ASSESSMENT OF THE WATER POVERTY INDEX AT MESO-CATCHMENT SCALE IN THE THUKELA BASIN

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Submitted in partial fulfillment of the requirements of the degree of

PhD

School of Bioresources Engineering and Environmental Hydrology

University of KwaZulu-Natal

Pietermaritzburg

2006

PREFACE

The research described in this thesis was undertaken in the School of Bioresources Engineering and Environmental Hydrology, University of KwaZulu-Natal, Pietermaritzburg, between April 2002 and July 2005, under the supervision of Professor R. E. Schulze.

The study respresents original work by the author and has not been submitted in any form for any degree or diploma to any University. Where use has been made of the work of others, it has been duly acknowledged in the text.

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ACKNOWLEDGEMENTS

The author wishes to express his most sincere gratitude and appreciation for the assistance given by the following:

Professor R. E. Schulze, Professor of Hydrology, School of Bioresources Engineering and Environmental Hydrology, University of KwaZulu-Natal, for his support and supervision of this research;

Professor G. P. W. Jewitt, Associate Professor of Hydrology, School of Bioresources Engineering and Environmental Hydrology, University of KwaZulu-Natal, for co-supervision of this study;

Professor J. C. Smithers, Head, School of Bioresources Engineering and Environmental Hydrology, University of KwaZulu-Natal, for making this study possible through this School;

Mr M. J. C. Horan, GIS Systems Programmer, School of Bioresources Engineering and Environmental Hydrology, University of KwaZulu-Natal, for his assistance; and

All my fellow post-graduate colleagues and friends, particularly, **Mr O. Idowu, Mr V. Kongo** and **Mr R. Themeli**, for their insights and companionship during the course of this study.

The research leading to this thesis was made possible by financial support from System for Analysis, Research and Training (START) and the National Research Foundation (NRF).

ABSTRACT

The connection between water and human wellbeing is increasingly causing concern about the implications of water scarcity on poverty. The primary fear is that water scarcity may not only worsen poverty, but may also undermine efforts to alleviate poverty and food insecurity. A review of literature revealed that the relationship between water scarcity and poverty is a complex one, with water scarcity being both a cause and consequence of poverty. Furthermore, water scarcity is multi-dimensional, which makes it difficult to define, while it can also vary considerably, both temporally and spatially. Finally, the relationship between water scarcity and poverty is a difficult one to quantify.

Within the context of water scarcity, indicators are viewed by many development analysts as appropriate tools for informing and orienting policy-making, for comparing situations and for measuring performance. However, simplistic traditional indicators cannot capture the complexity of the water-poverty link; hence a proliferation of more sophisticated indicators and indices since the early 1990s. The Water Poverty Index (WPI), one of these new indices, assesses water scarcity holistically. Water poverty derives from the conceptualisation of this index which relates dimensions of poverty to access to water for domestic and productive use. However, the WPI has not been applied extensively at meso-catchment scale, the scale at which water resources managers operate. In South Africa, the Thukela Catchment in the province of KwaZulu-Natal presents a unique opportunity to assess the WPI at this scale.

The Thukela is a diverse catchment with respect to physiography, climate and (by extension) natural vegetation, land use, demography, culture and economy. While parts of the catchment are suitable for intensive agricultural production and others are thriving economic centres, a large percentage of the population in the catchment lives in poverty in high risk ecosystems, with their vulnerability exacerbated by policies of the erstwhile apartheid government. Many rural communities, a high percentage of which occupy these naturally harsh areas, have low skills levels, with a high proportion of unemployed people, low or no income and low services delivery. Infrastructural development, which relates to municipal service delivery, is often made prohibitively expensive by the rugged terrain in which many people live. As in

other catchments in South Africa, the Thukela is affected by policies and initiatives aimed at accomplishing the objectives of post-1994 legislation such as the South Africa Constitution and the National Water Act. The potential of the WPI to assess the impacts of these initiatives on human wellbeing and to inform decision making in the Thukela catchment was investigated.

An analysis of a 46 year long series of monthly summations of daily values of streamflows output by the *ACRU* agrohydrological simulation model has shown that the Thukela, in its entirety, is a water-rich catchment. The reliability of the streamflows, which has implications for communities who collect water directly from streams, is high along main channels but can be considerably less along low order tributaries of the main streams. The flow reliability along the small tributaries is less in winter than in summer. A high percentage of the catchment's population, in addition to being poor and not having access to municipal services, live near, and rely on, the small tributaries for their water supplies. Admittedly, this analysis addresses only one dimension of water poverty, *viz.* physical water shortage. Nevertheless, the study revealed that despite the Thukela's being a water-rich catchment, many communities are still water stressed. A more holistic characterisation of the water scarcity situation in the Thukela catchment was achieved using the WPI.

A review of possible information sources for computing the WPI in South Africa found that many monitoring programmes, information systems and databases are either in existence and are active, or being restructured, or are under different stages of development. If and when they are all fully functional, they should be able to support national assessments of the WPI at meso-scale without the need to collect additional information. A combination of information from some of the active databases and secondary data from other local studies was used to compute the WPI in the Thukela catchment. The assessment uncovered the following:

- There is an apparent association between water poverty and socio-economic disadvantage in the Thukela catchment.
- There was an improvement in the water poverty situation in most parts of the Thukela catchment between 1996 and 2001, although the degree of improvement varied from subcatchment to subcatchment.

- Climate change, if it manifests itself by higher temperatures and reduced rainfall, will most likely worsen water poverty throughout the Thukela catchment, with the subcatchments in which many of the poor communities are located being more likely to experience the most severe impacts as the coping capacities of those communities are already strained under current climatic conditions.

The findings of this study illustrate the potential of WPI as a tool for informing decision making and policy evaluation at the meso-catchment scale at which many water-related decisions are made.

ABBREVIATIONS

ACRU	Agricultural Catchments Research Unit
ARC	Agricultural Research Council
BEEH	Bioresources Engineering and Environmental Hydrology
CIDA	Canadian International Development Agency
CMA	Catchment Management Agency
CSLS	Centre for the Study of Living Standards
CV	Coefficient of Variation
CWSS	Community Water Supply and Sanitation
DEM	Digital Elevation Model
DFID	Department for International Development, UK
DOH	Department of Health
DPSIR	Drivers-Pressures-State-Impacts-Responses
DWAF	Department of Water Affairs and Forestry
EA	Enumerator Area
EDR	Economic Dependency Ratio
EEA	European Environment Agency
EP	Potential Evaporation
EU	European Union
FAO	Food and Agricultural Organisation
FBW	Free Basic Water
FDC	Flow Duration Curve
GCM	Global Circulation Model
GDP	Gross Domestic Product
GIS	Geographic Information System
GLCF	Global Land Cover Facility
HDI	Human Development Index
HH	Household
HIS	Hydrological Information System
ICM	Integrated Catchment Management
IFR	Instream Flow Requirement
IPCC	Intergovernmental Panel on Climate Change
IRWS	Indicator of Relative Water Scarcity

ISCW	Institute for Soil, Climate and Water
IWMI	International Water Management Institute
IWRM	Integrated Water Resource Management
KPI	Key Performance Indicator
LDI	Land Degradation Index
LHWP	Lesotho Highland Water Project
MAP	Mean Annual Precipitation
MAPE	Mean Annual Potential Evaporation
MAR	Mean Annual Runoff
MAUP	Modifiable Areal Unit Problem
MD	Magisterial District
NBI	National Botanical Institute (now South African National Biodiversity Institute)
NGA	National Groundwater Archive
NGIS	National Groundwater Information System
NLCD	National Land Cover Database
NRF	National Research Foundation
NWA	National Water Act
NWRS	National Water Resource Strategy
OECD	Organisation for Economic Co-operation and Development
PAI	Population Action International
PI	Poverty Index
PN	Place Name
PSR	Pressures-State-Responses
QC	Quaternary Catchment
QCD	Quaternary Catchments Database
RIVM	National Institute for Public Health and Environment, Netherlands
RSA	Republic of South Africa
SADC	Southern African Development Community
SASRI	South African Sugarcane Research Institute
SAWS	South African Weather Service
SC	Subcatchment
SEI	Stockholm Environment Institute
SLF	Sustainable Livelihoods Framework

SP	Sub-place
SQ	Sub-Quaternary
START	SysTem Assessment Research and Training
STATSSA	Statistics South Africa
SWSI	Social Water Stress Index
UN	United Nations
UNCSD	United Nations Commission of Sustainable Development
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UNFPA	United Nations Population Fund
WfWP	Working for Water Programme
WHO	World Health Organisation
WMA	Water Management Area
WMS	Water Management System
WPI	Water Poverty Index
WRC	Water Research Commission
WRVI	Water Resources Vulnerability Index
WSA	Water Services Act
WSAM	Water Situation Assessment Model
WSI	Water Stress Index
WSP	Water Service Provider
WSSD	World Summit on Sustainable Development
WUA	Water User Association
ZAR	South African Rand

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1 INTRODUCTION

Water is the basis of life on earth; not only for that of humans, but also for ecosystems (Bos and Bergkamp, 2001) and the economy as well (Kasrils, 1999; Shiklamanov, 2000). However, the finite nature of freshwater resources, coupled with the ever increasing demand for water resulting from accelerated human population growth, as well as the emergence of newly industrialising economies and the increasing pressures of sectoral and international competition is quickly rendering water a scarce resource. Globally, 458 million people faced either water stress or water scarcity by 1995 (Engelman and Leroy, 1995), and this number was expected to increase about tenfold by 2050 (Gardner-Outlaw and Engelman, 1997; UNFPA, 1997). Increasingly, water scarcity is perceived as a limiting factor for both food security and industry in developing countries, as well as the most probable source of conflict between countries over a renewable resource (Ohlsson, 1998). Consequently, a considerable amount of research effort within the water resources fraternity is currently focused on water scarcity, i.e. its causes, impacts and evaluation, as well as the formulation and implementation of strategies for overcoming it.

The assessment of water scarcity has dovetailed with many existing and proposed local, national and international monitoring and evaluation initiatives. The United Nations Commission on Sustainable Development (UNCSD), in Chapter 40 of Agenda 21 (UNCSD, 1992), advocates the development and strengthening of local, national and international monitoring systems and databases in order to bridge the information gap and improve information availability, and to move towards sustainable development. Freshwater is mentioned explicitly among the comprehensive range of aspects of the environment for which data collection activities should be strengthened. In South Africa, the National Water Act (RSA, 1998) requires the Minister of Water Affairs and Forestry to establish national monitoring systems for the collection and storage of appropriate data and information necessary for the assessment of water resources. These measurements and monitoring programmes are yielding large volumes of data, and more is expected in the future. However, the raw data often provide little in terms of information that can readily be used by decision makers, unless they are synthesised and summarised into indicators (Pintér *et al.*, 2000).

Pressures for both summative and formative evaluations have re-ignited an interest in indicators (James, 2000). Unlike the situation in the social sciences and economics, where debates on the use of indicators in policy making date back to the early 20th century (Cobb and Rixford, 1998), recent developments such as Agenda 21 are credited as stimuli for indicator initiatives for environmental systems (OECD, 1993; World Bank, 1995; Walmsley *et al.*, 2001).

Within the water resources planning and management domain, the need to develop tools for measuring, tracking and evaluating the complex connection between freshwater availability and human wellbeing (Gleick *et al.*, 2003; Molle and Mollinga, 2003), as well as the understanding of the limitations of traditional measures (e.g. counts or percentages of population without access to water) in this regard (Gleick *et al.*, 2003), are in part responsible for the growing interest in indicators. Indicators which are commonly used to address water-related issues range from simple percentages of access to water and sanitation to sophisticated indices, such as the Water Poverty Index (Sullivan *et al.*, 2002), which take into account a spectrum of factors such as income-related wealth, availability of and access to water resources, management capacity, water use and environmental integrity. The simple indicators do not provide and information about the probable causes high or low levels of access to water or sanitation.

Despite the global endorsement of integrated, or holistic, approaches in catchment or water resources management, and the convergence of these approaches with the sustainable development concept, Walmsley (2001) found that research on catchment-level indicators of sustainability was still in its infancy. This finding is confounding, considering that the catchment is recommended for integrated ecosystems management and that indicators can be useful in providing information to decision makers about changes in catchment conditions. Even in cases where catchment indicators do exist, they are usually provided at the macro-scale, i.e. at river basin level, and not at the meso-catchment scale where most water resources management operations and research in South Africa, for example, are undertaken

(Dlamini and Schulze, 2004). Lack of resources, the complexity of developing catchment indicators and the lack of understanding of their use are some of the causes of the slow uptake of indicators in catchment water resources management (Wamsley, 2001).

The advent of a new government in South Africa in 1994 triggered a wide range of reforms which affected many aspects of life in the country. The water sector witnessed the promulgation of the National Water Act, NWA (RSA, 1998), which has been hailed worldwide as highly progressive. The NWA recognises that water is a scarce resource which must be shared equitably, utilised efficiently and managed sustainedly. Operationalising water resources planning and management strategies such as licensing of water use and re-allocation/redistribution of water, which may involve expropriation of existing water licences in order to redress past iniquities, are among many challenges facing water resources managers in South Africa. This situation creates an urgent need for suitable decision support systems, often in the form of indicators, to inform decision making in relation to these strategies.

Based on the data which are already, or will in future be, collected and stored by information systems, it is evident that there are many possible indicators which can be developed for servicing the NWA. This makes the choice of suitable indicators a challenging task. Choosing and understanding the relevance and meaning of the multitudes of already existing indicators is recognised even in disciplines such as economics and the social sciences, where indicators are well entrenched as decision making tools, as being tasks that require a cautious and systematic approach (Cobb and Rixford, 1998).

This study investigates the applicability of water scarcity, and water poverty indicators and indices in the planning, monitoring and management of water resources-related development initiatives at meso-catchment scale. The applicability of these indices, at this scale, could present a sound basis for their development or adaptation as tools for informing, monitoring and evaluating policies for water-related development. A concise summary of the structure of this study is presented in **Table 1**. **Chapter 1** is the background chapter which covers the problem statement and the primary objective of the study. It underscores the relevance and importance of indicators and indices in the water sector in South Africa. *Objective A* of the study is addressed in **Chapter 2** through a review of recent relevant literature on water scarcity.

Table 1.1 Structure of the thesis, mapping the link between the primary objectives and the specific issues addressed in the document

Problem Statement	
The Water Poverty Index (WPI) is a tool which can support the process of making decisions regarding the evaluation and monitoring the policies and strategies emanating from reforms in the water sector after the promulgation of the National Water Act (1998). Applying the WPI at the meso-catchment should provide information to water managers at the spatial scale at which they operate. If existing and planned monitoring programmes, information systems and databases can provide sufficient data to compute the index for South African assessments without having to collect project-specific data, the WPI can add value to these information systems.	
Primary Objectives	**Specific Objectives**
A) Place indicators and indices within a South African water resources planning, development and management context.	i. Review the link between water and socio-economic development ii. Review the definitions, dimensions and impacts of water scarcity iii. Review the use of indicators and indices in the assessment of water scarcity iv. Review the design, development and applications of water scarcity-related indicators and indices v. Review the water situation in South Africa
B) Determine prevailing water resources-related issues in the Thukela catchment at meso-catchment scale	i. Review biophysical characteristics and socio-economical profile of the Thukela catchment ii. Assess primary water resources endowment of the Thukela catchment
C) Develop a methodology for determining the applicability of multi-disciplinary indices at meso-catchment scale	i. Review the catchment as spatial unit for water resources management ii. Review scale issues in social and physical sciences iii. Use standard statistical techniques to analyse socio-economic variables at different spatial scales
D) Assess the water poverty in the Thukela catchment	i. Review existing and proposed monitoring programmes, information systems and databases which can support the WPI in South Africa ii. Identify and develop suitable indicators for computing the WPI in South African conditions iii. Evaluate spatial and temporal patterns of water poverty in Thukela catchment using the WPI iv. Determine the potential impacts of climate change on water poverty
E) Discuss the findings of the research relative to study area specific, and general South African, water-related policy issues	i. Identify specific policies to which the WPI can be applied ii. Identify and discuss the benefits and limitations of applying the WPI in South Africa iii. Suggest directions for future research concerning the use of multi-disciplinary indices to investigate the link between water and socio-economic wellbeing

The review commences with mapping out the link between the availability of water and socio-economic development before examining the design, development and application of frequently cited indicators in the water sector. **Chapter 2** also reviews the water situation in South Africa, focussing on the availability and utilisation of water resources as well as on the levels and impacts of water scarcity and strategies for overcoming such scarcity.

The literature review presents a mechanism for selecting suitable indicators and indices for characterising evaluating water poverty at meso-catchment scale. The applicability of these tools at this scale is tested in the Thukela catchment in the KwaZulu-Natal province of South Africa, which presents a unique opportunity to do this because of its diversity in relation to physiography, climate, land use demography, culture, politics and economy.

Chapter 3 considers one part of *Objective D* of the study, which is to assess water wellbeing at meso-catchment scale in the Thukela using the WPI. This chapter commences with establishing the availability of sufficient data for computing the WPI in South Africa by reviewing existing and proposed national monitoring programmes, information systems and databases. The availability of enough data to enable the evaluation of the index without the need for project-specific data collection programmes will not only render the evaluation of water poverty less expensive than it would have been otherwise, but using the WPI will add more value to these national information systems as well.

A detailed description of the Thukela catchment, the study area, is presented in **Chapter 4**. The purpose of this description is to reveal biophysical characteristics and socio-economic factors which may influence the current situation with respect to the availability, development and management of, as well as access to, water resources in the Thukela catchment (cf. **Table 1**).

In **Chapter 5**, an evaluation of the natural endowment of water resources in the Thukela catchment is presented. This evaluation partly addresses *Objective B* of the study (cf. **Table 1**). Streamflows simulated under baseline land cover conditions using a hydrological simulation model were used for the assessment. The streamflow magnitudes, distributions and variabilities were assessed and summarised with traditional hydrological analytical techniques such as flow duration curves, frequency analyses and measures of dispersion in order to determine the natural proneness of the Thukela catchment to water scarcity.

The Water Poverty Index, WPI (Sullivan *et al.*, 2002), is a sophisticated tool. It is gradually gaining acceptance and it can be used to facilitate local, regional, and international comparisons of water resources and allocation. While the utility of this index is in determining, at different scales, where the most serious water resource problems are likely to occur (Sullivan *et al.*, 2002), its application at catchment scale was, at the time of writing (April 2005), still limited to a single water poverty targeting study by Cullis and O'Regan (2004). An analysis of the applicability of this index at meso-catchment scale, i.e. *Objective C* of the research (cf. **Table 1**), is presented in **Chapter 6**. This analysis is crucial because it attempts to address lingering concerns about the conceptual validity of assessing socio-economic issues, which form key components of the index, in hydrologically derived spatial units such as catchments and subcatchments.

Chapter 7 consists of detailed descriptions of the data and the procedures which were followed in order develop appropriate indicators for, as well as the actual computation of, the WPI in the Thukela catchment. This is also forms a part of *Objective D,* which supplements the aspects covered in Chapter 3. **Chapter 8** contains detailed discussions on the findings of this study in relation to both study area specific, and general policy, implications. This chapter also contains conclusions and recommendations for future research emanating from this study.

2 WATER SCARCITY AND WATER POVERTY AND THEIR MEASUREMENT: A REVIEW OF LITERATURE

Water scarcity and poverty, as well as their associations and quantifications, are subjects of numerous recent studies and commentaries, e.g. WHO (1996), UNFPA (1997), World Bank (2001), Gleik *et al.* (2003) and Molle and Mollinga (2003). However, often in many of these studies, either water or poverty issues are investigated separately, without focussing on the interface between the two. This interface therefore presents a knowledge gap, and one which requires dedicated research in order to bridge. Molle and Mollinga (2003) concede that the link between water and poverty is complex and difficult to measure directly. Hence, indirect measures, such as indicators and indices, are increasingly viewed as suitable tools for characterising and quantifying the water scarcity-poverty association. However, discourse on the value of indicators in this regard is hampered by the lack of unified understanding of water scarcity. Water scarcity is often confused with similar concepts such as water stress, water shortage and water poverty. Therefore, this chapter attempts to establish common understanding of the concept of water scarcity and its link to poverty through a review of recent relevant literature. The sections on indicators and indices explore designs, development procedures, advantages and limitations of these tools in general, and in the context of describing and quantifying water scarcity and the water-poverty link. Currently, climate change and its envisaged impacts on water resources availability are topical issues, which are also relevant in the dialogue on water scarcity. Therefore, this chapter includes a brief review of climate change and its possible implications on water scarcity. In order to place water scarcity in perspective in the South African context, a case study which consists of a review of water issues in South Africa is also included in this chapter.

