearance, especially the external appearance, of the vegetation, partly resulting from, but not to be confused with, structure and function'.

Edwards (1983) finds that since growth form, cover, height and other attributes that qualify the various structural characteristics of vegetation show continuous variation, vegetation could be viewed as a multi-dimensional continuum that may be segmented at certain arbitrary defined points to provide a classification, which remain an abstraction. The objectives of Edwards' classification (1983: 705) are to provide a 'descriptive, consistent, easily applied system, with unambiguous, straight-forward terminology, which can be used in the field and with remote sensing and air photo techniques, and which can be used in conjunction with floristic and habitat terms to convey the essential physiognomy and structure of the vegetation'.

Edwards' system (1983) proposes the following set of attributes as the basis of his vegetation classification:

* A set of four growth form types, namely trees, shrubs, grasses and herbs.
* A set of four cover classes (by which is meant projected crown cover), namely closed, open, sparse and scattered.
* A set of four height classes. These classes, named high, tall, short and low are applied to each of the four growth form types by means of predetermined values in metre height.

In addition to the growth form types, Edwards (1983) distinguishes a shrub substratum class which he calls 'thicket and bushland'. To cope with situations where plant cover of the ground is less than or equals 0,1%, he introduces a set of desert vegetation classes.

These sets of attributes, therefore, lead to nine structural groups, namely:

* Forest and woodland (trees).
* Thicket and bushland (trees and shrubs).
* Shrubland.
* Grassland.
* Herbland.
* Desert woodland.
* Desert shrubland.
* Desert grassland.
* Desert herbland.

When one adds the parameters of the cover classes and height classes to the above structural groups, 72 formations, typically including descriptions such as 'tall open shrubland' or 'low sparse grassland', emerge. Rutherford & Westfall (1986) criticize these systems as they do not recognize geophytes or therophytes as classes exclusive of other forms.

In their vegetation structural classification studies of the Manyeleti Game Reserve in the north-eastern Transvaal, Bredenkamp & Theron (1985) propose a new criterium namely 'performance value' calculated from relative canopy cover and relative density of woody plants in the distinguished height classes.

They suggest that their Performance Value Structural System can be used for an intensive, localized and detailed analysis and accurate description of the structure of woody vegetation, especially for the Bushveld vegetation or at least for the Arid Lowveld as described by Acocks (1988).

Bredenkamp & Theron (1985: 46) further note that the system of Edwards (1983) is an 'excellent and efficient technique for the broad-scale structural classification of vegetation in southern Africa'.

Rutherford & Westfall (1986), however, find that there is no generally accepted classification of plants into growth forms, which they presume to be one of the reasons for emphasizing life forms in biome definitions.

1.6.2.3 Habitat and ecological classification systems

In doing plant-sociological or ecological surveys, great amounts of data are generated which must be classified according to some pattern or system so that maps of the extent and distribution of the pattern-units can be generated.

Scheepers (1987) finds that even with a limited comprehension of these patterns, one can try to develop hypotheses that can predict certain processes, e.g. species response to grazing and fire.

Rutherford & Westfall (1986) diagnosed seven biomes in southern Africa south of 22 °S. In its widest sense, they describe a biome as a broad ecological unit that represents a major life zone extending over a large natural area.

The basis for their classification includes explicit criteria of dominant and co-dominant life forms, both plants and animals, at a specific scale of 1:10,000,000 as well as certain climatic indicators such as precipitation and temperature expressed in a Summer Aridity Index (SAI). They define SAI (1986: 7) as 'the sum of the mean precipitation for the four hottest months of the year, taken as a natural logarithm for scaling purposes and subtracted from a constant to ensure ascending values with increasing aridity'. They find (1986: 43) that the 'success of the SAI can mainly be accounted for by the inclusion of both moisture and temperature, adequate levels of which are required for optimum plant growth'.

Rutherford & Westfall (1986) suggest that any definition of a biome should be made explicit by referring to:

* Maximum global limits which are set at a continental or subcontinental level.
* A unit mappable at a scale no larger than about 1:10 000 000.
* Primarily, dominant life forms, both plants and animals, in a climax system. They emphasize that a purely floristic classification should not be used in biome classification.
* Secondarily, major climatic features that most affect the biota. They stress that these climatic factors only be used to correlate the distribution of life form combinations.
* Natural and not major anthropogenic systems. Large areas of urbanization and cultivation therefore do not act as biome delimitators.

Plant taxonomists, concentrating on consistent and conservative plant characters which are relatively independent of climate, sometimes tend to obscure the main object of the plant ecologist's aim which is to establish plant-environmental relationships (Rutherford & Westfall, 1986).

Raunkiaer (1934), one of the earliest proponents of life forms as basis of classification, distinguishes five main life form classes, namely:

* Phanerophytes.

* Chamaephytes.
* Hemicryptophytes.
* Cryptophytes.
* Therophytes.

(Definitions are given in Appendix A p.167.)