2.1 The Role of Water and Water Scarcity in Development

Water is an important natural resource. It is the basis of life on earth, is the primary component of environmental functioning and is essential for human beings. Water is also fundamental for sustaining a high quality of life and for economic and social development (Shiklamanov, 2000). Throughout the history of humankind, water has always played a significant role in the development of societies. Early civilizations developed in regions with fertile land and adequate water supplies, and agriculture was established in those regions over a period of time (Chaturvedi, 2000). The role of water in historically more recent developments is conspicuous as an essential input or infrastructure resource to many agriculture, energy production, industrial manufacture, mining, water transport and water-based recreation industries. One of the consequences of the economic development and the improvement in the quality of life is the demand for even more water (Engelman and Leroy, 1993; Shiklamanov, 1997, UN, 1997). Winpenny (1994) states that while water scarcity has its roots in water shortage, it is also partly a product of affluence, expectations and customary behaviour.

Freshwater resources are finite. While the hydrosphere contains vast amounts of water estimated at 1 386 million cubic kilometres (Korzoun, 1978), only about 2.5% of that is freshwater, and most is largely unavailable for human use (Duddin and Hendrie, 1988; Falkenmark, 1994). The reason for this is that of the total freshwater stock on the earth, 68.7% is in the form of ice and permanent snow cover in the Antarctic, Arctic and mountainous regions; 29.9% is groundwater; and only 0.26% concentrated in river systems, reservoirs and lakes. The latter water sources are the most readily accessible for economic needs and are very important for aquatic ecosystems (Shiklamanov, 2000).

Population growth, the emergence of newly industrialising economies and the increasing pressures of international competition for water by riparian states are producing ever-increasing demands for the supply and management of the water resources. The continuously increasing demand for a finite resource implies that at some stage failure to meet the demand fully is inevitable. As of 1995, 31 countries with a combined population of over 458 million, faced either "water stress" or "water scarcity" (Engelman and Leroy, 1995). By 2050, the number of countries facing water stress or water scarcity is estimated to rise to 54, and their combined population to 4 billion, or 40% of the projected population of 9.4 billion (Gardner-Outlaw and Engelman, 1997; UNFPA, 1997).

The projected shortage of water will have profound impacts on human wellbeing. Water scarcity is increasingly perceived as a limiting factor for both agriculture and industry in developing countries. It is a probable future source of conflict between countries over a renewable resource, and is a source of increasing competition between rural agricultural areas and the urban industrial sector (Ohlsson, 1998). Ohlsson (1998) also states that water scarcity is conventionally perceived as a natural resource scarcity, and thus also as an absolute limit for development. Water can also be viewed as a commodity, the availability of which is a very real limit-to-growth upon economies (Johnston, 1999).

A link can also be mapped between poverty and water shortage. Water scarcity is both a cause and consequence of poverty (Abrams, 1999). Barker *et al.* (2000) state that poverty persists in the so-called marginal areas (e.g. arid with soils which are agriculturally unproductive and highly susceptible to erosion), most of which can be described as water scarce. **Table 2.1** provides a summary of the sectoral impacts of water shortage.

Table 2.1 Linkages between water and poverty (after World Bank, 2001)

Poverty dimension	Key Effects
Health	Water and sanitation-related diseases Stunted growth from diarrhea-caused malnutrition Reduced life expectancy
Education	Reduced school attendance due to ill health Water collection duties (girls)
Gender and social inclusion	Water collection burden borne disproportionately by women Limitations to women's entry into cash economy
Income/consumption	High proportion of budget used on water Reduced income earnings due to poor health Too much time spent collecting water Lack of opportunity for businesses requiring water inputs

The role of water in poverty alleviation is recognised by many analysts. Water resources development is very important for developing countries, where water for food and rural development has a dominant place (Chartuvedi, 2000). Therefore, growing scarcity and competition for water stands as a major threat to future advances in poverty alleviation (Barker *et al.*, 2000). The importance of water in poverty alleviation is also recognised in major international poverty alleviation initiatives and declarations. The Accra Declaration, which outlines Africa's primary water challenges and recommendations for action, recognises that "water can make a difference in African development ... reducing the proportion of population without access to basic water and sanitation…." (Africa Water Task Force and Local Organizing Committee, 2002). A review of the UNDP's Millennium Development

Goals reveals that seven of the eight Goals directly or indirectly involve water. The goals that involve water are shown in **Table 2.2**. The ways in which some of these goals (e.g. those that relate to education, health and equality) are linked with water are summarised in **Table 2.1**.

Table 2.2 Water-related Millennium Development Goals and Targets that 189 United Nations Member States pledged to meet by the year 2015 (after UN, 2000)

Sector	Goals	Targets
Food Security	Halve extreme poverty and hunger	Halve, between 1990 and 2015, the proportion of people whose income is less than 1US$ a day. Halve, between 1990 and 2015, the proportion of people who suffer from hunger.
Education	Achieve universal primary education	Ensure that, by 2015, children everywhere, boys and girls alike, will be able to complete a full course of primary schooling.
Equality	Promote gender equality and empower women	Eliminate gender disparity in primary and secondary education, preferably by 2005 and to all levels of education no later than 2015.
Health	Reduce under-five mortality by two-thirds	Reduce by two-thirds, between 1990 and 2015, the under-five mortality rate.
	Reduce maternal mortality by three-quarters	Reduce by three-quarters, between 1990 and 2015, the maternal mortality ratio.
	Reverse the spread of HIV/AIDS, malaria and other diseases	Have halted by 2015, and begun to reverse, the spread of HIV/AIDS. Have halted by 2015, and begun to reverse, the incidence of malaria and other major diseases.
Environment	Ensure environmental sustainability	Integrate the principles of sustainable development into country policies and programmes and reverse the loss of environmental resources. Halve, by 2015, the proportion of people without sustainable access to safe drinking water. By 2020, to have achieved a significant improvement in the lives of at least 100 million slum dwellers.

2.2 Definitions and Dimensions of Water Scarcity

Water scarcity is a term which is commonly used to describe a situation where there is not enough water to satisfy "normal" requirements. According to Winpenny (2001), this common-sense definition is of little use to policy makers and planners because it does not capture varying degrees of scarcity (e.g. absolute, seasonal, temporal, or cyclical). Winpenny (2001) concedes that defining water scarcity for policy making is difficult. An equally daunting task is trying to understand the volumes of literature on water scarcity. Terms such as water scarcity, shortage, and water stress, and the recent addition of water poverty, are commonly used interchangeably, yet they each have specific meanings. Different articles (e.g. FAO, 1995; Winpenny, 2001 and Sullivan *et. al,* 2002) make the following distinctions:

- *Water shortage*, or absolute shortage, refers to low levels of water supply relative to minimum levels necessary for basic needs. It can be measured by annual renewable flows (in cubic metres) per head of population, or its reciprocal, *viz.* the number of people dependent on each unit of water (e.g. millions of people per cubic kilometre of water).
- *Water scarcity* is an imbalance of supply and demand under prevailing institutional arrangements and/or pricing structures. It can be perceived as an excess of demand over supply, or a high rate of utilisation compared to available supply, especially if the remaining supply potentials are too difficult or costly to tap. This is a relative concept which is not easy to capture in single indices (Winpenny, 2001).
- *Water stress* is the manifestation of water scarcity or shortage, e.g. the growing conflict between users and competition for water, declining standards of reliability and service, harvest failures and food insecurity. Water stress is also difficult to capture in numbers, but a checklist approach can be used (FAO, 1995).
- *Water poverty* refers to the unavailability of sufficient water to meet existing needs because of the lack of, or incapacity to mobilise, resources (e.g. human, financial) in order to address a water shortage or scarcity (Sullivan *et al.*, 2002).

Also making a contribution towards the understanding of water scarcity are Molle and Mollinga (2003), who distinguish between types of scarcity according to its common causes. They identify five constraints and define the dimensions of water scarcity in relation to the measures that can be adopted in order to combat or redress it, as follows:

- *Physical scarcity* corresponds to absolute scarcity, whereby the water sources that are available are limited by nature. This is a common situation in semi-arid and arid areas.
- *Economic scarcity* is the impossibility to cater to one of the above water needs or uses because of the incapacity to commit human resources (e.g. labour and time

needed to procure water from very distant wells) or financial resources (e.g. payment for water) to access water.

- *Managerial scarcity* may occur because water systems are not properly maintained or managed, e.g. reservoir carry-over stocks may not be considered, aquifers may have been depleted, irrigation schemes may be wasteful of water, or water distribution networks are leaking. Improper management therefore induces this scarcity, since users who should normally receive water fail to be served properly.
- *Institutional scarcity* is a more subtle dimension of induced scarcity, signifying a society's failure to deal with rising supply/demand imbalances and to preserve the environment. Water shortages can be partly ascribed to the inability to anticipate such imbalances and to supply adequate technological and institutional innovations. This may also include (although it is linked to managerial scarcity) third-party impacts, i.e. water problems may be experienced by some downstream users because upstream patterns of land and water use have changed and now impact on downstream access to water (in quantity and/or quality).
- *Political scarcity* occurs in cases where people are barred from accessing an available source of water because they are in a situation of political subordination.

2.3 The Use of Indicators to Measure Water Scarcity

There has been an increasing international interest in the use of indicators to reflect a variety of issues. Generally, the growing interest is a result of pressures for both summative and formative evaluations (James, 2000). Popular global initiatives such as the United Nations Commission on Sustainable Development (UNCSD), in Chapter 40 of Agenda 21 (UNCSD, 1992), advocate the development and strengthening of local, national and international monitoring systems and databases in order to bridge the information gap and improve information availability, and stress the importance of moving towards sustainable development. This has resulted in measurements and monitoring programmes that yield large volumes of data. These raw data often provide little in terms of information that can readily be used by decision makers. Therefore, the data need to be synthesised and summarised into indicators that reveal trends. The development and use of indicators in order to determine progress towards sustainability goals is encouraged explicitly in Chapter

40 of Agenda 21 (UNCSD, 1992). From a perspective of the water sector, the interest follows the intuitive understanding of the importance of adequate, clean water to overall human wellbeing. Although the link between water and wellbeing is apparent, it is not easy to measure with traditional techniques. Therefore, indicators become important tools for measuring emerging water-related issues such as quality of life water scarcity, which are impossible (or prohibitively difficult) to measure using more conventional methods.

Indicators have become essential tools to policy makers (EEA, 1999). Therefore, the large numbers and wide varieties of indicators presently in use are not surprising. However, it is becoming more and more difficult for policy makers to grasp the relevance and meaning of the environmental indicators, given their numbers and diversity of use. Moreover, new sets of environmental indicators are almost certain to still be formulated. Therefore, the following sections review the design, development and application of water-related indicators to measure various aspects of human and ecosystem wellbeing, again with relevance to water. This review aims at promoting an informed and relevant choice, and appropriate use of indicators.

2.4 Definitions and Frameworks for Indicator Development

2.4.1 Definitions of Indicators

The choice and use of suitable indicators are not the only challenges associated with their recent proliferation. Terminological confusion arising from casual and interchangeable use of related terms such as variables, indicators and indices can confound the problem to inexperienced users of indicators. Several writers have made efforts at unambiguously defining these terms.

A *variable* is a characteristic or attribute of an object, phenomenon or event that may exhibit different values which are collectively known as data (Pintér *et al.*, 2000). *Data* are the primary, raw output of monitoring systems, surveys and other forms of measurement. They should preferably be stored as time series, and usually require analysis to be meaningful to the audience (Pintér *et al.*, 2000). Ott (1978) defines an *indicator* as a single number that is derived from a variable's values, and an *index* as a single number that is a mathematical aggregation of two or more indicators. A

Chambers Dictionary definition of an indicator is "... something that provides an indication or pointer – any device for exhibiting the conditions for the time being". The Organization for Economic Cooperation and Development (OECD) defines an *indicator* as a parameter, or a value from parameters, which provides information about a phenomenon and its (i.e. the indicator's) significance extends beyond the properties directly associated with the parameter value (OECD, 1993). Building on the previous definitions, Gleick *et al.* (2003) state that indicators are qualitative or quantitative measures, typically tracked over time, that provide information about the conditions of a system, or phenomenon. UNEP/RIVM (1994), cited by von Schirnding (2002), defines an indicator as a piece of information which is part of a specific management process and has been assigned a significance beyond its face value.

The main functions of indicators are to quantify information so that its significance is more readily apparent, and to simplify information about complex phenomena in order to improve communication (Peterson, 1997). It can be established from the definitions above that indicators add value to data by converting them into information that can be used directly to inform decision making. **Figure 2.1** illustrates the progression from data to readily usable information that can be displayed using indicators. The narrowing of the rungs from the initial broad measurement stepping up to the apex at the decision making stage, signify decreasing quantities of information, or loss of detail, with increasing synopsis and integration (Australian Department of the Environment, Sport and Territories, 1994; Briggs, 1996). Indicators are useful as management, research, educational and motivational, project assessment, as well as planning and policy tools (van Loon *et al.*, 2005), in a variety of fields such as economics, ecology, water resources and health at sectoral, local, national, regional or global levels (Hammond *et al.*, 1995). Different types of information can be displayed using different indicators, and these are organised and summarised into categories using their construction frameworks. The following sections discuss the frameworks on the basis of which indicators are developed and organised.

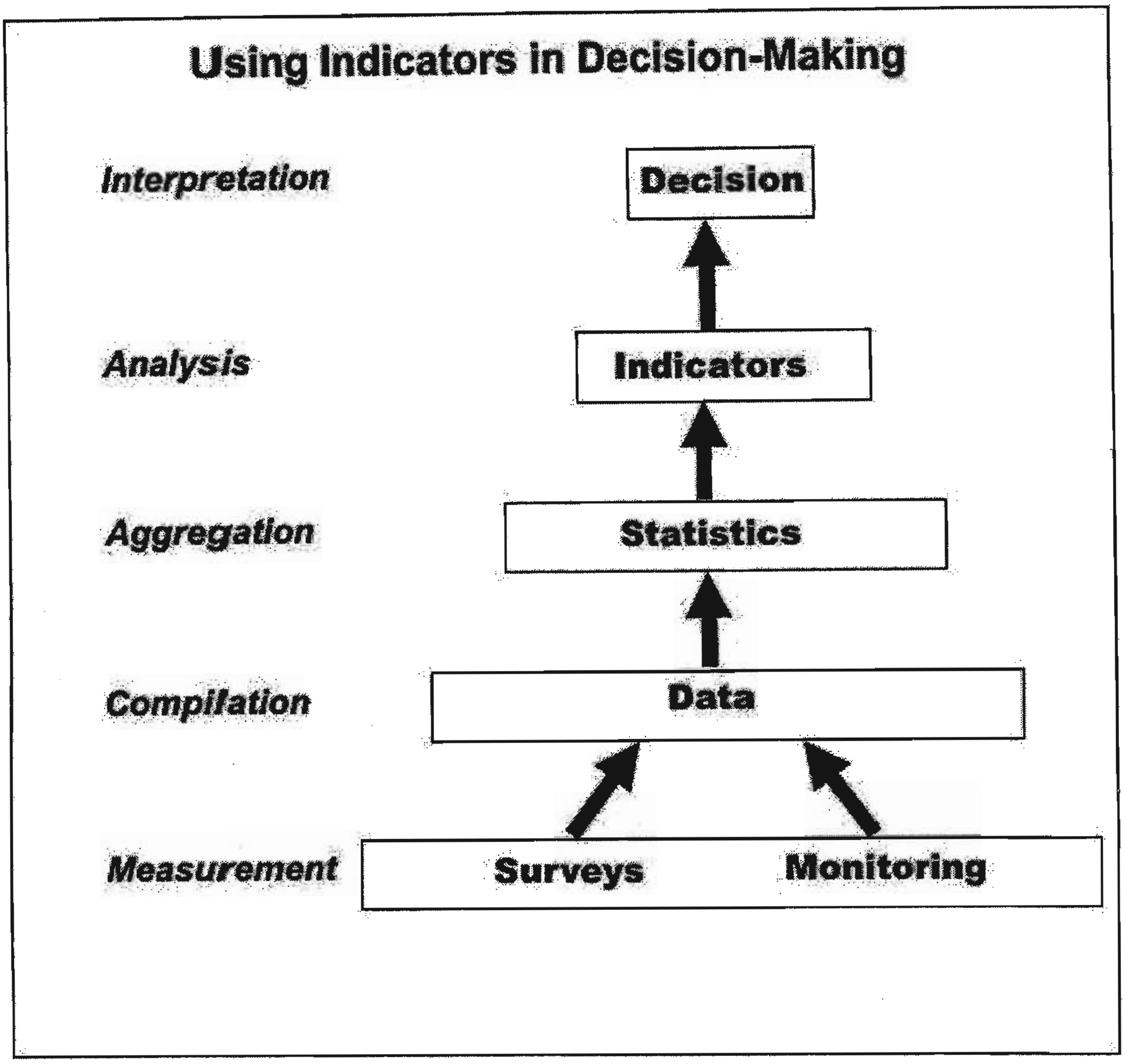


Figure 2.1 The use of indicators in decision making (after Briggs *et al.*, 1996)

2.4.2 Frameworks for the Development of Indicators

There are several frameworks around which indicators are developed and organised. Generally, the preferred framework depends on the purpose of the indicators to be generated, which may change over time as the scientific understanding of systems increases and societal values evolve (OECD, 1993). The choice of a framework may also be influenced by the field of application. Frameworks which are commonly used in environmental and sustainable development assessments are discussed in the subsections which follow.

2.4.2.1 The Pressure-State-Response Framework (PSR)

The Pressure-State-Response framework presented in 1993 by an OECD group working on the State of the Environment summarises indicators in the three categories (**Figure 2.2**). This framework is based on a concept of causality, i.e. human activities exert pressures on the environment, and change its state (quality and quantity of natural resources).

Society responds to the changes in environmental, economic and sectoral policies. Therefore, pressure indicators measure activities or processes that have a potential to change the status of a system negatively, state indicators measure the prevailing system conditions at a particular point in time, and response indicators describe measures implemented to counteract the pressure or to improve the adverse state. In terms of time, the three types of indicators can be thought of as measures of the past, present and future (van Loon *et al.*, 2005). Pressure indicators show what has been, and continues to be, done to generate a given situation, while state indicators describe the present status. Response indicators show what is being done to achieve future improvement.

2.4.2.2 The Drivers-Pressures-States-Impacts-Responses Framework (DPSIR)

The European Environment Agency (EEA) proposed Drivers-Pressures-States-Impacts-Responses (DPSIR) as a framework for developing and categorising indicators (EEA, 1999). Like the PSR, the DPSIR follows a systems approach to analyse the interactions between the environment and human systems (**Figure 2.3**).

Social and economic developments exert pressure and change the state of the environment. This leads to impacts on human wellbeing, ecosystems and materials which may trigger societal responses that feed back on the driving forces, or on the state, or impacts directly through adaptive or curative action. The DPSIR approach can find application in the water resources planning and management arena. McCartney *et al.* (2000) and Schulze (2003) present an adaptation of this approach to describe and structure the feedbacks and feed forwards from the interaction of society and the hydrological system.

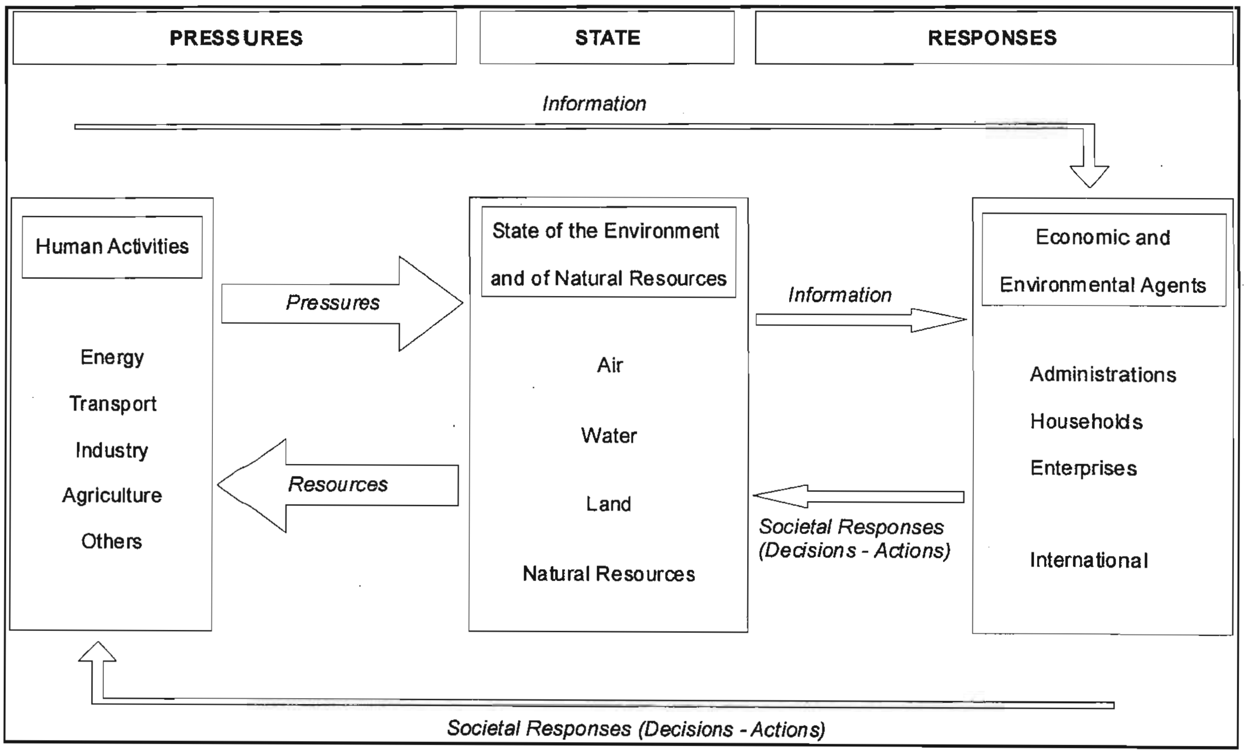


Figure 2.2 The Pressures-State-Responses Framework (OECD, 1993)

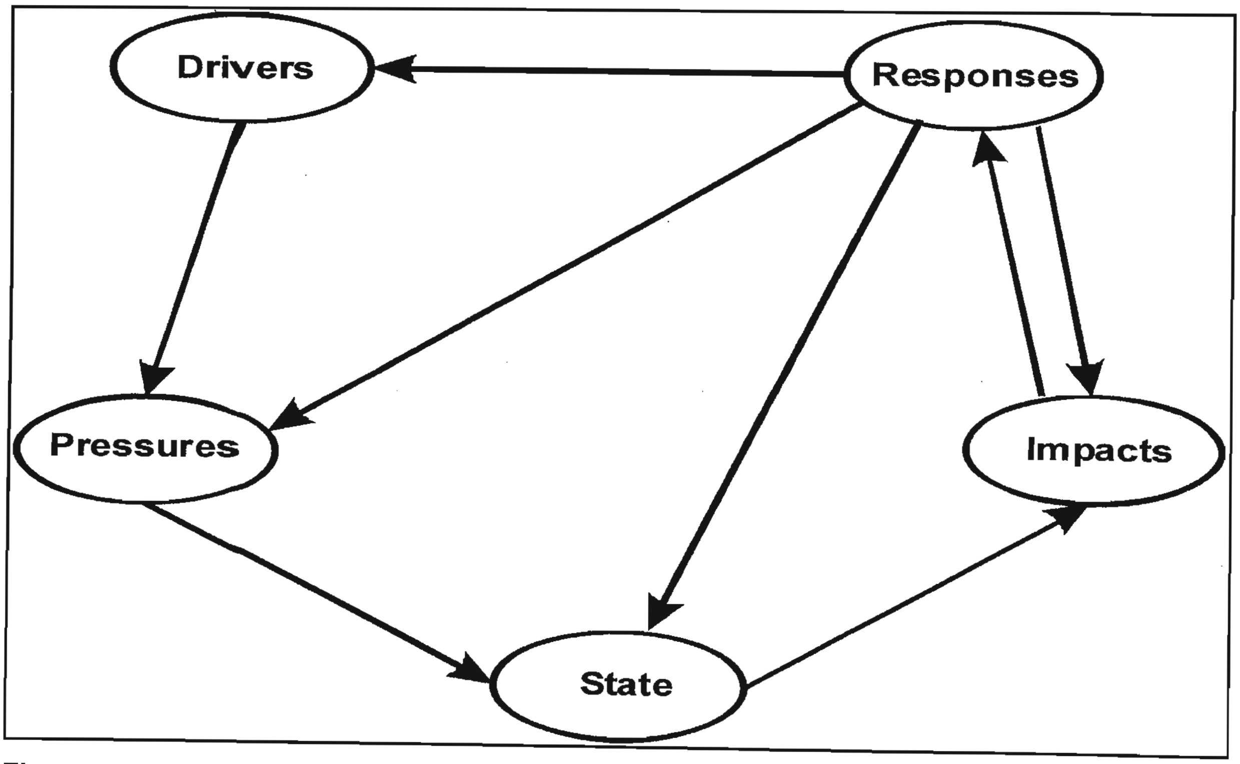


Figure 2.3 The Drivers-Pressures-States-Impacts-Responses Framework (EEA, 1999)

Examples of the driving forces, pressures, states, impacts and responses which are related from the water sector are summarised in **Table 2.3**.

While the PSR and DPSIR approaches attempt to be systematic, Bossel (1999) states that the fact that they identify isolated chains of cause and effect for a particular environmental problem, and corresponding indicators are monitored, leads to the neglect of the systemic and dynamic nature of the processes, as well as their being embedded in a larger total system containing many feedback loops.

Table 2.3 Changing hydrology at the river basin scale structured in terms of the DPSIR approach (Schulze, 2003 with adaptations from McCartney *et al.*, 2000)

Driving Forces	Pressures (i.e. causes of hydrological changes)	States (of hydrology: past, present, future)	Impacts (+ or – results of change)	Responses (international, national, local, institutional)
Inter-seasonal climate variability Greenhouse gas forcing Rising population Rising security expectations State subsidies and directives International market forces	Regional climate change Local land use change Channel manipulation (dams, channel modifications) Catchment water management Rural-urban migration	Rivers: quantity Rivers: seasonality Rivers: quality Groundwater Wetlands Reservoirs Lakes	Degradation of ecosystems Loss of water rights Increased need for reliable water supply Amplification of climatic extremes	Agenda 21 Johannesburg WSSD ICM/IWRM as legal instrument New management strategies New research directions Ecosystem rehabilitation Modelling

"The representation of impact chains by isolated DPSIR-chains will usually not be permissible, and will often not even be an adequate approximation. Impacts in one causal chain can be pressures, and in another can be states, and vice versa. Multiple pressures and impacts are not considered. The real, usually non-linear relationships between the different components of a chain cannot be accounted for. States and rates of change (stocks and flows) are treated inconsistently" (Bossel, 1999:14).

2.5 Types of Indicators

Indicators may be classified in many ways, for example, according to whether they are quantitative or qualitative, single-factor or composite, or according to what they are designed to measure. The choice of the suitable typology of indicators varies according to the preferences of different institutions and organisations. The most common typologies are discussed in the following sections.

2.5.1 Quantitative and Qualitative Indicators

Indicators may be classified broadly as quantitative or qualitative. The distinction between quantitative and qualitative indicators is that the former measures quantities while the latter give an indication of peoples' judgments, perceptions and opinions. This classification is simplistic and thus conceals the complexity and the uncertainty that may arise from the ways in which these two types of indicators are used (CIDA, 1997). Qualitative indicators are often confused with quality of life indicators because both of these indicators bear the term "quality". CIDA (1997) presents two ways by which quantitative and qualitative indicators may be distinguished.

First, these two classes of indicators may be differentiated by their source of information. Because quantitative indicators focus on areas that are easy to quantify, their information is often drawn from actual measurements obtained using physical measuring tools or counts from formal surveys such as censuses, enumerations and administrative records. On the other hand, because peoples' perceptions, opinions and judgments are not easy to measure, qualitative information is obtained from less formal surveys such as public hearings, attitude surveys, interviews, participatory rural appraisals, questionnaires, participant observations and sociological or anthropological fieldwork (CIDA, 1997).

Second, qualitative and quantitative indicators may be differentiated according to the way in which they are interpreted and used. Because of the formal way by which their information is drawn, quantitative indicators are usually analysed and interpreted using formal methods such as statistical tests, and the results of such tests are then used to suggest, for example, changes in policy. Although they are subject to quantification, qualitative indicators are often presented as descriptive statements rather than as statistics (CIDA, 1997).

Because quantitative indicators are derived from "cold" and "hard" facts and rigid numbers, they are more likely believed to be valid, truthful, objective and verifiable (CIDA, 1997). Quantitative indicators deal with outputs and are easier to define than qualitative indicators. Qualitative indicators, on the other hand, are seen as subjective, less reliable and difficult to verify because they deal with peoples' perceptions which are generally difficult to measure. However, these generalisations should not be confused with the usefulness of qualitative indicators. They are invaluable for the evaluation of the long term effects and benefits of projects or initiatives to communities. Therefore, they can be said to be measures of impacts (CIDA, 1997).

Kothari (2000) suggests that the lack of capacity among organisations to perform systematic qualitative data collection, analysis and synthesis is the main obstacle to increased use of qualitative analysis. It is probable that the combination of the suspicions about the reliability (CIDA, 1997) and the lack of expertise on qualitative indicators (Kothari, 2000) is the cause of the application of quantitative indicators to "essentially qualitative objectives" (Kothari, 2000:14). However, the validity and reliability of all indicators is not determined by whether they are qualitative or quantitative, but rather by their careful design, the use of reliable data and correct interpretation. By their nature, all indicators, both quantitative and qualitative, are fraught with value judgements, assumptions and implicit biases (CSLS, 2001; Gleick *et al.*, 2003). Therefore, complementarities and cross-validation of qualitative and quantitative indicators should be taken advantage of, as one type measures important aspects which are not addressed by the other (Jodha, 1989).

2.5.2 Composite Indicators

A composite, or integrative, indicator may consist of a single factor (i.e. simple index) or an amalgam of more than one factor (i.e. aggregated index). Single-factor indicators use a single data type or variable to measure the combined, or additive, effect of different factors to a condition, without identifying any specific one (van Loon *et al.*, 2005). They are also known as proxies because they give a measure of something that is not easy to measure using conventional methods (Gleick *et al.*, 2003). Single factor indicators or indices are developed by taking a single piece of information, or variable, that has known relationships with a number of other factors. Such composite indicators measure the additive effect of all the possible contributing factors to a condition, without analysing them individually. Examples of proxy indicators are GDP for measuring the level of development of a country, infant mortality rates for measuring the health of a community, or monetary wealth for judging an individual's happiness. A certain amount of money can express the ability to buy food, build a house, educate children, pay for healthcare and support oneself in old age. The main limitation of single-factor indicators is that they cannot capture all vital aspects of a phenomenon, such as sustainable development (Bossel, 1999). For example, when used as a measure of happiness, monetary wealth cannot account for personal tragedy or disability (Bossel, 1999).

Aggregated indices combine many pieces of individual data in a well-defined procedure in order to produce a single number that is an aggregate, or average, of all the data. Indices attempt to provide integrated assessments of complex systems. The main advantage of composite indicators is that they cover more aspects of a phenomenon, and may be readily understandable to policy makers and the public (van Loon *et al.*, 2005), especially at macro level (Pintér *et al.*, 2000). Aggregate indices are important in making macro-policy and giving a view of overall progress, but they serve their purpose only if their calculation and the underlying assumptions are apparent (Pintér *et al.*, 2000). Because they summarise a number of measures, indices overcome the difficulty in detecting trends based on a multitude of singular statistics (Ekos Research Associates Inc., 1998). Aggregated indices also improve comparability of across units (Gleick *et al.*, 2003). An index should be readily disaggregated to its components that may help find the specific reasons for the index going up or down and also answer questions of interest to decision makers working on lower scales (Pintér *et al.*, 2000).

Aggregate indices are an improvement on single-factor indicators, but the aggregation can conceal serious deficits (Bossel, 1999). Gleick *et al.* (2003) lists a number of these limitations, and these include:

- the difficulty of weighting diverse parameters which may often include measures that do not utilise the same units;
- the difficulty of interpreting over time a single number because of the many aspects that may influence it;
- the difficulty in discerning these influences in a single number and the difficulty in comparing results across units when the influential indicators may be different for different locations or countries;
- the subjectivity of the aggregation process which, according to Gleick *et al.* (2003:94), makes their development "an art rather than a science"; and
- the difficulty of choosing indicators to be included in the index.

Other disadvantages of indicators include the fact that the many methods of assigning weights to the components are subjective and, therefore, a specific form of aggregation may override the simplicity (the major advantage of weighting) by harbouring biases of the constructors of indices (CSLS, 2001). Correlations, dependencies and relationships may exist among various indicators, which may not be apparent to users who have not constructed the indicator (Gleick *et al.*, 2003). Because composite indicators may not relate directly to specific and measurable conditions, they may be difficult to test or verify (von Schirnding, 2002). The effects of the individual components and significant trends in an underlying component may be masked by other components (von Schirnding, 2002).

When assessing the limitations of indicators from a slightly different perspective, van Loon *et al.* (2005) suggests that the likelihood of loss of important pieces of information in the single aggregate value should not be viewed entirely as a disadvantage if the indicator is used for its true purpose, which is to point to the broad substance of the issue under investigation. The integrative indicator is a starting point that calls for a search to obtain further information (van Loon *et al.*, 2005).

By their nature, composite indicators attempt to capture a wide range of dimensions of a system. This often leads to the wrong perception that the more comprehensive they are, the better. However, certain comprehensive composite indicators such as the International Human Suffering Index, (Population Action International, 1987) tend to be controversial and least used. This index includes notions of personal freedom, which are difficult to measure. Comprehensiveness may then be an "enemy of effectiveness" (Cobb and Rixford, 1998:18).

2.5.3 The European Environment Agency Typology

The European Environment Agency (EEA, 1999) has developed a useful typology of indicators, whereby indicators are grouped into four classes: descriptive, performance, efficiency and total welfare.

2.5.3.1 Descriptive Indicators

Descriptive indicators describe the prevailing situation with regard to issues of interest in relation to the geographic levels at which they manifest themselves (EEA, 1999). They provide information about the overall state of a system and highlight factors that affect it. They are not linked to explicit objectives (OECD, 2003). They can be useful in obtaining baseline information on which to formulate subsequent policy options and plans, and to assess trends (von Schirnding, 2002). While descriptive indicators are essential building blocks, they state nothing about the importance, or significance, of whatever trends they illuminate (EU, 2005).

2.5.3.2 Performance Indicators

Performance indicators are linked to a reference value, or policy target, illustrating how far the indicator is from the desired level. They measure the distance between prevailing and desired situation. The strength of performance indicators is that they are benchmarked and thereby capable of conveying clear messages about policy performance, while running a lesser risk of misinterpretation and misuse (OECD, 2002). Their major limitation is that they are often so closely linked to specific policies that they will lose their continuity (and therefore significance of time trends) when policy is changed. Their relevance is highest at local and national scale, particularly if specific groups or institutions may be held responsible for changes in environmental pressures or states (EEA, 1999).

2.5.3.3 Efficiency Indicators

Efficiency indicators illustrate efficiency of production and consumption processes. They express the relationship between separate elements of the causal chain. These indicators provide insight into the efficiency of products and processes in terms of the resources used, and reflect on whether or not improvements are made. Efficiency indicators are particularly useful in measuring progress in "mainstreaming" environmental considerations into sectoral policies (EU, 2005).

2.5.3.4 Total Welfare Indicators

Total welfare indicators aggregate together economic, social and environmental dimensions in order to illustrate whether overall welfare is increasing or not. They tend to be the most highly aggregated indicators and, hence, they take the form of an index. Because of their high level of aggregation, total welfare indicators reflect the impacts of a wide range of different sectors and policies, and usually focus on entire countries. Total welfare indicators are unlikely to be of immediate relevance to programme or project managers (EU, 2005).

2.5.4 Attributes of Good Indicators

A wide variety of indicators is presently in use and new ones are continually being, or will be, developed. The number and diversity of indicators make choosing the right indicators a difficult task for both developers and users. The suitability of indicators may differ in different situations. While the specific characteristics of good indicators will be different in each community and programme, there are some general attributes and/or standards which good indicators should meet. Good indicators should be credible, relevant, sensitive, comparable, easy to understand and affordable

2.5.4.1 Credibility

Among other factors, the decision to choose and effectively use an indicator is influenced by its trustworthiness. In order for indicators to be credible, they should be defined in a way that is conceptually clear (Cobb and Rixford, 1998), be universally understood and be grounded in accepted practice, scientific theory and/or reliable local knowledge (Riely *et al.*, 1999). This is especially important for the understanding and acceptance of proxy indicators, which are indirect measures that provide information about conditions that are more difficult to measure. Credible indicators must also be based on good quality data which has been collected using sound methods. Even the most sophisticated sounding indicators are only as good as the quality of the original data collected.

2.5.4.2 Relevance

Relevant indicators provide information that is directly linked to the system. They fit the purpose for measuring, or saying something about what needs to be known.

2.5.4.3 Sensitivity

Indicators should be sensitive, i.e. responsive enough to detect changes of the measured attributes over time between an initial (baseline) measurement and subsequent (follow-up) measures. Time-insensitive indicators may be a result of choosing variables that are static, i.e. not changing over the period of measurement. Good indicators should also be able to detect the differences between groups, which are often hidden within those groups by aggregation.

2.5.4.4 Comparability

Comparability is an important attribute especially when assessing the situation in different regions or the differences in performances between programmes or projects. In order for indicators to be comparable they must, first, be conceptually equivalent (Riely *et al.*, 1999). However, the definition and setting of thresholds (maximum and minimum) for indicators may vary in terms of both quantity and quality, as well as from country-to-country, thereby making those indicators incomparable. For example, different countries' poverty lines may reflect quite different standards of living. Differences in data collection methods for the same indicator may also limit the ability to compare indicators with any degree of confidence. The comparability of indicators can be improved by the standardisation of indicator definition and data collection methods.

2.5.4.5 Affordability

The cost of obtaining an indicator is typically related to the time, personnel, and logistics costs associated with data collection, processing, and analysis. The cost varies significantly by indicator and data collection method, and may have implications on the accuracy and credibility of the derived indicator (Riely *et al.*, 1999). For example, indicators derived from existing secondary data are relatively inexpensive, but are often difficult to disaggregate and link directly to specific needs of projects and programmes. On the other hand, relevant and reliable indicators may be developed from project-dedicated surveys, but at a typically higher cost than those indicators obtained from secondary data.

2.5.5 Lessons from Past Experiences for Improved Development and Use of Indicators

The choice of good indicators and their correct use are often difficult exercises. Past efforts have often met obstacles that have blocked progress in this field. In their review of the history of indicators, Cobb and Rixford (1998) outline lessons that can be learned from successes and failures of the past that, hopefully, can be used to improve present and future development and use of indicators. These lessons are listed below:

- Having a number does not necessarily mean one has a good indicator.
- Effective indicators require a clear conceptual basis.
- There is no such thing as a value-free indicator.
- Comprehensiveness of indicators may be the enemy of effectiveness.
- The symbolic value of an indicator may outweigh its value as a literal measure.
- Indicators should not be conflated with reality.
- A good indicator's development programme requires more than good public participation processes.
- Measurement does not necessarily induce appropriate action.
- Better information may lead to better decisions and improved outcomes, but not as easily as it might seem.
- Challenging prevailing wisdom about what causes a problem is often the first step to fixing it.

- To take action, look for indicators that reveal causes, not symptoms.
- One is more likely to move from indicators to outcomes if one has control over resources.

2.6 Water-Related Indicators and Indices

There has been a steady increase over the past decades in the interest on indicators of quality of life-related to water. This trend is a consequence of the need to quantify the link between access to adequate and safe water supply and human wellbeing. The quantification of this link, or the impacts of improved water supplies on socio-economic wellbeing, presents some challenges including those of combining different data types. The following sections discuss the design, development and application of some frequently applied water-related indicators. Much of the discussion is drawn from a review presented by Gleick *et al.* (2003).

2.6.1 Indicators of Access to Water and Sanitation Services

Indicators of access to drinking water and sanitation services have been the most commonly used and cited in the water field over a long period of time (Gleick *et al.*, 2003). Despite their extensive usage, the definitions of these indicators have been neither constant over time and nor uniform from one country to another. **Table 2.4** and **Figure 2.4** demonstrate that the differences in definitions of access to water among countries are not only by the variables used, but also by the thresholds chosen. Gleick *et al.* (2003) shows how the definitions of access to water have changed over the past few years.

The definitions that were used in the mid-1990s are detailed in the World Health Organization's status report (WHO, 1996). Coverage of safe drinking water was defined as "the proportion of population with access to adequate amounts of safe drinking water located within a convenient distance from the user's dwelling" (Gleick *et al.*, 2003:97).