Dansereau, (quoted in Rutherford & Westfall, 1986: 11) even suggests that Raunkiaer's 'essential merit was in breaking away from taxonomic units'.

Rutherford & Westfall (1986) conclude that the fundamental and most widely accepted life form system of Raunkiaer forms the cornerstone for biome differentiation.

Some criticism levelled against Raunkiaer's division of plant life forms include:

* The omission of non-vascular plants (Adamson, in Rutherford & Westfall, 1986).
* At the southern African biome scale, the class of hydrophytes and halophytes (a sub-class of cryptophytes) is inadequately represented (Rutherford & Westfall, 1986).

In comparing and analysing 21 authors whose work, since 1936, propose biomes or other natural biotic divisions on the first level, Rutherford & Westfall (1986) find the five most frequently proposed divisions as being:

* Fynbos 86%.
* Grassland 67%.
* Arid Zone 62% (with the inclusion of some anomalies).
* Forest 57% (also with minor subdivisions).
* Savanna 48%.

They also note that the use of the term biome has increased in recent years and that in the last 15 years, 50% of the sources refer to major first divisions as biomes in contrast to about 10% previously.

From the analysis of the results of their own research, Rutherford & Westfall (1986) propose their own biome classification as follows:

* Savanna (comprising 46,16% of southern Africa south of 22 °S).
* Nama-Karoo (26,05%).
* Grassland (16,52%).
* Succulent Karoo (5,35%).
* Fynbos (3,36%).
* Desert (2,55%).
* Forest (0,01%).

In Figure E6.1 (p.257) the map of southern African biomes is shown at a scale of 1:10 000 000.

In order to correlate their biome classification with Acocks' (1988) Veld Types, Rutherford & Westfall (1986) find that although many of their biome borders follow those of the Veld Types, several Veld Types had to be divided because of different dominant life form combinations within the same Veld Type.

In Table E6.2 (p.258) a classification is shown of Acocks' Veld Types according to biomes.

Rutherford & Westfall (1986) also attempted to compare descriptions based on dominant growth forms as derived from Edwards (1983) with dominant life forms as proposed by Raunkiaer (1934) and with their own proposed biome nomenclature. In Table E6.3 (p.258) this comparison is shown.