Table 2.4 Definitions of "Access to Safe Drinking Water Source" (WHO, 1996)

Number of countries defining access as "Water sources at distance of less than…"									
	50 m	100 m	250 m	500 m	1000 m	2000 m	5 minutes	15 minutes	30 minutes
Urban	20	6	3	8	1	-	1	-	1
Rural	10	1	6	17	4	4	-	1	1

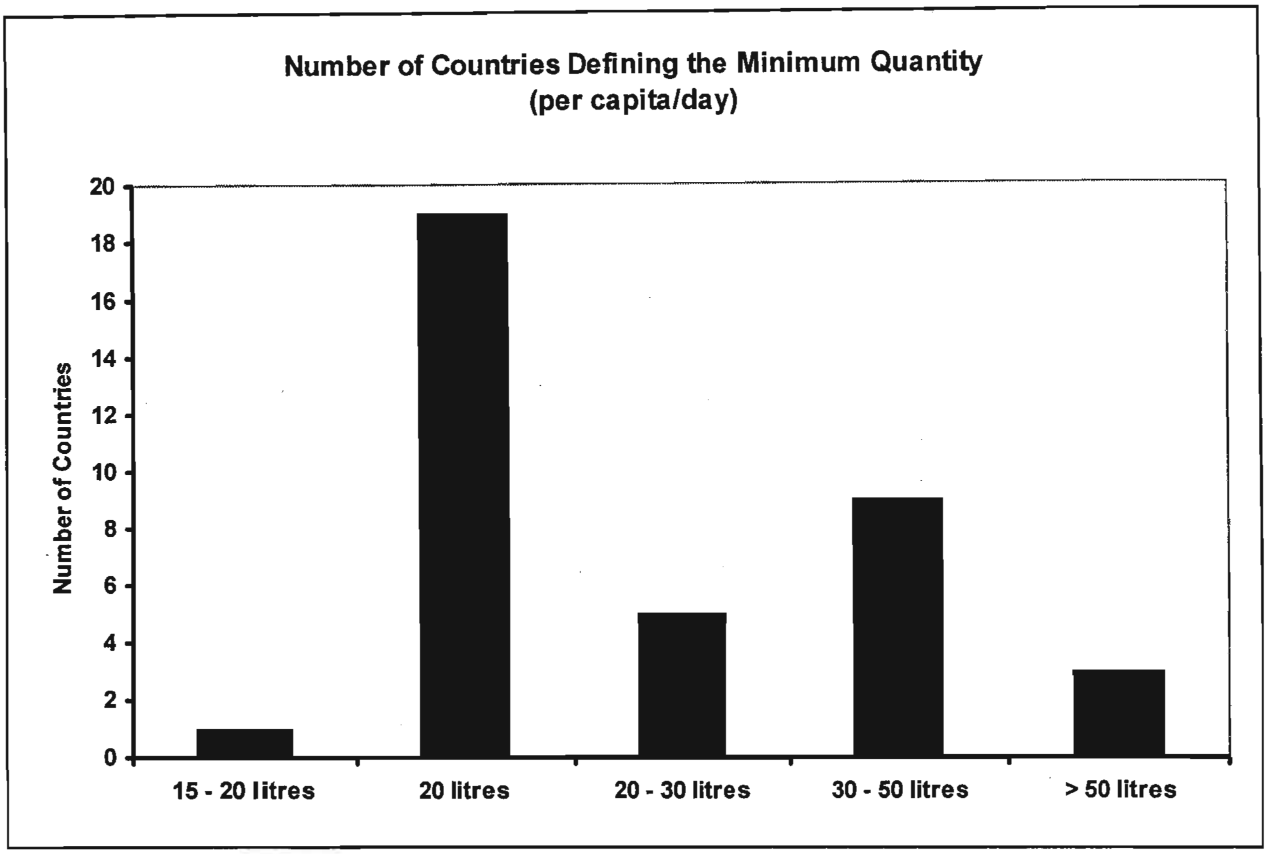


Figure 2.4 The number of countries defining a minimum quantity of water for rural inhabitants, per capita per day (after WHO, 1996)

Sanitation coverage was defined as the proportion of population with access to sanitary facility for excreta disposal in the dwelling, or located within a convenient distance from the user's dwelling. The terms "safe" and "adequate" are replaced with "improved" in the Global Water Supply and Sanitation 2000 Report (WHO, 2000a). According to Gleick *et al.* (2003), the new definitions assume that certain technologies are safer, or more adequate, than others, thus presenting technology as an indicator of improved water supply and sanitation. The coverage figures produced by the technology indicators do not provide information about the quality of the water provided or about its use (Gleick *et al.*, 2003).

The differences in definitions of access as an indicator of water wellbeing do not only limit any direct comparisons between countries or regions, but also make it difficult to make judgments on temporal trends (Gleick *et al.*, 2003).

2.6.2 Water Stress Index (WSI)

The Water Stress Index is an outcome of pioneering work initiated in 1974 by Prof Malin Falkenmark, a Swedish water expert. The WSI relates the amount of water available in a country to its population. The original version measures the number of people that can be supported by a country's or a region's natural endowment of water (Falkenmark and Lindh, 1974). Over the years, other researchers have inverted this to measure how much water is available per capita. In subsequent developments, and using Israel as a benchmark, Falkenmark (1990) identifies 2000 people as the maximum number of people that a developed society is able to support and manage per million cubic metres of water per year. Water stress thresholds (**Table 2.5**) were defined using 100 litres per capita per day for basic health and household needs. The WSI has been the most influential and powerful water index for the two decades of the 1980s and 1990s (Gleick *et al.*, 2003). Many individual practitioners (e.g. Engelman *et al.*, 2000) as well as institutions such as the Population Action International (PAI, 1993; 1997), have used the index to measure water-related quality of life.

Table 2.5 Definitions of water stress (after Falkenmark *et al.*, 1989)

$M^3 capita^{-1} annum^{-1}$	Category	WSI	Possible Symptoms
> 1700	Relatively water abundant	0 – 5	Seasonal and regional shortages
1000 – 1700	Water stressed	6 – 10	Periodic shortages
500 – 1000	Water scarce	11 – 20	Chronic shortages
< 500	Absolute water scarcity	> 20	Chronic shortages and tensions

Despite its popularity, the WSI has limitations which have been discussed by different authors such as Rijsberman (2004) and Gleick *et al.*, 2003). These limitations include:

- the assumption that water availability, measured as the total average annual renewable water resource of a country, is a suitable proxy of wellbeing, when it is only a measure of natural endowment, but one that does not provide any information about how the resources are mobilised or used;

- the inability to take into account the availability of infrastructure that modifies the availability of water to users;
- the assumption that water availability is constant over time, when it can vary considerable inter-annually and more so seasonally;
- the assumption that water is distributed uniformly over a country, when regional disparities can be enormous; and
- the exclusion of water in the form of precipitation that supports both natural and agricultural vegetation (so-called "green water"), because that water is seldom included in national water availability assessments.

2.6.3 The Social Water Stress Index (SWSI)

The WSI is often also criticised for not taking into consideration the capacity of countries to cope with absolute water scarcity. In an attempt to address this limitation, Ohlsson (1998) proposed a Social Water Stress Index. The SWSI is essentially a version of the WSI, whereby the WSI is adjusted by multiplying by the UNDP's Human Development Index (**Table 2.6**) as a proxy for coping capacity. The table shows that the number of people that can be supported by an amount of water, according to the SWSI is about double that which can be supported by the same amount of water when using the WSI. This highlights the possibility of augmenting the natural endowment of water resources, which is commensurate with the level of socio-economic wellbeing, in order to circumvent water stress (Ohlsson, 1998). A comparison of rankings of Southern African Development Community (SADC) countries according to their levels of water scarcity using the WSI and SWSI is shown in **Table 2.7**. The SWSI demotes poorer countries such as Malawi and Tanzania to higher stress categories than those according to the WSI. Although South Africa maintains the same category according to both indices, it is closer to the boundary of a lower stress category according to the SWSI than according to the WSI.

Table 2.6 Definitions of water stress and social water stress (after Falkenmark *et al.*, 1989; Ohlsson, 1998)

$M^3 capita^{-1} annum^{-1}$	Category	WSI	SWSI	Possible Symptoms
> 1700	Relatively water abundant	0 – 5	0 – 9	Seasonal and regional shortages
1000 – 1700	Water stressed	6 – 10	10 – 19	Periodic shortages
500 – 1000	Water scarce	11 – 20	20 – 29	Chronic shortages
< 500	Absolute water scarcity	> 20	> 29	Chronic shortages and tensions

Table 2.7 A comparison of the WSI and SWSI in SADC Countries for 1995 (after Ohlsson 1998)

Country	ARWPC	WSI	WSI Category	SWSI	SWSI Category
Angola	16 000	1	Relatively water sufficient	2	Relatively water sufficient
Botswana	10 138	1	Relatively water sufficient	1	Relatively water sufficient
Lesotho	2 476	4	Relatively water sufficient	9	Relatively water sufficient
Malawi	1 938	5	Relatively water sufficient	16	Water stressed
Mauritius	2 000	5	Relatively water sufficient	6	Relatively water sufficient
Mozambique	12 058	1	Relatively water sufficient	3	Relatively water sufficient
Namibia	28 438	< 1	Relatively water sufficient	1	Relatively water sufficient
South Africa	1 179	8	Water stressed	12	Water stressed
Swaziland	5 000	2	Relatively water sufficient	3	Relatively water sufficient
Tanzania	2 918	3	Relatively water sufficient	10	Water stressed
Zaire	22 506	< 1	Relatively water sufficient	1	Relatively water sufficient
Zambia	11 959	1	Relatively water sufficient	2	Relatively water sufficient
Zimbabwe	1 739	6	Water stressed	11	Water stressed

ARWPC – Available renewable water per capita per year

WSI – Water Stress Index (hundreds of people per million cubic metres of water)

SWSI – Social Water Stress Index (WSI divided by the Human Development Index)

2.6.4 Water Resources Vulnerability Index (WRVI)

The Water Resources Vulnerability Index was developed in 1997 by researchers at the Stockholm Environment Institute (SEI). It consists of three sub-indices, which may be made up of one or more other indicators. The three components are the Use-to-Resource Ratio Sub-Index, the Coping Capacity Sub-Index and the Reliability Sub-Index (**Figure 2.5**).

The Use-to-Resource Sub-Index measures the average water-related stress that both ecological and socio-economic systems place on a country's usable resources. The Coping Capacity Sub-Index measures the economic and institutional capacity of a country to deal with water-related stresses. The Reliability Sub-Index measures the levels of uncertainty of water supplies. This last sub-index is made up of three indicators.

All the indicators and sub-indices are subdivided in four classes of stress, *viz.* no stress, low stress, stress and high stress. In relation to the reliability, the indicators scores are then averaged to obtain the Reliability Sub-Index, and then all the sub-index scores are averaged to produce the WRVI. Raskin (1997) used the WRVI to assess the current and projected vulnerabilities of the water resources of countries.

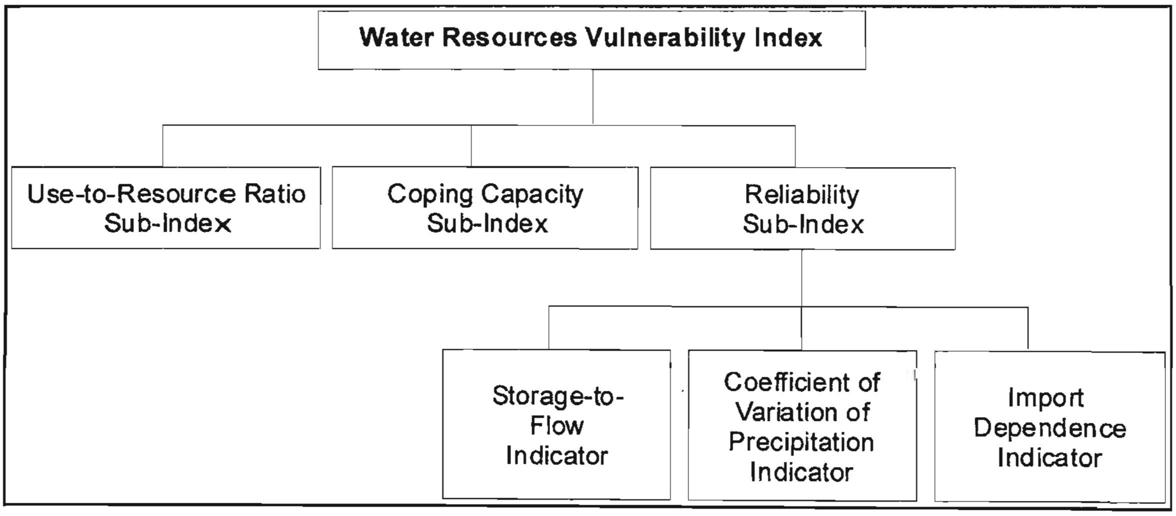


Figure 2.5 The SEI Water Resources Vulnerability Index (Raskin, 1997)

2.6.5 Indicator of Relative Water Scarcity (IRWS)

The Indicator of Relative Water Scarcity was developed by Seckler *et al.* (1998), researchers at the International Water Management Institute (IWMI). The IRWS is calculated from the percentage increase in water withdrawals over the 1990-2025 period and water withdrawals in 2025 as a percentage of the annual water resources of the country. Therefore, the IRWS measures the rate of increase of water use and the closeness of the use to the limit of total available water.

2.6.6 The Water Poverty Index (WPI)

The Water Poverty Index is one of the latest additions to the pool of tools for measuring water wellbeing. According to Prudhomme (2002), the development of the WPI was a response to a call, from the Department for International Development's (DFID), for the development of reliable measures of water wellbeing. This call followed a realisation that there was a shortage of generally acceptable quantitative measures for water assessment after the existing indicators were regarded as flawed for the purposes of rational, equitable and sustainable allocation (DFID, 2000). The Water Poverty Index is an interdisciplinary management tool, which integrates outputs from both the physical and social sciences, within a structured framework (Sullivan *et al.*, 2002). This index was designed as a tool for assessing poverty in relation to water resources. It links explicitly poverty, social deprivation, health, environmental integrity and water availability in order to enable policy makers to identify appropriate mechanisms to deal with the causes of these problems. The Water Poverty Index has five components derived from the main themes that address the link between water and human wellbeing (Sullivan, 2002):

- Availability of water **Resources** (physical limitations and natural conditions);
- **Access** to that water, through human ingenuity, natural conditions and social factors;
- The **Use** made of that water by different economic sectors and social groups;
- The **Capacity** of society to manage the resource; and
- The maintenance of **Ecological** integrity through allocation of adequate water supplies for ecosystem needs.

The components are sub-indices consisting of an average of one or more standardised indicators with scores ranging from 0 and 100. The sub-indices are then combined using the following mathematical formula in order to obtain the composite WPI, which also ranges between 0 and 100:

$$WPI_i = \frac{\sum_{i=1}^{N} w_{x,i} X_i}{\sum_{i=1}^{N} w_{x,i}}$$

where WPI_i is the Water Poverty Index value for a particular region. It is the weighted sum of the five components. The weight w is applied to each component (X) of the WPI structure for that region, with X referring to the value of the component. Small numbers denote high levels of water poverty while high values indicate low levels of water poverty.

The WPI, has to date, been tested and used to assess water poverty at community and at national scale. Sullivan *et al.* (2003) used the WPI to compare the levels of water poverty between communities in South Africa, Tanzania and Sri Lanka. This tool was used at national level by Lawrence *et al.* (2002) to rank 147 countries according to their levels of water poverty. Cullis and O'Regan (2004) attempted to map levels of water scarcity using the WPI in selected subcatchments of the Thukela catchment in South Africa. The application of the WPI at catchment scale is discussed in greater detail later. Prudhomme (2002) discusses the potential of adapting the WPI to incorporate climate change projections.

The main advantages of the WPI are its comprehensiveness as it attempts to address limitations of the simple indices such as the WSI (Rijsberman, 2004) and the fact that it is computed from simple, well-known, intuitively understandable and trusted indicators which are drawn from the water, agriculture, social, economic and environmental sectors(**Table 2.8**). These indicators can also be described in terms of the DPSIR framework (**Table 2.8**). However, in striving to capture the multiple dimensions of the water-poverty relationships holistically, the WPI becomes too complex and difficult to understand intuitively (Rijsberman, 2004). Hope and Gowing (2003) point out that the WPI does not adequately capture all locally-derived dimensions and determinants of poverty. The developers of the index acknowledge that the WPI is not a definitive or a totally accurate measure of any specific situation (Sullivan *et al.*, 2002). They also concede that its assessment at national level cannot reflect the diversity which is found within the water sector of every country. Therefore, they suggest that local or community level assessments should be undertaken for more precise decision-making purposes. Molle and Mollinga (2004) point out that like all multi-dimensional indices, the WPI "conflate desperate and often correlated pieces of information, with arbitrary weights, giving rise to intriguing associations" in terms of ranking countries according to their water poverty levels. Gleick *et al.* (2003) also mention that more research still needs to be done on both the construction and the application of weights to the components of the WPI.

Table 2.8 Indicators and components of the WPI described according to the DPSIR framework (after UNESCO, 2003)

DPSIR	WPI Indicator	WPI Component
Driving force (e.g. population density, poverty)	% households receiving a pension/remittance or wage Expenditure measured by ownership of durable items	Capacity Capacity
Pressure	Domestic water consumption rate Agricultural water use Water use for livestock Industrial water use	Use Use Use Use
State	Surface water assessment Groundwater assessment Reliability of resources Water quality assessment	Resource Resource Resource Resource
Impact on environment	People's use of natural resources Crop loss % of households reporting erosion of land	Environment Environment Environment
Impact on people	Access to clean water Reports of conflict over water use Access to sanitation % of water carried by women Time spent in water collection Access to irrigation coverage Under-five mortality rate % of households reporting illness due to water supplies	Access Access Access Access Access Access Capacity Capacity
Response	Education level of population Membership in water user associations	Capacity Capacity

The developers of the WPI acknowledge its limitations and state that it is still work in progress (Sullivan *et al.*, 2002). In their review of virtues and limitations of indicators and indices, Molle and Mollinga (2003), as well as Gleick *et al.* (2003), conclude that in addition to many factors including sound conceptual foundation, indices can be useful tools in development planning and decision making if their computations are transparent and their limitations explicitly recognised, and this is certainly the case with the WPI.

2.6.7 Other Indicators and Indices

There are many other measures such as the Index of Human Insecurity (Lonergan *et al.*, 2000), the Human Poverty Index (UNDP), or the Environmental Sustainability Index, all of which give some indications of water wellbeing. However, water is such a small factor in these and other similar indices that they provide very little information of value about water issues. In fact, the water indicator would have to show a major movement in order to effect a significant change in the overall index value (Gleick *et al.*, 2003). Therefore, these indices are considered not to be suited to measuring water wellbeing.

2.7 Water Scarcity and Climate Change

Physical and empirical relationships between the atmospheric concentrations of greenhouse gases such as carbon dioxide and methane and the Earth's climate are nowadays well known and accepted. Therefore, the unabated rising global temperatures to unprecedented levels over the past 50 years is widely understood to be an indication of a changing global climate as a result of human induced high concentrations of the greenhouse gases in the atmosphere (IPCC, 2001a). Global Circulation Models (GCMs), which attempt to represent the physics and dynamics of climate processes by mathematical expressions, are currently regarded as the only credible tools available for simulating the response of the global climate system to increasing greenhouse gas concentrations (IPCC, 2001a). Output from GCMs is used to make estimates of climate variables such as air temperature, precipitation, incoming radiation, vapour pressure and wind speed for the whole world (IPCC, 2001a). In order to estimate plausible future climate trends, scientists devise future climate scenarios based realistic assumptions of energy demand, emissions of greenhouse gases and land use change, as well as assumptions about the behaviour of the climate system over long time scales, particularly, that of the global air surface temperature (Prudhomme, 2002).

Notwithstanding the limitations of, and uncertainties associated with, GCM simulations (cf. Prudhomme, 2002; Hewitson *et al.*, 2005), global climate change is not only widely accepted in the scientific community as a reality, but has also been shown to be occurring already (DFID, 2003; Warburton and Schulze, 2005a, Warburton and Schulze, 2005b, Warburton *et al.*, 2005). The Intergovernmental Panel on Climate Change (IPCC) predicts that climate change could lead, *inter alia*, to,

- increases in the probability of extreme warm days;
- drier southern and the northern latitudes, and wetter tropics;
- increases in climate variability and the frequency of severe weather events;

- loss of wetlands;
- water quality degradation; and
- decreases in soil moisture content (IPCC,2001a).

Uncertainties remain regarding the rate and magnitude and how these changes would manifest themselves at regional and local scale (Hewitson *et al.*, 2005). While studies are beginning to uncover information about possible impacts of climate change on water resources, the likely impacts of climate change on climate sensitive key elements of human development, such as socio-economic systems like agriculture, forestry, fisheries, human health, as well as terrestrial and aquatic ecosystems are still a matter of speculation. It is expected that most, if not all, countries will experience climate change. However, the extent to which each country will be affected depends on whether or not vulnerabilities occur already (DFID, 2003). For example, in terms of water resources in Africa, which is regarded as one the regions that are most vulnerable to the natural variability of climate (Leonard, 2004), predictions suggest that climate change will further reduce water availability in regions which are already water scarce, particularly in the sub-tropics, due to increased droughts, increased evaporation, and changes in rainfall patterns (DFID, 2003). In regions that tend to suffer less from water scarcity, however, precipitation is expected to increase, and the incidence of floods may increase (DFID, 2003).

Adaptation to climate change is a priority for ensuring the long-term effectiveness of investments which are made towards poverty eradication and sustainable development (DFID, 2003). However, the adaptive capacity of many of the vulnerable communities is low (Vogel and Reid, 2005). The IPCC (2001a) lists the following as some of the many factors which could make it difficult for African countries to adapt to climate change:

- the prevalence of poverty, inequitable land distribution, low education levels,
- the absence of social safety nets, especially after harvest failures,
- coping strategies already being strained due to HIV/AIDS and increasing population densities, and

- a high dependence on rain-fed agriculture (IPCC, 2001b).