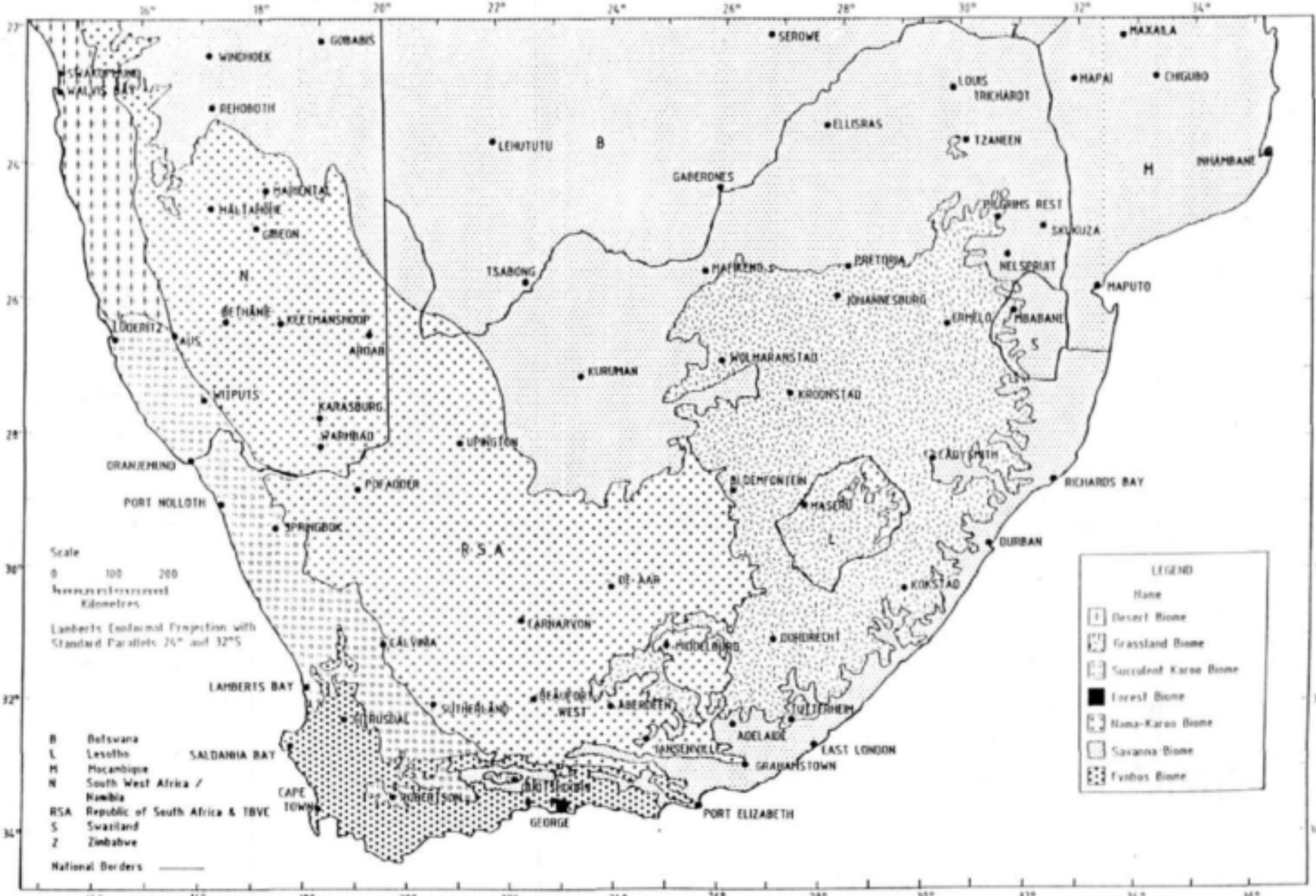


FIGURE E6.1: THE BIOMES OF SOUTHERN AFRICA
(FROM RUTHERFORD & WESTFALL, 1986)

TABLE E6.2: ACOCKS' VELD TYPES CLASSIFIED ACCORDING TO BIOMES (FROM RUTHERFORD & WESTFALL, 1986)

SAVANNA BIOME	GRASSLAND BIOME	NAMA-KAROO BIOME	FYNBOS BIOME	SUCCULENT KAROO BIOME	FOREST BIOME
COASTAL TROPICAL FOREST TYPES 1 2 3* 6 7 INLAND TROPICAL FOREST TYPES 8* 9 TROPICAL BUSH & SAVANNA TYPES 10 11 12 13 14 15 16* 17* 18 19 20 FALSE BUSHVELD TYPES 21 KAROO & KAROOID TYPES 23 25 32* FALSE KAROO TYPES 37* 40* FALSE GRASSVELD TYPES 67 68 FALSE SCLEROPHYLLOUS TYPES 70*	COASTAL TROPICAL FOREST TYPES 3* 5 INLAND TROPICAL FOREST TYPES 8* FALSE BUSHVELD TYPES 22 TEMPERATE & TRANSITIONAL FOREST & SCRUB TYPES 44 45 PURE GRASSVELD TYPES 48 49 50 51 52 53 54 55 56 57 58* 59 60 FALSE GRASSVELD TYPES 61 62 63 64 65 66	TROPICAL BUSH & SAVANNA TYPES 16 17* KAROO & KAROOID TYPES 24 26* 27 28* 29 30 31* 32* 33* FALSE KAROO TYPES 35 36 37* 38 39* 40* 41 42 43* PURE GRASSVELD TYPES 58*	COASTAL TROPICAL FOREST TYPES 4* KAROO & KAROOID TYPES 34* FALSE KAROO TYPES 43* TEMPERATE & TRANSITIONAL FOREST & SCRUB TYPES 46 47 SCLEROPHYLLOUS BUSH TYPES 69 FALSE SCLEROPHYLLOUS BUSH TYPES 70*	KAROO & KAROOID TYPES 26* 28* 31* 33* 34* FALSE KAROO TYPES 39* 43*	COASTAL TROPICAL FOREST TYPES 4*

* VELD TYPES PRESENT IN MORE THAN ONE BIOME

TABLE E6.3: BIOME NOMENCLATURE SHOWING TERMS FOR THE BIOMES, EQUIVALENT TRADITIONAL TERMS IN SOUTHERN AFRICA, DESCRIPTIONS BASED ON DOMINANT GROWTH FORMS DERIVED FROM EDWARDS, AND DOMINANT LIFE FORMS AS DESCRIBED BY RAUNKIAER (FROM RUTHERFORD & WESTFALL, 1986)

PROPOSED BIOME	TRADITIONAL TERM IN SOUTHERN AFRICA	DESCRIPTION EDWARDS (1983)	DOMINANT LIFE FORMS RAUNKIAER (1934)
DESERT	DESERT	(THEROPHYTIC) DESERT	THEROPHYTES
GRASSLAND	GRASSLAND	GRASSLAND	HEMICRYPTOPHYTES
SUCCULENT KAROO	KAROO	DWARF SHRUBLAND	CHAMAEPHYTES
FOREST	FOREST	SHRUB/WOODLAND	PHANEROPHYTES
NAMA-KAROO	KAROO	GRASSY, DWARF SHRUBLAND	HEMICRYPTOPHYTES CHAMAEPHYTES
SAVANNA	SAVANNA	GRASSY, SHRUB WOODLAND	HEMICRYPTOPHYTES PHANEROPHYTES
FYNBOS	FYNBOS	GRASSY, DWARF SHRUBBY, SHRUB/WOODLAND	PHANEROPHYTES CHAMAEPHYTES HEMICRYPTOPHYTES

It is of interest to note that the Grassland Classification and Mapping Task Group (cf. Grassland Biome Project of Scheepers, 1987) and researchers on the Fynbos Biome Project both accept biomes as a first level vegetation classification delimiter. Their goals are to produce classifications and maps on which the classificatory approach implies adherence to a vegetation community-unit theory. For the Grassland Biome Project they foresee that it would take about one year to determine a specific classification system and another four years to produce a good refinement of the Acocks map. They stress that care should be taken to uphold the Acocks nomenclature as far as possible when mapping units are named, so as to avoid possible future confusion.

1.6.3 CONCLUSIONS AND PROPOSAL

For any vegetation classification and mapping system, the following questions should be posed (Bredenkamp, 1989. pers. comm.):

* What is the purpose of the classification?
* What is the scale at which the classified vegetation units are to be mapped?
* What is the floristic composition structure, succession phase and general state of existing vegetation in the study area?

Answers to the first two questions will determine the level of detail required in answering the third question.

Scheepers (1987) suggests that any vegetation classification should be able to generate a series of hypotheses with predictive power. These hypotheses are necessary input in the total landscape planning and management process.

In emphasizing the importance of vegetation, Rutherford & Westfall (1986: 64) conclude by pointing out that 'any classification of natural systems that ignores vegetation (the primary producer component) is likely to be irrelevant to functioning of the ecological system'.

In Table E6.4 a proposal is made to fit the three approaches to vegetation classification (as discussed above) to the hierarchical feature classification system with associated non-spatial attributes as proposed by Clarke, *et al.* (1987).

It should be noted that it is proposed to list fauna as attributes of the level IV vegetation spatial features.

TABLE E6.4 A proposed classification system for vegetation

FEATURES LEVEL I II III IV	NON-SPATIAL ATTRIBUTES
Natural resources data	
Vegetation	
Biome	
Desert	
Grassland	
Succulent-Karoo	
Nama Karoo	
Savanna	
Fynbos	
Forest	Example of Level IV: Forest: * Life form: Phanerophytes * Structural description: Shrub/ Woodland * Floristic description: (according to Veld Type 4: Knysna Forest (Acocks,1988)) * Fauna: Taxa normally found in biome
Veld Type	
Veld Type 1	
Veld Type 2	* Biome type: e.g. Savanna * Floristic description: according to Acocks (1988) * Fauna: Taxa normally found in Veld Type
etc. to Veld Type 70	

CLASS 1 NATURAL RESOURCES DATA

Category 1.7: Zoology

1.7.1 INTRODUCTION

Rutherford & Westfall (1986) observe that there is little available distribution data for most zoological taxa in southern Africa. They add that zoologists have in the past tended to specialize according to taxonomic groups rather than ecologically functional groups. This one-sided approach has resulted, according to Rutherford & Westfall (1986), in a lack of an ecologically based zoological synthesis which in turn has limited comparisons between zoological taxa at biome scale to very few groups. They find (1986: 5) that even if one resorts to using taxonomic units for animal classification, it still does not answer the question of what constitutes 'dominance in a system with, for example, both large mammals and insects?'

The mobility and therefore constantly varying densities of zoological species are some of the other constraints in describing a spatial classification system for animals.

Rutherford & Westfall (1986) observe that since vegetation determines the structural nature of animal habitat, there should theoretically be a close correspondence between animal and plant distribution.

They quote, however, several sources whose work seem to indicate little or no correspondence, and find that vegetation types and climatic factors do not necessarily determine animal distribution.

Rutherford & Westfall (1986) conclude that the animal component as a whole is not necessarily a reliable criterium to determine biome-status classifications of areas in southern Africa.

1.7.2 CLASSIFICATION SYSTEM APPROACHES

1.7.2.1 Using vegetation units as the determinator

Smith (1974) also finds that plant and animal distributions do not coincide. Any attempt to combine plant and animal distribution into one classification system leads to many unworkable classification units (Smith, 1974). He nevertheless proposes, as a method of integrating animals into a cohesive biotic scheme, that plant formations be used as the determining biotic unit and that animals merely be associated as attributes of the life forms of plants.

In Table E6.4 (p.260) an example is shown of a description of zoological taxa as attributes of vegetation formations.

Farrell, *et al.* (1978) consider feeding habits a useful basis for classification of fauna, especially for herbivorous mammals. They distinguish between grazers (subdivided into medium/tall grass and short grass feeders), browsers and intermediate feeders which either browse or graze depending on the seasonal availability of food.

1.7.2.2 Ecological approach

Deshmukh (1986) finds that while an ecological entity or community may be a coherent unit, the whole can only be understood by a consideration of the constituent populations and their interactions. Using the organism as basic unit, Deshmukh (1986) proposes three hierarchical ecological levels of organizations, namely:

* A population: a 'group of individual organisms of the same species in a given area' (1986: 4). The inherent biology of the species and the way in which members of the population interact with their environment, determine the density and distribution of the population.

* A community: a 'group of populations of different species in a given area' (1986: 4). These groups may comprise all the populations in that area - all plants, animals and micro-organisms. A community has diversity as a major characteristic. Deshmukh (1986. 5) defines diversity as 'a combination of the number of species and the number of individuals of each species in a community'. The influences of the abiotic environment, inter-action between communities and change in communities through time, determine the occurrence of a particular community at a given location.