2.8 Water Scarcity and its Implications in South Africa

South Africa is classified as a water-stressed country by virtue of its having less than 1 700 cubic metres of water available per person per year (cf. **Table 2.7**), and the country will move into a water-scarcity category of less than 1 000 cubic metres per person per year by 2025 if water use patterns are not changed (Seckler *et al.*, 1998). This section reviews the extent of the water stress situation and its impacts in different sectors at national scale. The review commences by exploring the availability of water resource in relation to its utilisation before discussing measures of overcoming water scarcity in South Africa.

2.8.1 Patterns of Rainfall and Evaporation in South Africa

The area-weighted mean annual precipitation (MAP) for South Africa is estimated to average at less than 500 mm (Lynch, 2004), which is consistently lower than the world average of 860 mm/y (Meissner, 1999; Schulze, 1997). South Africa is, predominantly, a country experiencing summer rainfalls, except for the southwestern areas, mainly in the Western Cape province, which receives most of its rainfall in winter. Approximately 35% of South Africa averages less than 300 mm per annum, while only about 7 % has a MAP exceeding 800 mm. KwaZulu-Natal is the wettest province, while the Northern Cape province is the driest (Schulze, 1997). The Western Cape has the highest spatial variability of MAP within any of the nine provinces of South Africa.

South Africa has an area-weighted mean annual potential evaporation (MAPE) of about 2300 mm (Schulze, 1997). Mean annual potential evaporation "lows" are around 1400 mm in the Drakensberg and 1600-1800 mm along the eastern and southern coastal areas, with a general southeast-northwest increasing trend, with "highs" exceeding 3 000 mm per annum in the northwest of the country (Schulze, 1997). The average aridity index, which is expressed as MAPE divided by MAP, of 5.1 classifies South Africa as a semi-arid country. In fact, South Africa is the third driest country in the southern African region, after Namibia and Botswana respectively (Meissner, 1999). **Table 2.9** provides the summary of the key MAP and MAPE statistics for all the provinces of South Africa.

Table 2.9 Statistics of MAP (mm) and MAPE (mm) per province of South Africa (after Schulze, 1997)

	MAP				MAPE				Aridity Index
Province	**Mean Value**	**CV (%)**	**Maximum Value**	**Minimum Value**	**Mean Value**	**CV (%)**	**Maximum Value**	**Minimum Value**	**MAPE/ MAP**
Limpopo	527	28	2031	200	2218	6	2592	1896	4.2
Mpumalanga	736	24	1933	341	1946	6	2335	1537	2.6
North-West	481	21	782	246	2646	8	3058	2116	5.5
Northern Cape	202	43	540	20	2690	6	3028	1890	13.3
Gauteng	668	38	900	556	2178	3	2372	1960	3.3
Free State	532	22	1689	275	2233	11	2677	1152	4.2
KwaZulu-Natal	845	20	1967	417	1770	8	2097	1067	2.1
Eastern Cape	552	43	1722	96	1930	15	2616	1232	3.5
Western Cape	348	72	3345	60	2230	13	2714	781	6.4

2.8.2 Availability of Water Resources in South Africa

The total surface runoff in South Africa is only about 53 billion m^3 per annum (Basson *et al.*, 1997), which represents about 9 % of the MAP, with 91% of all precipitation therefore evaporating again (Whitmore, 1971; cited by Schulze, 1997). This compares poorly with the world average runoff ratio to rainfall of 35% (Schulze, 1997). About 60 % of the surface runoff is derived from only 20% of the land area. Because of the highly variable streamflows and the fact that most of the larger rivers draining the country are shared by one or more neighbouring states, only 33.3 out of the 53 billion m^3 per annum can be utilised (Basson *et al.*, 1997). Surface water resources have undergone considerable development. More than half of the mean annual runoff of the country is currently held in dams, which have a total storage capacity of about 27 billion m^3. Compared to surface water, groundwater resources, which range between 2 and 5.4 billion m^3 per annum, are relatively small (Meissner, 1999).

2.8.3 Water Utilisation in South Africa

The total water use for 1996 was estimated by Basson *et al.* (1997) as 20 045 million m^3 per annum with the following distribution of uses:

- Water use in South Africa is still dominated by irrigation, representing about 54% of the total water use in the country, most of which is used consumptively.
- Domestic and general urban use of water constitutes about 11% of the total usage, which is larger in magnitude than the approximately 8% currently used by mining and some separate large industries outside municipal areas.
- Afforestation, which uses large quantities of water before it reaches the streams or rivers (± 8% of total) is more dominant in the wetter eastern parts of the country.
- Environmental requirements constitute approximately 19%, and this proportion is relative to the total water use in each region and not relative to the size of the river or resources in the region.

Basson *et al.* (1997) estimated that, should the then population growth trends and usage patterns prevail, the total requirements for water in these sectors would approximately double over the following 30 years, or would grow at an estimated 3% of the 1996 demand per annum. By far the dominant growth in water requirements is foreseen in the domestic, urban and industrial sectors and this trend is largely driven by population growth together with the concomitant urbanisation, increased standards of living and services as well as the supporting economic growth and industrialisation (Basson *et al.*, 1997; Meissner, 1999).

2.8.4 Water Scarcity in South Africa

It is apparent that, in relation to available water, the present water use trends are generally high and unsustainable. Meissner (1999) asserts that if these rates persist, the existing supplies cannot keep pace by the year, while Basson *et al.* (1997) estimate that in many parts of South Africa the water requirements will, by 2030, exceed their maximum yield. Using the water stress index (cf. **Section 2.7.3**), Gardner-Outlaw and Engelman (1997) compiled the estimates of the levels of water scarcity for individual countries of the world between 1950 and 2050. With about

3 654 m^3 per capita, South Africa was relatively water sufficient in 1950. However, the country was, in 1995, already water stressed as the water availability had fallen to 1 206 m^3 per annum following the increase of the human population from about 13.683 million to about 41.465 million within the same period. South Africa is likely to be water scarce by 2025, irrespective of the population projection scenario (i.e. low, medium, or high). If the high population projection scenario is anything to go by, South Africa will experience absolute water scarcity, as water availability will have plummeted below the 500 m^3 per capita per annum level by 2050.

Seckler *et al.* (1998), using the Indicator of Relative Water Scarcity (cf. **Section 2.7.5** for its description), place South Africa in Group 1, a group which consists of countries that are water scarce by both criteria of the IRWS (i.e. the percentage increase in water withdrawals over the 1990-2025 period and water withdrawals in 2025 as a percentage of the annual water resources of the country). The 2025 withdrawals of these countries are 191 % of 1990 withdrawals and 91 % of available water resources. Seckler *et al.* (1998) state that without other water augmentation techniques such as desalinisation of brackish water, many of these countries either have reached or will by 2025 have reached, the absolute limit in the development of their water supplies, with some already drawing down limited non-renewable groundwater supplies.

A comparison, by Lawrence (2002), of 147 countries of the world according to their levels of water poverty (WPI) further highlights the water scarcity situation in South Africa. South Africa is ranked at 103, below countries such as Botswana and Swaziland. South Africa is in the most water poor one-third of all the countries together with Morocco, Kenya and Zambia, among others. This index is criticised for creating such peculiar ranking orders as it also places next to each other countries such as the USA and Laos, or Thailand and Sweden (Molle and Mollinga, 2003). However, in the case of South Africa, the dearth of water resources is put into perspective as it reduces the overall index despite the relatively high ranking on the other sub-indices which reflect the progressive policies on access to, and management of, water in the country.

2.8.5 Impacts of Water Scarcity in South Africa

Lack of adequate supplies of renewable freshwater could become the main constraint on the economic development of affected countries (Biswas, 1992). This is already the case in several water scarce countries in northern and southern Africa, whereby freshwater resources are imposing limits on present use of the resource and on economic development (Gardner and Outlaw, 1997). Water crises will present more and more countries with obstacles to better living standards and improved health and even risks of outright conflict over access to scarce freshwater supplies (Hinrichsen *et al.*, 1998; Ohlsson, 1998).

2.8.5.1 Water-Related Diseases

Water-related diseases are among the most common causes of illness and death, affecting mainly the poor in developing countries. **Table 2.10** gives examples of water-related diseases and strategies to prevent them. The diseases that are associated with water scarcity are also known as water-washed diseases (e.g. scabies, trachoma) because they are caused by bacteria or parasites that take hold when there is insufficient water for basic hygiene (washing, bathing, etc.). In 2000, the estimated mortality rate world-wide due to water/sanitation/hygiene associated diarrhoeas and some other water/sanitation associated diseases (schistosomiasis, trachoma, intestinal helminth infections) was 2 213 000 (UNESCO, 2003).

In South Africa, a demographic and health survey conducted by the Department of Health revealed that child mortality rates appeared to have a strong association with the prevailing water and sanitation situations (DOH, 1998). **Table 2.11** shows that child mortality rates more than doubled where the source of drinking water was other than piped water. Where good and modern sanitation such as flush toilets exist, child mortality rates are 7.7 per 1000 compared to 34.9 per 1000 where there is either no improved sanitation or only rudimentary practices are in use.

Cholera is another water-related disease which is responsible for loss of life in many developing countries. In South Africa, cholera claimed a combined 351 lives out of 124 613 reported cases over two epidemic outbreaks from 15.08.2000 to 31.07.2001 and from 1.08.2001 to 31.12.2002 (**Table 2.12**).

Table 2.10 Summary of water-related diseases (after Cairncross, 1986)

Transmission Mechanism	Diseases (examples)	Preventative Strategy
Water-borne	Diarrhoea, Cholera, Typhoid	- Improve water quality - Prevent casual use of unimproved sources
Water-washed	Roundworms (Ascarisis), Trachoma	- Improve water quality - Improve water accessibility - Improve hygiene
Water-based	Bilharzia (Schistosomiasis), Guinea Worm (Dracunculiasis)	- Decrease need for water contact - Control snail population - Improve water quality
Water-related insect vector	Malaria, River Blindness (Onchocerciasis), Sleeping Sickness (Trypanosomiasis)	- Improve surface water management - Destroy breeding sites of insects - Decrease need to visit breeding sites - Improve design of water storage vessels

Table 2.11 Infant and child mortality by selected water-related environmental factors (after DOH, 1998)

Environmental Factor	Neonatal Mortality	Post-neonatal Mortality	Infant Mortality	Child Mortality	Under-5 Mortality
Drinking water:					
piped	17.3	18.0	35.3	11.6	46.5
other	25.0	39.0	64.0	27.7	89.9
Sanitation:					
flush	16.3	13.1	29.4	7.7	36.9
latrine	20.2	25.2	45.4	15.0	59.7
other	23.5	41.0	64.4	34.9	97.1

Between 1.01.2003 and 31.07.2003, the number of cholera infections abated, but the 40 fatalities out of 3 774 reported infections still indicate a high death rate (**Table 2.12**). An overwhelming majority of cholera cases was reported in the Eastern Cape province (3 142), followed by KwaZulu-Natal (528).

2.8.5.2 Trans-National Boundary Water Issues

South Africa shares many of its major rivers with its neighbouring states, i.e. Botswana, Mozambique, Namibia, Swaziland, Lesotho and Zimbabwe. The shared river systems are listed in **Table 2.13**. South Africa is the largest consumer of water in the SADC region (Meissner, 1999). It withdraws more than 80% of all the water that is available in the region, although only 10% of the total water resources of the region occur in South Africa (Meissner, 1999).

Table 2.12 Cholera in South Africa as on 31.07.2003 (after Dikgale, 2003)

Province	Total Cases to Date (since 01.01.2003)	Number of Deaths (since 01.01.2003)	Date of last Reported Case	Case Fatality Rate
Eastern Cape	3 142	37	19.06.2003	1.18%
Free State	0	0	No cases	
Gauteng	3	0	17.04.2003	
KwaZulu-Natal	528	0	31.07.2003	0.00%
Limpopo	0	0	No cases	
Mpumalanga	100	3	08.07.2003	3.00%
Northern Cape	0	0	No cases	
North West	0	0	No cases	
Western Cape	1	0	21.01.2003	
TOTAL	3 774	40		1.06%
Closed Epidemic 01.08.2001 – 31.12.2002	18 224	122		0.67%
Closed Epidemic 15.08.2000 – 31.07.2001	106 389	229		0.22%

Table 2.13 Some transboundary river basins with portions in South Africa (after Conley, 1996; Turton, 1999a)

River/Basin	Total Area(km^2)	Area (km^2) in RSA, % Total ( )	Countries Sharing
Limpopo	413 000	110 000 (26.6)	Botswana, Mozambique, Zimbabwe
Orange	973 000	380 000 (39.1)	Lesotho, Botswana, Namibia
Komati	50 000	31 500 (63.0)	Swaziland, Mozambique

Asmal (2000) notes that shared river systems present opportunities for regional co-operation, e.g. the Lesotho Highland Water Project involving Lesotho, or the Komati Basin Water Authority involving Swaziland. However, regional tensions and conflicts may occur when one or more states feel (s) that water resources are not shared fairly. Turton (1999a) observes that out of 17 shared river basin commissions in the Southern African region, almost 60% are flawed such that the involved states may be said to be to be in a state of "negative peace" and that the transition to one of "positive peace" seems to be unlikely. Positive peace focuses on the existence of prospects for social development, whereas negative peace exists when there is a mere absence of war (Ohlsson, 1995). Therefore, water scarcity can also be viewed as a threat to international peace (Ohlsson, 1995). In three out of the four basins that South Africa shares with its neighbouring states, i.e. the Limpopo, Pongola/Maputo/Usuthu and Komati, there are muted tensions around the shared water systems (cf. Conley, 1996; Turton, 1999a). Turton (1999b) seems to suggest a link between water and the leading role of the South African Defence Force in the SADC sanctioned military intervention during the 1998 civil strife in Lesotho. Attention is also drawn to the fact that the pre-1994 government of South Africa supported a military coup in Lesotho in 1986, “shortly before the Lesotho Highland Water Project (LHWP) was agreed upon between the two states” (Turton, 1999b). According to Turton (1999b), there may be some truth to the conclusion cautiously drawn by Homer-Dixon (1994:19) that “the desire for water was an ulterior motive behind South African support for the (original) coup” in Lesotho.

Despite the apparently prevailing state of negative peace in relation to shared water systems in southern Africa, particularly those that are shared with South Africa (Turton, 1999a), South Africa shows genuine commitment towards harmonious relationships with the other riparian countries through the National Water Resource Strategy (DWAF, 2004a) which describes procedures of operationalising the National Water Act. According to the NWRS, the Act is one of the few national water laws in the world that makes specific provisions for water allocations for meeting the needs of neighbouring countries with which watercourses are shared.

Jenkins (1997) states that unless effective counter-measures are adopted in order to control the escalating water scarcity, South Africans will soon find themselves in a situation already experienced in many cities such as Khartoum, whereby people spend an average of about two-thirds of their monthly income on the acquisition of drinking water. According to Seckler *et al.* (1998), countries that are, or will be, experiencing water scarcity by 2025 can be expected to increase their cereal grain imports as growing domestic and industrial water needs are met by reducing withdrawals for irrigation. The decline of agricultural production in South Africa during droughts and the subsequent increased importation of maize (Meissner, 1999) can be viewed as a predictor of the situation in the country under conditions of water scarcity.

2.8.6 Measures of Overcoming Water Scarcity in South Africa

Overcoming water scarcity is one of the many issues which are already, or will in the near future be afflicting humanity. Many approaches to managing water scarcity are suggested in literature. Winpenny (1994) makes a basic distinction between what he calls “supply-oriented” approaches and “those that rely on demand management”. The “supply-oriented” approaches are traditional measures which are aimed at satisfying the water needs of growing populations by augmenting supplies (Louw and Kassier, 2002). These approaches include:

- surface water capture and storage;
- groundwater (both renewable and non-renewable) exploitation;
- conjunctive use of surface- and groundwater;
- long distance conveyance and inter-basin transfer;
- pollution control;
- desalinisation of brackish water; and
- other non-conventional methods (Winpenny, 1994).

The major limitations of relying only on the augmentation of water supplies in order to combat water scarcity include the fact that new water sources have become less accessible, more expensive to develop and less acceptable from an environmental point of view (Louw and Kassier, 2002). According to Louw and Kassier (2002), this has resulted in a shift from supply-based approaches to water conservation and demand management. Winpenny (1994) places the water demand approaches into the following four broad categories:

- Enabling conditions in the form of institutional and legal changes that foster utility reforms, privatisation, macro-economic and sectoral policy;
- Market-based incentives such as active use of tariffs, pollution charges, groundwater markets, surface water markets, water auctions and water banking;
- Non market-based incentives, e.g. restrictions, quotas, norms, licences, exhortations, public information; and
- Direct interventions and programmes such as canal lining, leak detection, water-efficient user appliances, industrial recycling, reuse and water use efficiency.

In South Africa, the National Water Act (RSA, 1998) creates the foundation on which all water scarcity management initiatives are based. The very first line of the preamble to the Act recognises that water is a scarce resource. The Act sets sustainability, equity and efficiency as "central guiding principles in the protection, use, development, conservation, management and control of water resources".

These guiding principles recognise

- the basic human needs of present and future generations;
- the need to protect water resources;
- the need to share some water resources with other countries;
- the need to promote social and economic development through the use of water; and
- the need to establish suitable institutions in order to achieve the purpose of the Act.

Detailed descriptions of the strategies for achieving the objectives of the NWA are contained in the First Edition of the National Water Resource Strategy, NWRS (DWAF, 2004a). The NWRS describes how the water resources of South Africa will be protected, used, developed, conserved, managed and controlled in accordance with the requirements of the policy and law (DWAF, 2004a). The NWRS also describes elaborately the strategies for the protection of water resources, water use, water conservation and water demand management, water pricing, water management institutions, monitoring and information systems for water resources, and disaster management. These aspects of the NWRS can also be viewed as strategic level efforts aimed at addressing or overcoming water scarcity in South Africa.

The NWA makes provision for the establishment of a Water Use Licensing, Registration and Revenue Collection programme. This programme aims at determining, on an on-going basis, the status of water resources in South Africa by measuring water usage against actual available water, in order to make informed decisions regarding the renewal of old licences and granting of new ones, as well as setting water tariffs. The actual registration process started in 2000. Records of water users, their locations, types of water use and the amount of water they use are captured and stored in a Water Use Authorisation and Registration Management System (WARMS). The WARMS internet page, which is accessible through the DWAF website, contains all the information on the WARMS programme.

The NWRS also places emphasis onto creating awareness and understanding of water issues among water users and other stakeholders, and outlines the Water Research Commission's plans for water research. While it was shown earlier that uneasy calm may be prevailing among some states that are sharing water systems with South Africa, the NWA recognises the necessity of regional and international co-operation in water matters. South Africa interacts politically and technically with the countries with whom international rivers are shared through a number of bilateral and multi-lateral commissions and committees (DWAF, 2004a).

2.9 Discussion and Conclusions

Water is an important resource in human wellbeing in terms of health, food security, socio-economic development, aesthetic and spiritual fulfilment. Seven of the eight Millennium Development Goals for the improvement of the quality of life, particularly in poverty stricken countries, relate directly or indirectly to water. Therefore, it is not surprising that scarcity of water is perceived to be a limit to development.

Water scarcity is a complex phenomenon, which is difficult to characterise and quantify. It is multi-dimensional, highly dynamic, has varying degrees of severity, and may manifest itself differently at different points in space and time, and for varied durations. The understanding of water scarcity is made difficult by, *inter alia*, the diversity of its causes, manifestations, impacts, and the ambiguity and differences of its definition, as encountered in literature. The definitions discussed in **Section 2.2** are distinctive and, hence, are adopted for the remainder of this document.

The quest to understand water scarcity, i.e. its impacts, the progress or regress of initiatives aimed to redressing it, as well as the need to create awareness, has led to an increasing interest in the use of indicators in the water sector. Many water resources- related indicators have been, or are being, developed while some have been proposed in order to provide information to policy makers. For example, with respect to water and development, indicators can be used in determining areas with or without access to sufficient water resources for either or both of domestic and productive use, tracking efficiency and trends of water use, as well making decisions regarding water allocation.

Indicators have many functions which include synthesising large quantities of data to usable information, discerning trends, simplifying complex systems, informing and educating audiences, creating awareness, as well as monitoring and evaluating projects. However useful indicators may be, they are by their nature simplistic and probably imperfect representations of reality which should be used cautiously. Developers and users should always bear in mind that indicators are mere pointers which seldom explain why a particular situations exists. Indicators are also subject to deliberate and inadvertent misuse. While a clear conceptual foundation minimises the chances of misinterpreting indicators, there is not much that can be done to curb their abuse beyond exercising cautious use of indicator information. Indicators are frequently developed for specific locations and scales. Caution therefore needs to be exercised when they are applied in areas for which they were not developed. Unavailability of adequate data limits the development of comprehensive indicators. Although thorough assessment is desired, too many indicators may limit the effectiveness of a monitoring and evaluation task. The definitions of indicators change over time and from country to country, and this limits their comparability. No indicator is purely objective. Indicators are reflective of the assumptions, values and biases of the developers. The value of indicators as decision making tools is undoubted. However, they have limitations (cf. **Section 2.5**). Developers should acknowledge this while users of indicator information (e.g. policy makers), on the other hand, should be cautious enough to recognise and understand the significance of those limitations to the decisions which have to be made.