* An ecosystem: 'The whole biotic community in a given area plus its abiotic environment' (Deshmukh, 1986: 5). In an ecosystem the biotic components are linked as food chains. Thus, according to Deshmukh (1986), ecosystem ecology emphasizes the movement of energy and nutrients among it's biotic and abiotic components. In any ecosystem, intricate relationships exist between species, and the various food chains depend on the maintenance of high species diversity. Any human action or development in the ecosystem may affect particular species and hence the entire system (Bosward, 1980).

1.7.3 CONCLUSIONS AND PROPOSAL

Due mainly to the mobility of most zoological taxa and the resultant variations in density of species in a given area at any given time, it is most difficult to describe and classify zoological taxa, especially mammals, on a spatial basis.

Although Rutherford & Westfall (1986) quote several sources who found that vegetation types do not necessarily determine animal distribution, there are those (Smith, 1974 and Farrell, *et al.*, 1978) who nevertheless propose vegetation formations as the determinator in animal species distribution.

At most an attempt can be made to map the distribution of species on an ecological classification basis.

In Table E7.1 a proposal is shown of classifying zoological taxa on four hierarchical ecological levels of organization. The highest level recognized by Deshmukh (1986), namely ecosystem is, due to its constituent components and processes involved, difficult to present spatially on a map.

TABLE E7.1 A proposed classification system for zoology
(after Deshmukh, 1986; Clarke, *et al.*, 1987 and adapted by author)

FEATURES LEVELS I II III IV	NON-SPATIAL ATTRIBUTE
Natural resources	
Zoology	
Ecological Community	System, Zoological taxa observed/ normally found, observation point, density and numbers of various taxa, time and date
Ecological Populations	Zoological taxon observed/normally found, observation points, density/ numbers of species, time and date, species conservation management status, species conservation threat status, species conservation genetic status

CLASS 2 LAND USE DATA

1. Introduction

In order to plan for and to manage any given area from a landscape planning perspective, it is imperative to be able to work from a survey or a map which indicates current land use and land cover. Traditional methods of surveying and mapping, whilst accurate, were often time consuming and expensive. Maps are usually also outdated quickly by changes in land use, of which rapid urbanization is the most common phenomenon.

The level of detail in a map is the result of the method used to survey and map that given area. The level of detail attainable with a certain surveying method, also leads to a classification system of land use/land cover (LULC) commensurate with that method.

The spatial and temporal nature of LULC should be recognized and allowed for in any classification system approach.

2. Methods of data collection and classification

LULC data have historically been gathered using low altitude aerial photography and ground crews to establish maps and details of land cover data summaries (Shih, 1988).

One of the general aims of land use control is to limit and regulate occupancy of flood-prone areas by activities that take up natural flood storage or that suffer heavily from flooding (Dunne & Leopold, 1978). This zoning approach allows the maintenance of socially desirable land uses such as open space in the heart of congested urban areas.

The USGS is currently producing digital LULC maps for the entire

United States using its Geographic Information Retrieval and Analysis System (GIRAS). Although GIRAS is a polygon based vector data system, digital data in raster format with a 200 x 200 m cell size is also available from the USGS.

Because the data source for these maps are medium and small scale aerial photographs, the photo scale of 1:58000 and smaller permits realistic categorization of only the first two levels of the Anderson system, (cf. Anderson, *et al.*, 1976). The smallest feature being mapped is four hectares for urban and related features and 16 hectares for non-urban LULC features.

The USGS GIRAS data base currently consists of seven country-wide data layers, namely:

* LULC;
* political units;
* hydrologic units;
* census county subdivisions;
* federal land ownership;
* state land ownership;
* elevation;
* It is also envisaged to make available a soil map registered to the 1:250 000 USGS base maps (Hudson & Krogulecki, 1987).

While these conventional methods are accurate, they are also expensive, time consuming, difficult to update and often repetitive. Since the early 1970s, with the United States LANDSAT programmes of using satellite remote-sensing, data for LULC classification purposes have become available. Among many advantages of these newer techniques, is the ability to frequently update LULC information at relatively low cost.

Land use cannot be directly measured by remote-sensing but can be inferred from land cover which in turn can be reasonably identified from satellite data. Land use can thus be seen as a social classification of the earth's surface whereas land cover is a physical classification (Randall, 1988).

Since there currently exist many different sources of information and information gathering methods on LULC, the USGS developed a standardized system of classification which is compatible with remotely-sensed data (Anderson, *et al.*, 1976). In Table E8.1 (p.268) the framework of this system is shown and in Appendix D the complete classification system for the Level I category : 'Urban and Built-up land' and Level II category: 'Residential' (from Anderson, *et al.*, 1976) and from the Standard Land Use Coding Manual (SLUC) of the United States Urban Renewal Administration, (1965) is shown as an example.