Out of the indicators and indices reviewed in **Section 2.6**, the WPI, which was selected for this study, is the most comprehensive as it takes into account socio-economic-political and environmental issues. While the index itself is relatively new, its constituents are simple, well-known, intuitively understandable and trusted indicators which are drawn from the water, agriculture, social, economic and environmental sectors. Therefore, evaluating the index may not require new datasets, but can make use of those datasets that are already available in many countries, and certainly so in South Africa. The WPI does not only satisfy affordability among the attributes of good indicators, but also inherits reliability and credibility from the component indicators. However, the sophistication of the WPI as a result of thematically grouping the indicators in order to form the main components and, subsequently, combine them into a single index value, leads to the loss of the immediate intuitive understanding of the index. This disadvantage is not limited to the WPI, but applies to all aggregated indices. The claim by Molle and Mollinga (2003) that the WPI creates strange rankings and associations should not be viewed as a limitation of the index, but as an opening of another paradigm by which the water-poverty linkage can be conceived. This perception of the WPI created the need for the determination of the potential of the WPI in the assessment of socio-economic development in relation to the availability of, access to, and utilisation of, water resources in South Africa. While the individual constituents of the WPI are relevant and reliable measures of the different issues that are intuitively understood to relate water and human wellbeing, the index in its compound form does not have a theoretical foundation on the basis of which a causal relationship between water availability and poverty can be assumed. This implies that the WPI is not designed to describe the cause-effect relationship of the water-poverty relationship. Its functions are quantifying, tracking and communicating trends of overall water wellbeing. The potential of using the index at meso-scale is the subject of investigation of this study.

Climate change has become a reality that could have ramifications in all environmental and socio-economic spheres of life. Climate change could exacerbate water scarcity, especially in already vulnerable regions that also lack in adaptation capacity, which is the case across large tracts of Africa. The consensus among many scientists regarding the occurrence of climate change is only the first step in the right direction. More data and research are required in order to improve the understanding of the still uncertain areas of climate change, for example the rate and magnitude of changes, their manifestations and impacts in different sectors at different scales, as well as vulnerabilities and suitable adaptation strategies.

The case study of water scarcity in South Africa reveals that, naturally, the country is not generously endowed with an abundance of water resources in relation to other countries and regions of the world. Even within the country, the distribution of water resources is not uniform in space or time. Increased population and economic development lead to both increased competition and demand for the limited water resources. Calculations of the Water Stress Index using projected populations show that South Africa will be a water scarce country by 2025, unless economically viable alternatives for, or supplementary water sources to, naturally renewable water resources are found. The finiteness of water resources implies that the further development of the resource to augment supply in order to meet the ever-increasing demand is only a temporary solution, which might soon be unavailable as an option for dealing with water scarcity. With other supply oriented measures such as desalination of brackish water being economically unviable at present because of high costs, water conservation and water demand management approaches appear to be sound means of overcoming water scarcity. Water scarcity has negative implications for food security, regional political stability (South Africa shares four major rivers with its neighbouring states) and economic development. The National Water Act lays the legislative foundation for the sustainable, equitable and efficient utilisation and management of water resources in South Africa. The strategies for achieving the overall objective of the Act are described in the NWRS. Although the NWRS provides guidelines for general water resources management and not specifically for overcoming water scarcity, they include measures, which could also help reduce chances of the occurrence of water scarcity.

The following chapter, **Chapter 3**, reviews existing and planned national water-related monitoring programmes and information systems in order to determine whether sufficient data and information are available to enable the computation of the WPI without resorting to collecting field data again, not only for the Thukela catchment, but for national evaluations as well.

3 REVIEW OF EXISTING SOURCES OF DATA AND INFORMATION FOR COMPUTING THE WATER POVERTY INDEX IN SOUTH AFRICA

3.1 Introduction

Many monitoring programmes, information systems and databases are in existence in South Africa. With respect to their status, some of these systems are either active, or have been discontinued, or are being restructured, or are being developed from the beginning, or planned for the future. This study hypothesises that these information systems can already be, or will be capable of, supplying data and information for the computation of the water-related indicators and indices (cf. **Chapter 2**) such as the WPI, without the need for additional data collection initiatives. Therefore, the following sections review these systems, focussing particularly on their relevance to computing the WPI (cf. **Chapters 2** and **7**), in the Thukela catchment, and nationally. Other issues which are considered include the custodians of the information systems, as well as costs, reliability, smallest spatial unit and smallest time-step of the information. If the outcome of the review is affirmative, evaluations of water poverty could be more affordable and rapid than if special information collection initiatives were to be necessary.

3.2 Water Resources-Related Monitoring Systems

The need for appropriate information for the assessment of South Africa's water resources is recognised and emphasised by the NWA (RSA, 1998), which legislates the development of national water resources monitoring programmes and information systems. These systems are intended to provide information for the assessment of the quantity, quality, and use of available water resources in the country.

A number of monitoring and information systems are already in existence and operational, and these are maintained by the national Department of Water Affairs and Forestry (DWAF). Presently, DWAF is restructuring and amalgamating these systems in order to improve their integratedness and efficiency. These monitoring and information systems include: the Hydrological Information System (HIS), the Water Management System (WMS), the National Groundwater Information System

(NGIS), the Water Use Authorisation and Registration Management System (WARMS), Water Works (i.e. the information system for the Working for Water Programme), the Water Services Information System (WSIS) and the Water Situation Assessment Model, WSAM, (Schultz and Watson, 2002).

3.2.1 The Hydrological Information System

The HIS contains hydrological data and information about rivers, dams and associated gauging stations, and includes descriptions, records of flows, rainfall, evaporation and water quality from more than 800 national monitoring stations (e.g. flow gauges, reservoirs take-offs and meteorological stations). The majority of the flow gauges are operated by DWAF, while meteorological information is obtained from the South African Weather Service and the Agricultural Research Council. The data and information are accessed via HYDRSTA, a server-based commercial system with GIS functionality.

3.2.2 The Water Management System

DWAF is facilitating the development of the WMS, which is a coordinated information system consisting of existing and planned water quality-related monitoring programmes undertaken by its directorates and other organisations. The WMS is expected to be fully operational by 2007 when all the monitoring systems for the different programmes, including those that are under development, are also fully functional.

3.2.3 The National Groundwater Information System

National Groundwater Information System (NGIS) is a collection of projects designed to manage groundwater information in South Africa (DWAF, 2004b). The system will be distributed among regional offices and will integrate both spatial and non-spatial data and information. The NGIS also boasts of improved visualisation and analytical functionality. The projects in the NGIS include REGIS Africa and the National Groundwater Archive (NGA). The NGA is a relational database management system that stores data and information on major aquifers and the levels of their exploitation. It replaces the Open National Groundwater Database (Open-NGDB). The NGA is linked to the WMS for boreholes whose groundwater quality has been analysed.

3.2.4 The Water Use Registration Management System (WARMS)

The WARMS aims to capture and record all usage of water in South Africa, as dictated by the NWA, in order to generate information that will enable proper planning and management of water resources. This information is also used by DWAF when billing water users. However, not all water users are eligible for registration. Small-scale uses such as domestic, non-commercial gardening and livestock watering as well as usage of water in emergency situations are classified as Schedule 1 uses for which registration is not necessary. Users who receive water from a local authority, a water board, an irrigation board or another bulk water supplier are also not required to register their use. WARMS captures information about the water user, i.e. name, location, as well as on the use of the water (e.g. the type of use and the amount of water to be used).

The registration process commenced in 2000 and by 2004 some 62 000 water users had been registered. According to DWAF (2004d), this figure is said to represent about 80 % of all the users that are required to register. Validation of the users is undertaken concurrently with the registration by experts in the regional offices of DWAF. The database is not recommended for use yet because the validation process has not been completed. DWAF (2004d) lists deficiencies associated with the WARMS database, and these include:

- the duplication of records and information,
- users registering amounts of water they would like to have instead of actual volume of water they use,
- problems with unsurveyed properties, and
- the registration of Schedule 1 use.

3.2.5 The Water Service Information System (WSIS)

The WSIS was developed by DWAF's Directorate of Water Services to capture and store information which could be used to monitor the progress and impacts of water-related programmes such as the Community Water Supply and Sanitation (CWSS) and the Free Basic Water Project (FBW). The information is organised as key performance indicators (KPI) to monitor, *inter alia*, costs of projects, the number of water service providers, number of people served, sustainability of schemes, capacity building, community empowerment, job creation and environmental impacts of projects. Regular reporting through WSIS is undertaken at project, community, municipal district, province and national level. The WSIS is also linked to a GIS in order to enable spatial representation of the information.

3.2.6 Other Water-Related Information Sources

There are other information systems which are specific to certain projects, institutions or models, such as the Working for Water Information System, the Water Situation Assessment Model (WSAM) and the *ACRU* Agrohydrological modelling system-based Quaternary Catchment Database.

3.2.6.1 The Working for Water Information System (WaterWorks)

The Working for Water Programme (WfWP) was launched as a national initiative aimed at controlling alien invasive plants, which use an estimated 3 300 million m^3 of water, or 7% of South Africa's mean annual runoff (Versfeld *et al.*, 1998). The monitoring unit of the Working for Water programme, which assesses the progress and impacts of the programme, is developing a project-dedicated information system. WaterWorks, as this system is known, records the details of the individuals working on the projects, as well as the areas cleared, plant species and their densities in a spatial database. A research project is currently utilising remote sensing and satellite imagery to update information on level of invasion in South Africa. A number of studies have investigated the impacts of the Working for Water programme on the hydrology and socio-economic wellbeing of cleared catchments. However, these studies are often individual case studies which do not form part of a regular national monitoring and evaluation system (DWAF, 2004).

3.2.6.2 The Water Situational Assessment Model

The Water Situational Assessment Model was developed by the Systems Analysis sub-directorate of DWAF as a decision support tool for water resources-related planning at reconnaissance level. The model is supported by a database that represents the risk-based water resources, land use and water use situation in 1995 for all Quaternary Catchments in South Africa and those shared with South Africa. It also has demographic information with projections up to 2025, which provides a basis for analysis of future scenarios of water consumption. Model input data were obtained from different organisations. While the WSAM provides a useful database of water availability and use at the quaternary level, there are concerns about methods used to calculate the water balance (DWAF, 2001b).

3.2.6.3 The *ACRU*-based Quaternary Catchment Database (QCD)

The Quaternary Catchment Database was developed, and is maintained, by the School of Bioresources Engineering and Environmental Hydrology in the University of KwaZulu-Natal. This database stores at Quaternary Catchment level hydroclimatic, biophysical, and land use information which is primarily used as input for the *ACRU* agrohydrological modelling system (Hallowes *et al.*, 2004). The data and information to populate the database were sourced from different organisations such as meteorological information from the South African Weather Service (SAWS), Agricultural Research Council (ARC), South African Sugarcane Research Institute (SASRI), municipalities, private companies and individuals; soils and land type information from the Institute for Soil, Climate and Water (ISCW) of the Agricultural Research Council; information on natural vegetation information from the National Botanical Institute (NBI); and land cover and land use information from the Council for Scientific and Industrial Research (CSIR). In addition to detailed simulations of the catchment hydrology, the *ACRU* model outputs crop yield estimates, sediment yield estimates and estimates of design floods. The QCD also supports the simulation of potential impacts of different plausible scenarios of land use and management, and those of future climate change, on water resources. While the standard spatial unit of the database is the Quaternary Catchment, an option is available to enable the subdivision the Quaternary Catchments into smaller units, i.e. Quinary Catchments, in order to enable more reliable hydrological simulations, especially, in Quaternaries with high spatial variability (Hallowes *et al.*, 2004).

3.2.7 Usefulness of the Water-Related Information Systems for the WPI

The water-related information systems and databases could become useful sources of data and information for the computation of the WPI, especially the resource component which takes into account the quantity, quality and variability of water resources. For example, the Hydrological Information System and the National Groundwater Archive can provide information about water quantity, while indicators of water quality can be derived using data from the Water Management System. The sparseness of the networks that support the HIS, the NGA and the WMS limits their usefulness at spatial scales smaller than Tertiary Catchments. In addition to providing quantities of flows, output from hydrological models such as WSAM and *ACRU* can be used to assess the variability of water resources at specific locations. The smallest spatial unit for databases both these models is the Quaternary Catchment. However, the sub-units of Quaternary Catchments can be delineated for specific modelling studies using the *ACRU* model.

The Water Services database provides information which can be used to derive indicators of access to water and sanitation services. However, such indicators would be relevant for areas in which these services are provided by the State or municipal organisations such as the Free Basic Water initiative. The same can be said of the Key Performance Indicators which, otherwise, would be useful as measures of the communities' capacity to manage water resources.

In relation to the computation of the WPI, the WARMS can provide information for the computing indicators of the levels of water use, especially, after all water users have been registered and the information is validated. Because information is captured at individual user level, the information can be aggregated to spatial scales appropriate for specific evaluations of the WPI.

The main limitation of the WARMS is in capturing water use by the rural poor, which falls into to the Schedule 1 category and, hence, they are not required to register their use either for domestic purposes or for non-commercial livestock watering. However, if these users do not obtain their water from the source, information on their water use could possibly be obtained from the Water Service Providers (WSP) or Water User Associations (WUA) that supply them with water. Some information on water use by poor farmers is captured by WARMS through Schemes Management Parameters if those farmers abstract their water from government irrigation schemes.

Output from WSAM can be used to estimate sectoral water use. However, the information from the WSAM is not available at spatial resolutions finer than the Quaternary Catchment.

The WMS can be a source of information evaluating indicators of quality of the aquatic ecosystem. The National River Health Programme, one of the monitoring programmes which support the WMS, aims at producing State of the Rivers Reports for all major river systems in South Africa by 2008. Other indicators of the quality of the aquatic ecosystem can be developed from information on the levels of infestation of rivers by invasive alien plant species. This information will be captured in the WaterWorks database of the Working for Water Programme.

3.3 Land Cover and Land Use-Related Monitoring Systems and Databases

3.3.1 National Land Cover Database (NLCD)

The National Land Cover Database is a product of the National Land Cover Project coordinated by the Environmentek Division of the CSIR, which is also the custodian of the database. The database contains land cover classification for South Africa and neighbouring states such as Swaziland, Lesotho and Mozambique. The land cover classes were mapped from precision-corrected satellite images captured between 1994 and 1995 at a standard scale of 1:250 000. The NLCD is in the public domain and can be purchased as a whole or in part, at a nominal cost of ZAR749.99 for the former.

The 31 broad level thematic land cover and land use classes within the Land Cover Database can be adapted to suit individual user requirements (cf. Thompson, 1996). Within the context of the WPI, the area under certain land uses such as irrigated agriculture can be used to derive indicators of access to water for productive uses. Land degradation such as soil erosion can lead to excessive deposition of sediments in rivers and reservoirs, which may have impacts on physical water quality and eutrophication levels. Therefore, the size of degraded land as a fraction of total catchment area can be adopted as an indicator of the quality of the aquatic environment.

The major limitation of this database is that it is, by now, dated. Despite its age, it is still trusted and utilised by researchers and analysts from academic institutions, consulting firms and other organisations. A follow-up national land cover project using 2001 satellite imagery aimed at providing more recent and more detailed information, is underway and, for parts of southern Africa, may already be used by researchers.

3.3.2 Annual National Agricultural Survey and the Agricultural Census

The National Agricultural Survey and the Agricultural Census is undertaken by the Sectoral Economics Unit of Statistics South Africa, a statutory agency responsible for the collection, storage, analysis and dissemination of official and other statistics. Up to 1996, the annual surveys were targeted at commercial farmers, hence neglecting rural subsistence farmers (the poor) in what used to be homeland states. The 1997 survey focused on small-scale and subsistence farming, including those in the former independent homeland states and took gender issues into consideration. Prior to 2002, the last Agricultural Census had been undertaken in 1993. The Agricultural Censuses are conducted every five years through mail-based questionnaires. Like the pre-1996 annual surveys, the 1993 census questionnaires, and those before, neither included subsistence farming nor disaggregated the farming practices according to gender. The former independent homelands were also not included in the agricultural censuses. The revival of the mail-based five year census in 2002 represents a more inclusive census in terms of the former independent homelands and gender disaggregation. However, the focus is still on commercial farmers and the activities of subsistence farmers are still not covered by the census. The information which was collected during the 2002 census includes:

- details of the farming unit such as the area and market value of the farm, the number of owners, family members and employees involved in farming activities, and farming debt;

- data on land utilisation, employees' remuneration, gross farming income and expenditure, equipment purchased, and amount spent on buildings erected and development work undertaken; and
- the market value of movable farming assets.

Results of the census are used in the compilation of South Africa's National Accounts. Other users of the census are private sector and respondents in analyses of comparative business and farmers' performances, agricultural associations, unions and individual farmers to determine the contribution of the agricultural industry or division to the total economy of the country. When comparing the results of the 2002 census with previous censuses, StatsSA (2005) warns that caution should be exercised because of the following:

- alterations in the boundaries of geographical areas;
- fluctuating climatic conditions; and
- alterations in branches of farming and rotation of crops.

The pre-2002 mail-based agricultural censuses were characterised by poor or low response rates (Ehlers and Frick, 2000). Better relations between statistics producers and farmers were envisaged to improve the response rates for the 2002 census.

The National Agricultural Surveys and Censuses are reliable data sources (Ehlers and Frick, 2000), which can be used in the evaluation of water poverty. Its potential application regarding the WPI is in the development of indicators of access to, efficiency and productivity of, agricultural water use.

3.4 Socio-Economic and Demographic Databases: National Population Census

The National Population Census surveys are undertaken by Statistics South Africa, the statutory agency responsible for the collation, storage, analysis and dissemination of official and other statistics. The National Population Censuses are conducted every five years, with the most recent one undertaken in 2001. Since 1996, the censuses have been all-inclusive as all areas of residence such as households and hostels throughout South Africa were surveyed by more than 100 000 enumerators. Each interviewer was assigned an enumerator area (EA) to do the count. The EAs are the smallest spatial unit and their delimitation was based on fair distribution of work to enumerators. While the EAs were used during the survey in 2001, the National Population Census Database has Sub-Place Names (SP), which consist of one or more EAs, as the smallest spatial unit of aggregation. The spatial units at all the scales are geographically referenced. Tabular output from this database can be linked to maps using GIS in order conduct spatial analysis, as has been the case in this study.

The cost of managing the National Census database is borne by the State. The data are available *gratis* to non-commercial users. The data can be obtained from the StatsSA's Head Office in Pretoria or any of the Regional Offices.

The data are grouped into broad sectoral categories such as demography, education, employment and income, household and individual services, health and disability, transport and dwellings. The variables making up each major category are disaggregated by race, gender and age.

The census database is a reliable source of information which is used by many different users such as State institutions, academic researchers, consultants and individual analysts. The 1996 census, in particular, was at that time considered the most comprehensive census ever undertaken in South Africa. In order to ensure that the statistics accurately reflect the situation on the ground, post surveys are usually undertaken to estimate undercount and adjust the data accordingly. The census database is accompanied by comprehensive metadata which provides information about the data. The questionnaires and the codes which were used during the surveys are explained in the host of documents that constitute the metadata.

The National Population Census database is a core dataset for the computation of the WPI at different spatial scales (e.g. subcatchments), as has been illustrated in this study. Two main components of the WPI, namely, access and capacity can be calculated from the census data. The variables which are related to service provision such as types of sources of domestic water supply and types of sanitation practices can be included in the computation of the access sub-index of the WPI. Indirect measures of socio-economic wellbeing and literacy such as individual or household income and highest level of education reached can be adopted as indicators of human capacity, which encompasses the ability to effectively manage water resources.

3.5 Conclusions

This chapter has reviewed existing and planned national water-related information systems and databases in South Africa in order to determine whether these systems have the potential to support the evaluation of the WPI without resorting to collecting project-specific data. The results of the review are summarised in **Table 3.1**. At the time when the data could be used to compute the WPI for this study (March, 2004), only eight out of the fifteen reviewed information systems were partially complete. While these systems may have been active, one or more of their subsystems were still under development. Once they are completed and fully functional, these systems can support regular nationwide evaluations of the WPI at Quaternary Catchment level. Five years is a very suitable interval for the evaluation of the WPI, especially if these assessments were to coincide with the national population censuses, on the basis of which existing national policies are evaluated and new ones formulated.