Jensen (1983), in pointing out differences between various LULC classifications, observes that emphasis and ability to incorporate information obtained by using remote-sensors, are the major ones. He classifies the USGS system (Anderson, *et al.*, 1976) as resource oriented in contrast to the people or activity emphasis of the SLUC system (Urban Renewal Administration, 1965). Jensen (1983) recognizes the need to merge the two approaches. Generally speaking, Level I and II (one and two digit categories, see Table E8.1 p.268 and Appendix D p.182) emphasize land cover as basis whereas Levels III and IV (three and four digit categories, see Appendix D) put more emphasis on land use or activity.

TABLE E8.1: Land use and land cover classification system for use with remote-sensor data (Anderson, *et al.*, 1976)

LEVEL I	LEVEL II
1 Urban or Built-up land	11 Residential 12 Commercial and Services 13 Industrial 14 Transportation, Communications and Utilities 15 Industrial and Commercial Complexes 16 Mixed Urban or Built-up Land 17 Other Urban or Built-up Land
2 Agricultural Land	21 Cropland and Pasture 22 Orchards, Groves, Vineyards, Nurseries and Ornamental Horticultural Areas 23 Confined Feeding Operations 24 Other Agricultural Land
3 Rangeland	31 Herbaceous Rangeland 32 Shrub and Brush Rangeland 33 Mixed Rangeland
4 Forest Land	41 Deciduous Forest Land 42 Evergreen Forest Land 43 Mixed Forest Land
5 Water	51 Streams and Canals 52 Lakes 53 Reservoirs 54 Bays and Estuaries
6 Wetland	61 Forested Wetland 62 Nonforested Wetland
7 Barren Land	71 Dry Salt Flats 72 Beaches 73 Sandy Areas other than Beaches 74 Bare Exposed Rock 75 Strip Mines, Quarries and Gravel Pits 76 Transitional Areas 77 Mixed Barren Land
8 Tundra	81 Shrub and Brush Tundra 82 Herbaceous Tundra 83 Bare Ground Tundra 84 Wet Tundra 85 Mixed Tundra
9 Perennial Snow or Ice	91 Perennial Snowfields 92 Glaciers

This standardized classification (Table E8.1 p.268) allows for the verification of the satellite-sourced data by ground-truth information gathering.

Wolfaardt (1987) points out, however, that it is more difficult to distinguish between and classify artificial (cultural) landscape data than natural (physical) landscape data originating from remote-sensing devices. Accuracy can best be accomplished by statistically comparing remotely-sensed data to representative ground truth of the corresponding area.

Methods of assessing the classification accuracy are important because category terms must be defined and acceptable criteria established if professionals are to successfully use the remotely-sensed land information (Jensen, 1983).

It should be noted that the smallest mapping unit for urban areas and water bodies on the USGS LULC maps is four hectares. For the rest of the categories, the smallest mappable unit is 16 hectares. Jensen (1983) proposes that the minimum parcel size to be mapped should, regardless of the surveying method, have dimensions equivalent to approximately 2 x 2 mm of the map scale.

Figure E8.1 (p.270) shows the relationship between area in hectares for square parcels of 2 x 2, 3 x 3 and 5 x 5 millimetres (minimum mapping units) and map scale.

Shih (1988) found that digital LANDSAT data, classified into LULC categories by either a supervised semi-manual or an unsupervised automated method, fed into a computerized GIS, shows an excellent agreement for most land use categories when merged and compared on a GIS with digital maps obtained through conventional surveying methods.

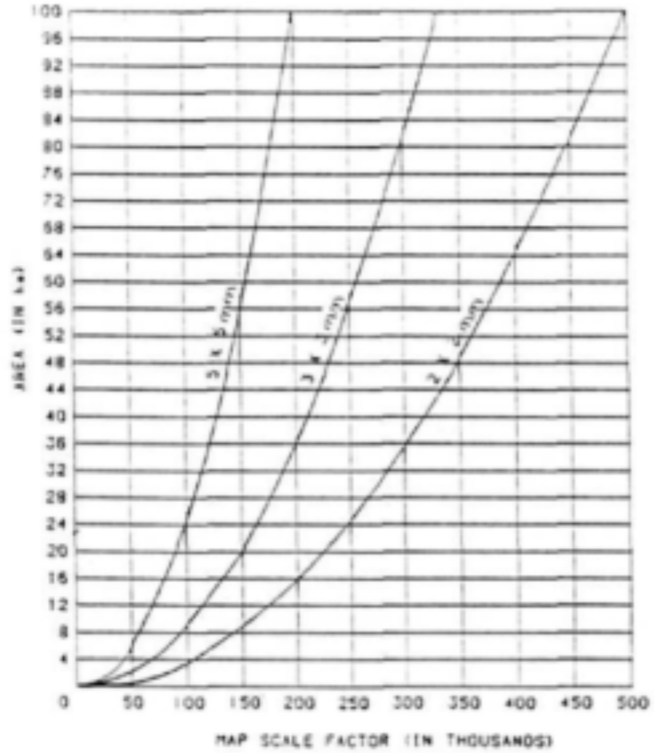


FIGURE E8.1: RELATIONSHIP BETWEEN AREA IN HECTARES FOR SQUARE PARCELS OF 2X2, 3X3 AND 5X5 mm (MINIMUM MAPPING UNITS) AND MAP SCALE (FROM JENSEN, 1983)

Dulaney (1987) found the currently available USGS LULC digital data an inexpensive, easily integrated source of land use and land cover information in his study to find an Environmental Methods Testing Site (EMTS) for the U.S. Environmental Protection Agency.

Jensen (1983) finds that Level I classes (see Table E8.1 p.268 and Appendix D) can be mapped from LANDSAT image data whereas the type and detail of information typical of Levels II, III and IV require the use of high, medium and low altitude aerial photographs respectively.

In Table E8.2 the various classification levels are shown each with its typical data characteristics.

TABLE E8.2: Comparison between classification levels and typical data characteristics (from Jensen, 1983)

CLASSIFICATION LEVEL	TYPICAL DATA CHARACTERISTICS
I	LANDSAT Type of Data
II	High altitude data taken at 12 400 m or above; Scale 1:80 000 or smaller
III	Medium altitude data taken between 3100 and 12400 m ; Scale 1:20 000 to 1:80 000
IV	Low altitude data taken below 3100 m; Scale: larger than 1:20 000

Various other U.S. authors have used the USGS system of Anderson, *et al.* (1976), and adapted it to suit their specific areas of study.

For use in Florida U.S.A., Breedlove, Dennis & Associates Ecological Consultants (1989) have retained seven of the Level I categories namely Urban or Built-up Land, Agriculture, Rangeland, Forest Land, Water, Wetlands and Barren Land, but have incorporated Transportation, Communication and Utilities as an eighth category and 'Special Classifications' as a ninth Level I category. Their Levels II, III and IV categories differ vastly from both Anderson, *et al.* (1976) and the Urban Renewal Administration (1965); the reason being different local circumstances in Florida. Most of the Level III and IV descriptions as used by the Urban Renewal Administration (1965) and by Breedlove, Dennis & Associates (1989) should rather be accomodated in the list of non-spatial attributes as proposed by Clarke, *et al.* (1987).

3. Conclusions and proposal

Shih (1988) demonstrated that using LANDSAT data to classify LULC is superior to conventional methods. The main reason is the cost comparison; the LANDSAT data method costs approximately one tenth of the conventional method (Glover, quoted in Shih, 1988). Cost is here defined in terms of time and money spent gathering information. Another reason is the relative ease with which data updates are accomplished.

Assuming that classification systems are a necessary component of effective urban and suburban LULC planning and management, it is important to point out that there is no ideal LULC classification scheme and it is unlikely that one will be developed which is universally acceptable (Jensen, 1983).

Land cover Level I categories such as Rangeland, Forests, Water and Wetlands as proposed by Anderson, *et al.*(1976), could reasonably be accommodated in Level I categories such as Biology, Geomorphology and Hydrology as proposed by Clarke, *et al.* (1987). It is proposed that only land use categories with emphasis on people or their activities be classified in this category. It is furthermore suggested that the Level I categories of Building and Structure, Communication Network and Land Use as proposed by Clarke, *et al.* (1987) could be combined in a Level I category merely named 'Land Use'. In setting up this proposed land use classification system (see Table E8.3 p.273) care was taken to classify only mappable spatial entities (or features) in a hierarchy and rather use the non-spatial attribute lists to accommodate certain Level III and IV entities as proposed by various other authors.

In contrast with the natural data resource classes and categories described earlier and where only the underlying principles are shown, the comprehensive classification of land uses is shown in Table E8.3.

TABLE E8.3: A proposed classification system for land use
(From Clarke, *et al.*, 1987; Breedlove, Dennis & Associates Ecological Consultants, 1989; Anderson, *et al.*, 1976 and adapted by the author.)

SPATIAL FEATURES LEVELS I	II	III	IV	NON-SPATIAL ATTRIBUTES
Land use				
	Agricultural			
		Cultivated land		Crop, Type, Yield, Irrigation
		Vineyard		Type, Yield, Irrigation
		Orchard		Type, Yield, Irrigation
		Plantation		Type, Tree density, Plant date
		Nursery		Type
		Stock		Type
		Poultry		Type
	Commercial and Services			
		Commercial		Type/Activity, Retail/Wholesale
		Services		Type/Activity
	Communication			
		Air		
			Airports	Name, Type, Status, Elevation
			Runway	Length, Width, Orientation, Number, Surface, Status
			Helipad	Diameter, Orientation, Number, Surface, Status
			Navigational aid facility	Name, Type
		Sea and inland water		
			Harbour/port	Name, Activity
			Dock	Activity, minimum draught, name, Handling capacity
			Shipyard	Name, Activity
			Channel	Name, Width, Minimum draught
			Navigational facility	Name, Type
		Roads		
			Road	Name, Class, Route number, Number of carriageways, Number of lanes, Surface, Status
			Path/Track	Surface, Status, Use
			Intersection	Name, Roads intersecting
			Tollgate	Name, Number of gates, Toll fee