Table 3.1 A summary of water-related national information systems

Component	Data Source	Spatial Unit	Frequency	Status
Resource	Hydrological Information System	Quaternary Catchment	Annual	Partly
	National Groundwater Archive	Sub-Quaternary Catchment	Annual	Partly
	Water Situation Assessment Model	Quaternary Catchment	Monthly	Complete
	ACRU Quaternary Catchment Database	Quaternary Catchment	Daily	Complete
	Water Management System	Sub-Quaternary Catchment	Annual	Partly
Access	Water Services Information System	Sub-Quaternary Catchment	Five Years	Complete
	National Population Census	Sub-Place Name	Five Years	Complete
	National Land Cover Database	Sub-Quaternary Catchment	Once-Off	Partly
	National Agricultural Survey and Census	Sub-Quaternary Catchment	Annual, Five Years	Partly
Capacity	Water Services Information System	Sub-Quaternary Catchment	Five Years	Complete
	National Population Census	Sub-Place Name	Five Years	Complete
Use	Water Use Registration Management System	Sub-Quaternary Catchment	Annual	Partly
	Water Situation Assessment Model	Quaternary Catchment	Annual	Complete
Environment	Water Management System	Sub-Quaternary Catchment	Annual	Partly
	National Land Cover Database	Sub-Quaternary Catchment	Once-Off	Partly
	National Land Degradation Index	Magisterial District	Once-Off	Complete

While attempts were made to make this review as comprehensive as possible, it is by no means definitive. There was obvious bias towards national information systems in the water and related sectors. The author acknowledges that volumes of valuable information are held by private companies, academic institutions and other government and non-governmental organisations which were not reviewed for purposes of this exercise. Subject to the financial and time limitations of this study, a conscious decision was made by the author to focus mainly on those information systems which are easily accessible and the acquisition of the information from which is affordable.

4 DESCRIPTION OF THE THUKELA CATCHMENT

The preceding two chapters reviewed the literature on water scarcity and information systems which can support the computation of water-related indices. In **Chapter 2**, a review of the prevailing situation in South Africa was presented in regard to water scarcity at national scale. This chapter focuses the investigation of water scarcity onto the Thukela catchment, which is the selected case study area. The review of literature revealed that water scarcity is a function of physical water shortage and the capacity to mobilise social, political and financial resources in order to cope with this shortage. It is because of this link between human wellbeing and shortage of water that certain authors (e.g. Sullivan *et al.*, 2002; Lawrence *et al.*, 2002) refer to water scarcity as water poverty. The purpose of this chapter is to describe the biophysical characteristics and socio-economic profile of the Thukela catchment in order to establish the extent to which these factors influence water poverty.

This chapter commences with descriptions of the geographical location and natural environment, i.e. climate, geology, relief and soils of the catchment. The sections on the socio-economic wellbeing analyse the historical background, present settlements, economic wellbeing and levels of service delivery. The demographic and the socio-economic profile of the Thukela catchment was assessed using data from the 1996 and 2001 National Population Censuses. Included in this chapter is a brief section on water availability. The section on water availability is short because it is intended to give an overview rather than a full analysis, to which an entire chapter (**Chapter 5**) is dedicated.

4.1 Physical Description

4.1.1 Location and Physiography

The Thukela catchment extends latitudinally from 27°25' to 29°24'S and longitudinally from 28°58' to 31°26'E. It is located entirely within the province of KwaZulu-Natal in South Africa (**Figure 4.1**). The catchment covers an area of 29 036 km^2. The Thukela River, which derives its name from an isiZulu word that means 'to startle' as it comes crashing downstream in a flood, has its source in the Drakensberg mountain range in the west of the catchment.

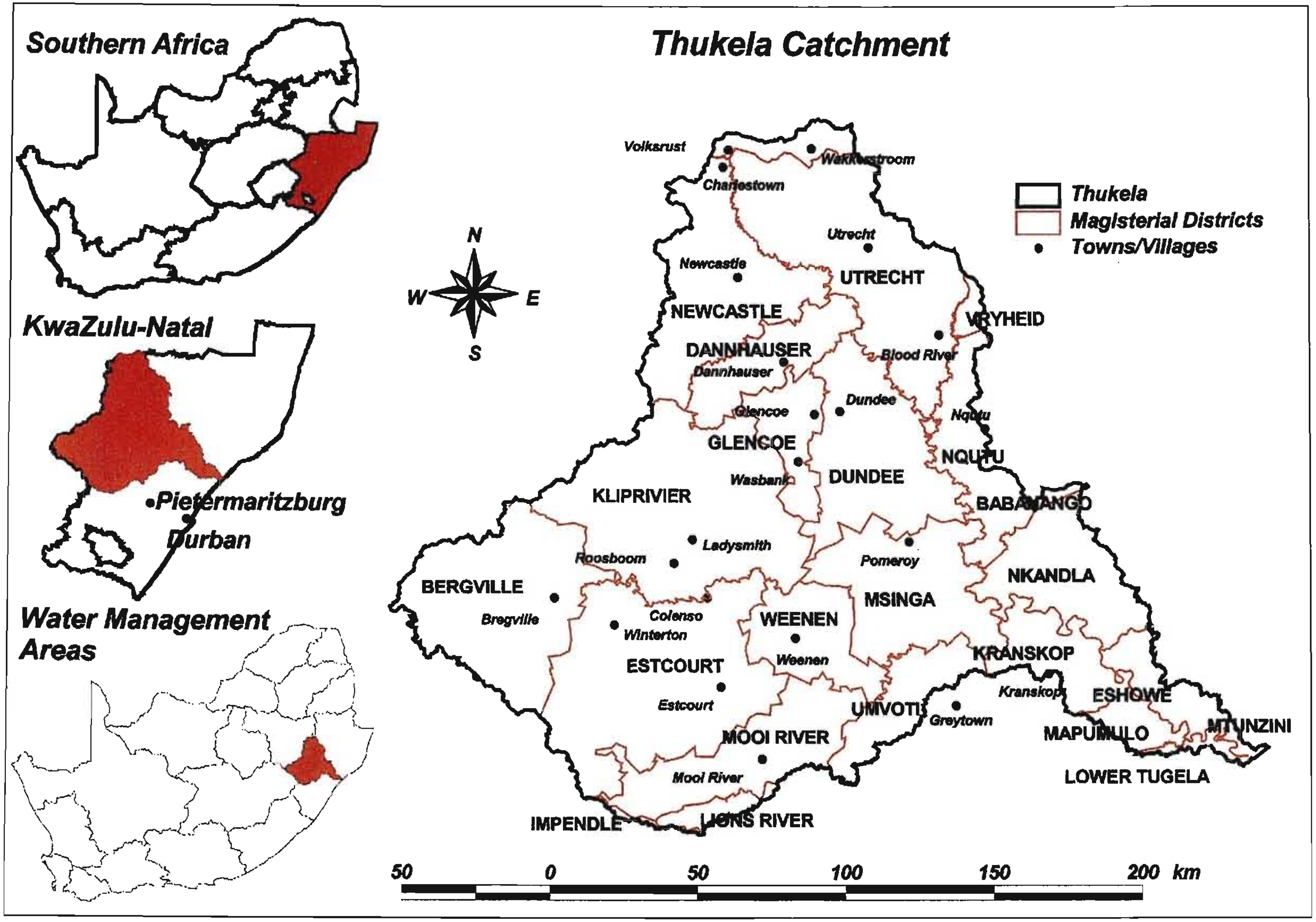


Figure 4.1 Location of the Thukela catchment in Kwazulu-Natal, South Africa, also in relation to Water Management Areas and magisterial districts

The Drakensberg is a declared World Heritage Site and, in places, has altitudes exceeding 3000 m (**Figure 4.2**). The Thukela then flows eastward from a steep escarpment across low mountains of high relief, open hills of high relief (**Figure 4.2**) and lowlands of low relief and, thereafter, through a deeply incised valley until it reaches the Indian Ocean approximately 85 km north of Africa's major port city of Durban (**Figure 4.1**). The mainstem Thukela's major tributaries are the Little Thukela, Mooi and Bushman's Rivers which join from the southwest, and the Klip, Sundays and Buffalo Rivers flowing in from the north.

The Thukela catchment is one of South Africa's 22 Primary Catchments and 19 designated Water Management Areas (**Figure 4.1**). The State's Department of Water Affairs and Forestry (DWAF) has delineated the Thukela into 86 Quaternary level operational subcatchments (QCs), while other researchers have delineated the QCs further into a total of 113 meso-subcatchments (Jewitt *et al.*, 1999) and more recently into 235 subcatchments (Schulze *et al.*, 2005).

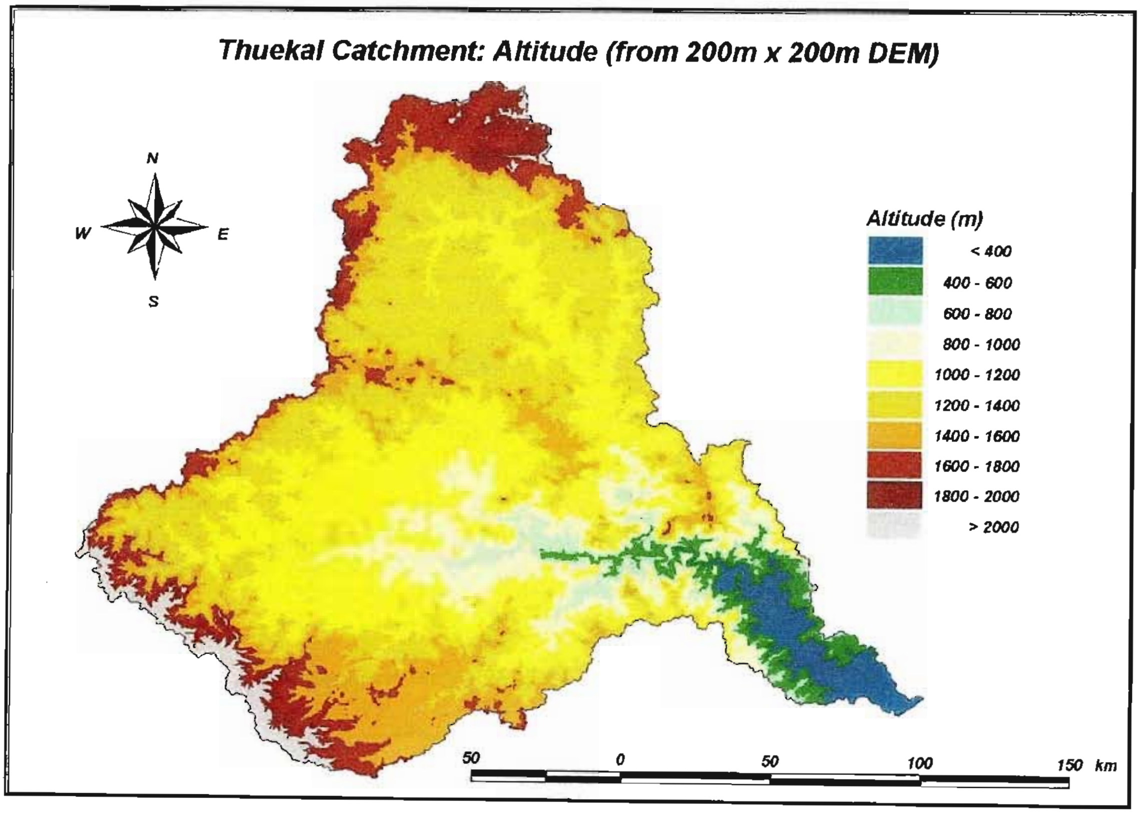


Figure 4.2 Altitudenal zones in the Thukela catchment

4.1.2 Climatology

Like all climate and other climate-related variables, rainfall, and with that the major ecological regions within the Thukela catchment (**Figure 4.3**) as defined by Edwards (1967), varies spatially. Mean annual precipitation (MAP) in the Thukela ranges from around 2000 mm in parts of the Drakensberg to as low as 550 mm in the drier, lower valley regions (**Figure 4.4**; Dent *et al.*, 1989; Lynch, 2004). Significant from a water poverty perspective is the relatively high inter-annual variability of rainfall, generally in the range of 20 – 30% (Schulze, 1997; **Figure 4.5**). The driest year in 10 records only about 60% of MAP. Equally as important for WPI studies as its variability is the strong concentration of rainfall in the summer months. Most of the rainfall (> 80%) is received during the wet summer season between October and March (Schulze, 1997).

The coastal region is an exception to this because it has relatively wet winters during which about 30% of the annual rainfall is received. In relation to the other months, January is the wettest month, with the rainfall ranging between 100 – 300 mm (mostly 120 – 150 mm). July is the driest month, with means of that month's rainfall over most of the catchment being about 10 mm.

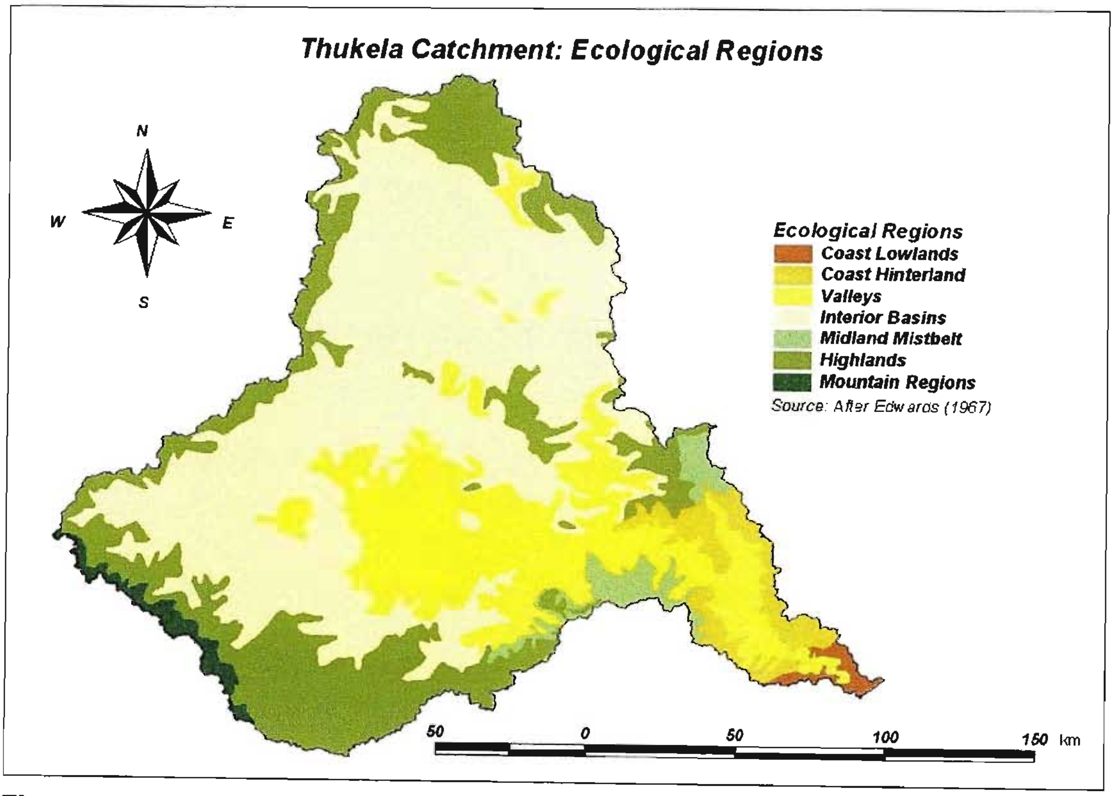


Figure 4.3 Major ecological regions in the Thukela catchment (after Edwards, 1967)

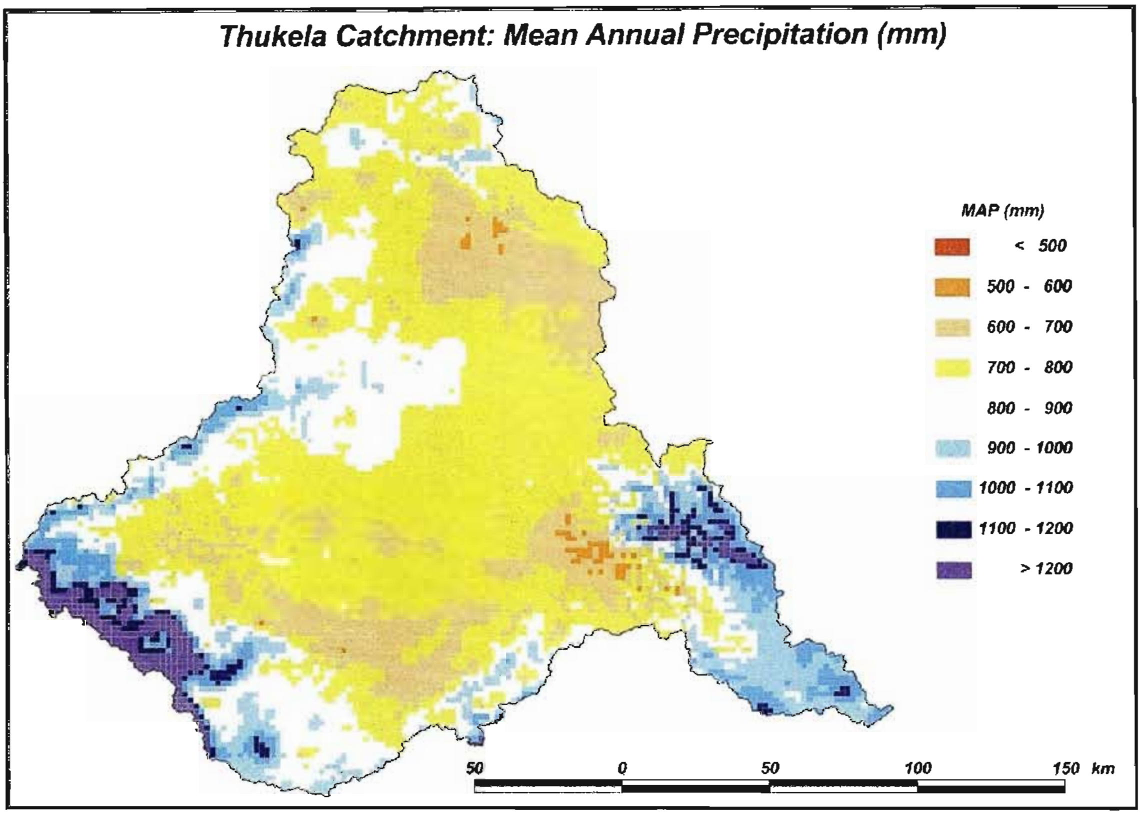


Figure 4.4 Mean annual precipitation (mm) in the Thukela catchment (after Dent, Lynch and Schulze, 1989)

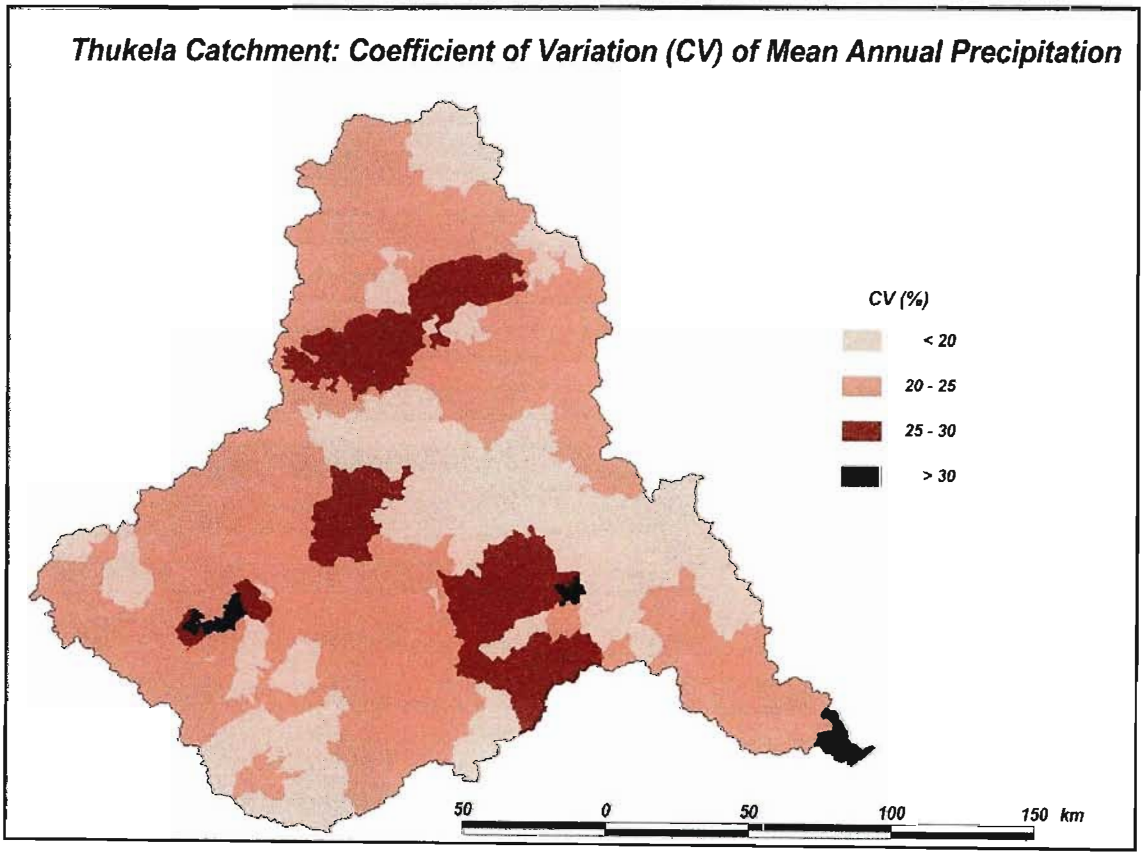


Figure 4.5 Inter-annual coefficient of variation (CV, %) of rainfall in the Thukela catchment (Source: School BEEH, 2005)

The key statistics of monthly and annual rainfall in are summarised by ecological region in **Tables 4.1** to **4.7**. Specific subcatchments, designated SC (cf. **Chapter 5** for detailed descriptions and **Figure 5.3** for layouts and numbering of the subcatchments), were selected as being representative for each ecological region.