TABLE E8.3: continued

SPATIAL FEATURES LEVELS I	II	III	IV	NON-SPATIAL ATTRIBUTES
		Rail		
			Railway	Number of lines, Gauge, Use, Status, Electrified, Name
			Station	Name, Type
			Repair facilities	Name, Use, Type
		Telecommunication		
			Transmitting station	Name, Type, Use, Frequency, Power, Direction, Spread angle
			Relay stations	Name, Type, Use
			Lines	Type, Number, Use
	Cultural			
		Religious		
			Church/Synagogue	Denomination, Name
			Parochial school	Denomination, Name
			Cemetries	Name
		Entertainment		
			Theater	Name, Type, Construction
			Museums	Name, Type
			Library	Name, Type
			Art Galleries	Name, Type
			Zoos	Name, Type
			Historic sites	Name, Type
			Amusement parks	Name, Type
	Industrial			
		Producing facility		Activity, Name, Process, Products
		Storage facility		Name, Type, Product, Capacity
	Institutional			
		Educational		
			School	Name, Class, Activity
			College	Name, Class, Activity
			Technikon	Name, Class, Activity
			University	Name, Class, Activity
		Governmental		
			Office building	Name, Type, Use
			City Hall	Name, Type, Use
			Police station	Name, Type, Use
			Fire station	Name, Type, Use
			Post office	Name, Type, Use

TABLE E8.3: continued

SPATIAL FEATURES LEVELS I	II	III	IV	NON-SPATIAL ATTRIBUTES
			Court houses	Name, Type, Use
			Maintenance yards	Name, Type, Use
			Depots	Name, Type, Use
		Medical and Health Care		
			Hospital	Name, Type, Use
			Clinic	Name, Type, Use
			Nursing Home	Name, Type, Use
		Correctional		
			Prison	Name, Type, Use
			Juvenile centres	Name, Type, Use
		Military		
			Army installations	Name, Type, Use
			Air Force installations	Name, Type, Use
			Navy installations	Name, Type, Use
			Medical Services installations	Name, Type, Use
	Mining			
		Open cast		Name, Type, Yield, Status
		Underground		Name, Type, Yield, Status
		Prospecting		
		Dump		
		Slimes dam		
		Mine shaft		
	Open Land			
		Natural area		Name, Type, Status, Authority
		City parks		Name
		Conservation area		Name, Type, Status, Authority
		Camping ground		Name, Type, Use
		Undeveloped land in urban area		
	Recreation			
		Golf course		Name, Number of holes
		Car racing tracks		Name
		Swimming pools		Name, Pool size
		Outdoor sport facilities		Name, Activities
		Indoor sport facilities		Name, Activities
		Riding stables		Name
	Residential			
		Area		Name, Type, Unit density
			Unit	Name, Type, Construction, Stories

TABLE E8.3: continued

SPATIAL FEATURES LEVELS I	II	III	IV	NON-SPATIAL ATTRIBUTES
	Social			
		Administrative area		Name, Authority
		Cadastral		Name, Number, Owner, Authority
		Social Statistical		Demographic Statistics
	Utilities			
		Electricity Supply		
			Generating station	Name, Type, Energy source, Capacity
			Transmitting lines	Type, Capacity
			Distributing sub-stations	Name, Type, Class, Capacity
		Water Supply		
			Treatment facilities	Name, Type, Capacity
			Tanks	Name, Type, Capacity
			Pipes	Type, Diameter, Capacity
			Pumping station	Name, Type, Capacity
		Sewage Treatment		
			Treatment facilities	Name, Type, Capacity
			Pipes	Type, Diameter, Capacity
			Pumping stations	Name, Number, Type, Capacity
		Solid Waste Disposal		
			Treatment facilities	Name, Type, Process, Capacity
			Dumping facilities	Name, Capacity
		Gas Supply		
			Storage facilities	Name, Type, Capacity
			Pipes	Type, Diameter, Capacity
		Oil Supply		
			Storage facilities	Name, Type, Capacity
			Pipes	Type, Diameter, Capacity
			Pumping station	Name, Number, Type, Capacity

APPENDIX F NEW SOUTH WALES PLANNING AND ENVIRONMENT COMMISSION
ENVIRONMENTAL IMPACT ASSESSMENT CHART
(BASED ON ENVIRONMENTAL STANDARD EI-4)
(FROM BOSWARD, 1980)

WHEN PROPOSALS MAY CAUSE SIGNIFICANT ENVIRONMENTAL IMPACT OR BECOME CONTROVERSIAL, PROPER ASSESSMENT INVOLVES THE CO-ORDINATED PARTICIPATION OF THE PROPONENT, THE DETERMINING AUTHORITY, OTHER PUBLIC AUTHORITIES AND THE PUBLIC.