Table 4.1 Monthly and annual statistics of rainfall (mm) in the Mountain Region, represented by SC15 (Source: School BEEH, 2005)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Mean	200.0	184.1	176.6	69.7	23.5	9.3	10.9	35.5	57.8	96.2	144.7	187.6	1195.7
St. dev	82.6	92.8	101.4	44.1	31.1	15.6	17.7	41.0	74.2	53.0	81.9	84.8	308.3
% C.V	41.3	50.4	57.4	63.3	132.5	168.1	161.6	115.6	128.5	55.1	56.6	45.2	25.8
Minimum	45.6	15.2	35.6	0.0	0.0	0.0	0.0	0.0	2.9	12.5	0.0	60.6	525.3
Maximum	417.3	430.9	473.6	245.7	159.6	74.7	90.7	194.6	451.5	285.1	402.1	539.5	1843.6
Driest in 10	121.5	78.9	64.3	20.0	0.0	0.0	0.0	0.0	10.9	49.7	51.0	96.1	845.5
Median	184.4	171.1	157.8	63.3	12.4	3.0	1.9	21.5	32.8	85.3	141.0	171.9	1232.7
Wettest in 10	326.3	315.9	311.5	115.7	63.1	31.4	29.8	94.4	127.4	163.6	221.0	279.4	1558.2

Table 4.2 Monthly and annual statistics of rainfall (mm) in the Highlands Region, represented by SC79 (Source: School BEEH, 2005)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Mean	144.3	111.8	109.5	55.3	17.7	10.6	10.1	30.4	47.1	69.9	137.2	143.3	887.2
St. dev	58.4	54.0	53.6	31.9	22.5	22.0	13.6	30.5	56.9	35.5	63.5	60.4	176.2
% C.V	40.5	48.3	49.0	57.6	127.2	207.0	134.4	100.6	120.8	50.8	46.3	42.1	19.9
Minimum	51.9	11.5	6.2	2.0	0.0	0.0	0.0	0.0	0.0	17.3	36.4	0.0	491.0
Maximum	295.1	225.4	253.9	166.6	94.5	120.8	41.0	96.7	311.5	178.0	304.8	304.2	1279.6
Driest in 10	74.9	40.5	52.7	15.7	0.0	0.0	0.0	0.0	8.9	29.0	61.7	67.2	667.2
Median	143.6	105.6	98.7	51.0	8.3	1.3	2.5	17.8	24.6	63.2	124.8	142.4	885.2
Wettest in 10	221.1	191.8	173.1	90.0	56.3	28.3	34.2	83.7	106.6	121.8	232.3	208.0	1117.1

Table 4.3 Monthly and annual statistics of rainfall (mm) in the Midland Mistbelt Region, represented by SC103 (Source: School BEEH, 2005)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Mean	112.2	86.8	66.7	37.5	13.2	8.5	9.5	16.6	39.3	65.5	86.3	103.9	646.0
St. dev	61.7	55.1	36.6	25.9	19.1	14.5	18.4	19.8	67.6	36.9	41.0	76.2	133.4
% C.V	55.0	63.5	54.9	69.1	145.4	171.7	194.6	119.1	171.8	56.4	47.5	73.3	20.7
Minimum	0.0	14.8	4.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.8	24.5	320.9
Maximum	309.0	264.4	148.8	110.9	99.0	65.4	106.1	90.6	404.8	161.0	192.2	534.8	914.8
Driest in 10	50.4	31.0	16.3	6.5	0.0	0.0	0.0	0.0	0.0	18.2	40.2	51.4	498.3
Median	103.1	71.1	72.9	33.1	9.6	0.0	0.4	9.4	22.8	61.8	81.1	91.8	629.5
Wettest in 10	204.8	157.9	108.9	72.6	39.9	32.0	28.7	48.0	58.8	114.6	131.2	155.7	815.3

Table 4.4 Monthly and annual statistics of rainfall (mm) in the Interior Basins Region, represented by SC86 (Source: School BEEH, 2005)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Mean	137.5	107.4	85.1	39.7	16.1	6.6	7.9	19.0	40.3	86.6	113.5	135.6	795.3
St. dev	71.9	63.3	45.1	28.1	20.1	9.9	16.1	20.4	46.0	53.4	53.7	76.3	162.2
% C.V	52.3	58.9	53.0	70.9	125.2	149.5	203.9	107.1	114.0	61.7	47.3	56.3	20.4
Minimum	0.0	0.0	2.8	0.0	0.0	0.0	0.0	0.0	0.0	22.6	0.0	0.0	440.1
Maximum	297.9	228.4	209.6	95.6	75.2	34.5	74.6	74.2	243.0	274.7	254.9	345.0	1086.4
Driest in 10	56.7	25.1	31.1	0.3	0.0	0.0	0.0	0.0	1.1	27.2	50.7	53.8	587.0
Median	143.0	100.9	81.9	39.0	8.9	0.8	0.0	14.1	31.2	73.2	114.8	128.1	821.9
Wettest in 10	226.6	198.7	148.0	87.1	43.5	23.2	21.0	48.9	79.8	160.5	189.2	236.7	991.6

Table 4.5 Monthly and annual statistics of rainfall (mm) in the Valleys Region, represented by SC69 (Source: School BEEH, 2005)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Mean	131.1	111.7	86.6	39.1	11.7	5.4	4.5	15.5	42.0	65.2	83.2	121.7	717.6
St. dev	71.3	64.4	52.1	24.8	15.8	9.0	7.8	18.8	57.7	46.9	48.4	63.0	154.3
% C.V	54.4	57.6	60.2	63.4	135.9	166.4	171.3	121.2	137.5	71.9	58.1	51.8	21.5
Minimum	35.9	21.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.4	6.6	20.4	305.1
Maximum	337.9	281.4	207.8	107.2	72.2	37.8	29.7	70.5	285.8	193.7	260.7	331.0	1095.8
Driest in 10	52.0	32.2	18.9	12.2	0.0	0.0	0.0	0.0	0.0	16.4	34.3	47.7	538.7
Median	113.3	106.4	93.2	37.9	4.6	0.0	0.0	10.1	20.9	56.2	79.9	112.2	721.0
Wettest in 10	234.6	196.5	156.2	69.3	31.1	19.9	19.3	43.9	91.2	131.3	140.4	212.9	886.6

Table 4.6 Monthly and annual statistics of rainfall (mm)in the Coast Hinterland Region, represented by SC111 (Source: School BEEH, 2005)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Mean	132.8	119.8	99.1	54.7	38.3	21.6	24.4	35.7	87.0	102.2	117.6	122.0	955.1
St. dev	63.9	89.3	66.3	41.5	45.9	24.8	33.3	32.2	121.7	48.1	59.1	66.8	233.3
% C.V	48.1	74.5	66.9	75.9	119.7	114.9	136.5	90.2	139.8	47.1	50.2	54.7	24.4
Minimum	0.0	0.0	0.0	1.8	0.0	0.0	0.0	0.0	7.4	24.8	29.9	43.9	567.8
Maximum	272.2	405.9	314.2	190.2	213.8	99.0	152.1	152.2	794.4	230.9	408.5	374.8	1824.4
Driest in 10	59.7	41.0	29.1	14.2	1.9	1.7	0.9	6.3	15.2	43.7	61.4	51.3	706.2
Median	123.7	95.2	100.9	47.2	23.3	12.4	11.6	25.7	55.8	91.6	114.1	108.8	907.0
Wettest in 10	226.6	244.3	188.5	104.3	90.5	55.5	58.5	82.8	203.5	163.1	176.3	185.3	1229.2

Table 4.7 Monthly and annual statistics of rainfall (mm) in the Coast Lowlands Region, represented by SC113 (Source: School BEEH, 2005)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Mean	135.8	121.6	101.9	60.7	56.3	33.8	32.2	41.0	81.7	107.7	118.0	91.6	982.4
St. dev	81.6	84.4	72.3	48.7	87.9	37.3	38.1	33.5	96.6	59.7	67.3	45.0	263.9
% C.V	60.1	69.4	71.0	80.3	156.2	110.3	118.6	81.5	118.2	55.5	57.1	49.2	26.9
Minimum	0.0	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.1	39.3	0.0	472.0
Maximum	449.0	358.3	359.4	188.3	535.7	145.6	206.7	118.6	624.4	285.5	484.8	224.8	1862.2
Driest in 10	46.0	33.4	16.8	6.2	0.5	0.1	3.4	4.1	16.6	39.6	67.1	42.4	686.5
Median	128.5	104.6	94.9	47.4	31.3	22.0	21.4	29.2	61.2	98.4	108.9	87.1	938.6
Wettest in 10	216.3	218.6	174.7	144.5	129.2	96.4	79.7	97.9	167.7	186.8	172.7	155.1	1363.2

Mid-summer monthly means of daily maximum temperatures in January range between about 26 and 28°C, with the highest values of up to 32°C occurring in the valleys while in the high Drakensberg mountains they seldom exceed 20°C (Schulze, 1997). The Drakensberg mountains also have the lowest monthly means of daily minimum temperatures, with sub-zero means of minima not uncommon in July. Unlike the low temperatures of the Drakensberg range of mountains, the coastal areas are fairly mild during mid-winter with means of daily minimum temperatures averaging about 10°C in July. The monthly means of minimum and maximum temperatures for all the major ecological regions of the Thukela catchment are summarised in **Table 4.8**.

Table 4.8 Monthly means of daily maximum and minimum temperatures (°C) for selected subcatchments representing major ecological regions (Source: School BEEH, 2005)

Ecological Regions (SC)		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Mountain Region (15)	Min	11.8	11.6	10.2	7.1	3.8	0.8	0.9	2.8	5.6	7.6	9.3	10.8
	Max	24.3	23.5	22.5	20.3	17.7	15.6	15.8	17.6	20.7	21.4	22.1	23.9
Highlands (79)	Min	12.6	12.5	10.9	7.8	4.1	0.7	0.9	3.2	6.2	8.2	9.9	11.7
	Max	24.7	23.9	23.3	21.1	18.6	16.6	16.8	18.6	21.2	21.5	22.2	24.1
Midland Mistbelt (103)	Min	15.1	15.0	14.0	11.2	7.9	4.8	4.9	6.9	9.3	11.0	12.6	14.2
	Max	26.0	26.0	25.2	23.4	21.3	19.1	19.4	20.9	22.6	23.4	24.0	25.9
Interior Basins (86)	Min	14.0	13.7	12.4	9.4	5.7	2.5	2.5	4.8	8.0	10.0	11.6	13.2
	Max	26.1	25.7	25.1	23.1	21.1	18.7	19.0	20.9	23.1	23.7	24.4	25.9
Valleys (69)	Min	15.5	15.4	14.1	10.7	6.6	3.2	3.2	5.6	8.9	11.2	13.0	14.6
	Max	28.3	28.0	27.1	24.9	22.7	20.3	20.7	22.5	24.5	25.4	26.5	28.1
Coast Hinterland (111)	Min	18.3	18.4	17.5	15.1	12.0	9.0	8.9	10.6	12.9	14.3	15.8	17.4
	Max	27.3	27.4	26.8	25.3	23.8	21.9	21.9	22.7	23.5	24.2	25.0	26.8
Coast Lowlands (113)	Min	19.7	19.7	18.8	16.2	13.1	10.2	10.0	11.7	14.0	15.6	17.0	18.7
	Max	27.9	27.9	27.4	25.9	24.5	22.9	22.6	23.0	23.9	24.6	25.4	27.2

Atmospheric moisture demand in the catchment varies widely, both spatially and temporally. **Figure 4.6** shows the distribution of average annual reference potential evaporation (E_p) when using the A-pan as a reference. E_p is high, at between 1600 and 2000 mm per annum (Schulze, 1997). Highest monthly means of E_p (200-220 mm) coincide with high means of maximum temperatures in January and similarly the lowest values, still around 100-110 mm per month, occur in July (Schulze, 1997). The monthly means of E_p in selected subcatchments that represent the major ecological regions in the catchment are summarised in **Table 4.9**. The ratio of mean annual rainfall to mean annual E_p, which is used as an indicator of aridity levels (UNESCO, 1979), shows that about 88% of the Thukela catchment is semi-arid (**Figure 4.7**). This implies that despite the rainfall *per se* not necessarily being low everywhere, it is not sufficient to satisfy the atmospheric moisture demand.

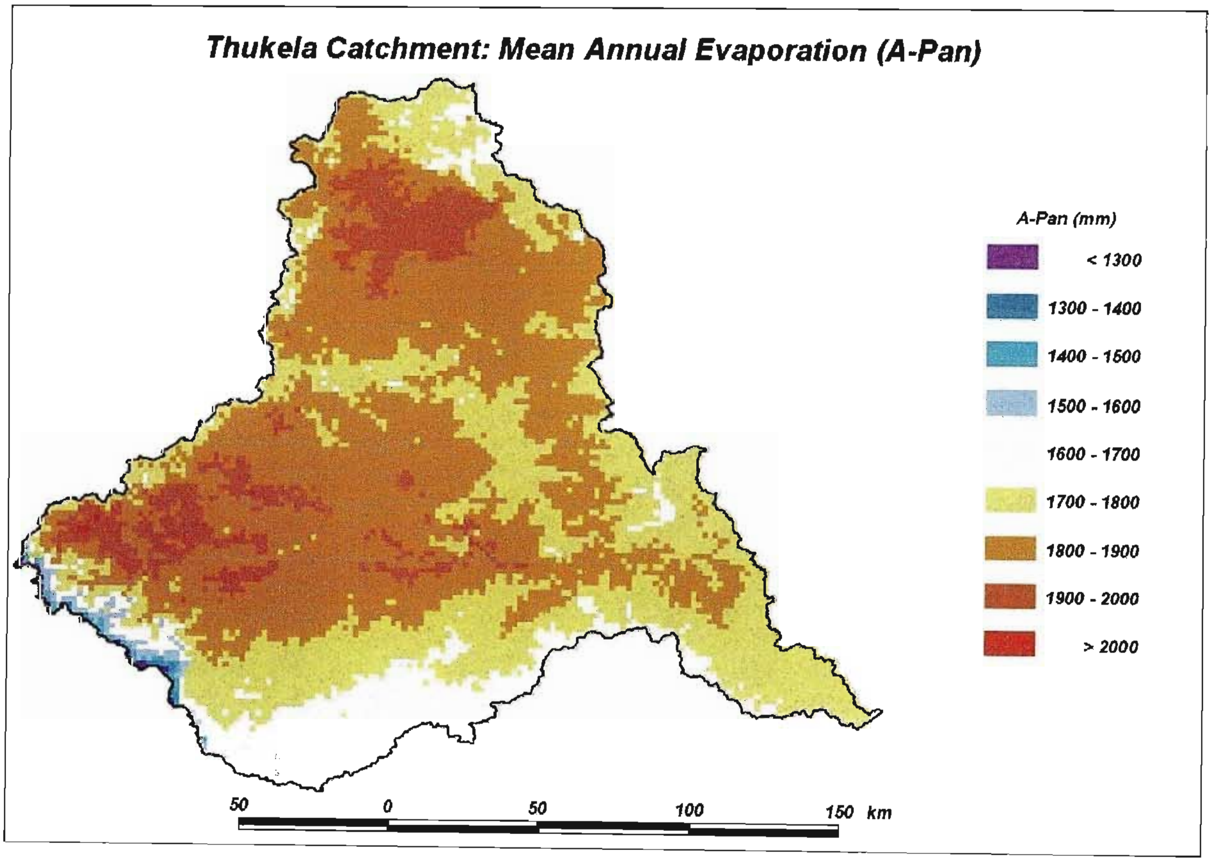


Figure 4.6 Mean annual potential evaporation (mm) in the Thukela catchment, using A-pan equivalent values as reference (after Schulze, 1997)

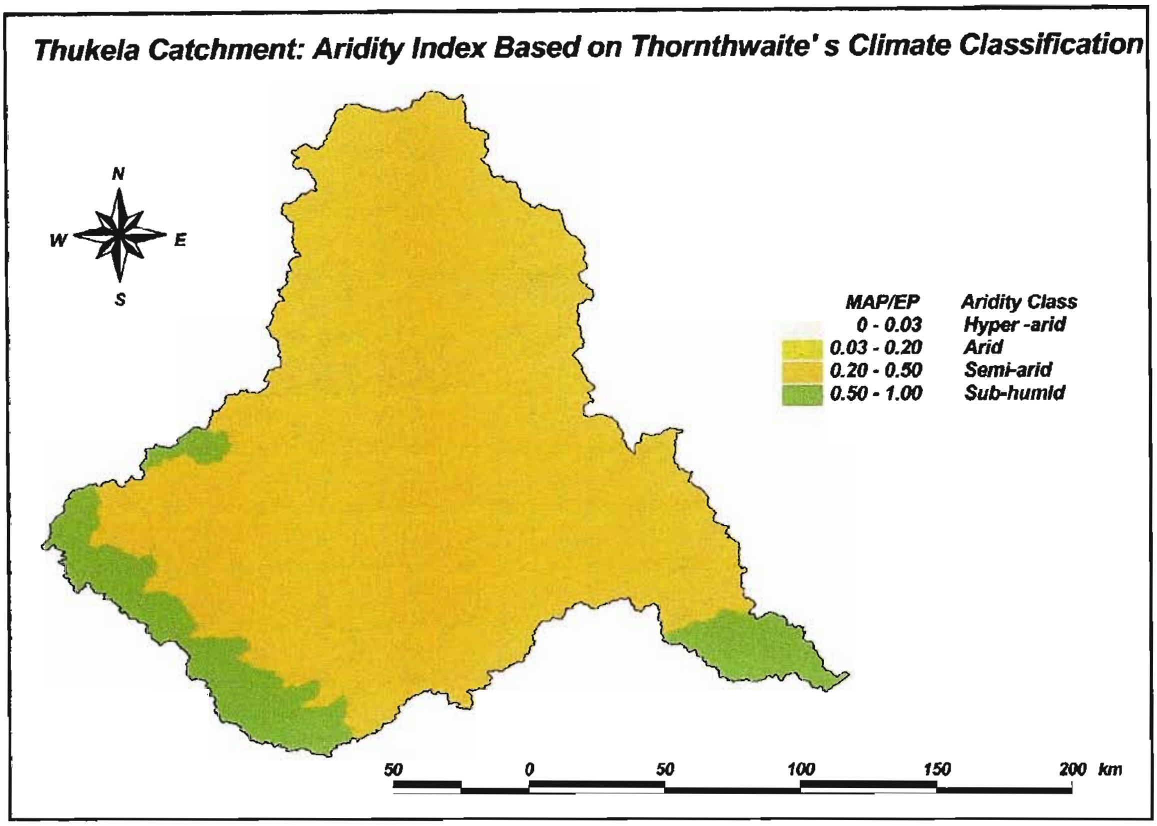


Figure 4.7 Spatial patterns of aridity in the Thukela catchment, based on Thornthwaite's Aridity Index (UNESCO, 1979)

Table 4.9 Monthly means of reference potential evaporation (mm), using A-pan equivalent values as the reference, for selected subcatchments representing major ecological regions in the catchment

Ecological Regions (SC)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Mountain Region (15)	175.4	148.5	134.9	117.3	96.1	89.0	99.3	135.0	155.2	156.4	157.3	181.5
Highlands (79)	174.5	148.8	141.7	121.1	103.3	91.6	102.8	133.8	153.2	155.8	157.1	178.6
Midland Mistbelt (103)	186.4	160.2	152.3	124.9	110.3	96.4	104.8	134.6	153.8	165.1	167.3	188.0
Interior Basins (86)	194.7	164.0	155.9	125.8	107.7	93.5	104.3	140.3	163.1	174.8	177.9	202.0
Valleys (69)	206.1	176.1	163.8	126.8	106.5	92.6	102.1	135.7	163.7	180.6	187.6	209.5
Coast Hinterland (111)	186.3	162.4	160.4	127.7	110.3	91.7	102.1	125.2	139.2	165.5	166.3	187.6
Coast Lowlands (113)	188.7	164.6	164.3	129.7	110.4	88.1	101.4	122.0	134.0	165.5	168.5	190.6

4.1.3 Geology

The Thukela catchment contains a rich mix of rock types ranging in age from ancient to recent formations (**Figure 4.8**). A large proportion of the catchment is underlain by sedimentary rocks, in the form of arenites and mudstones, which make up about 33%

and 26.7% of the catchment's area, respectively. The arenites form a broad band which is broken by exposed patches of dolerite intrusions. The western side is dominated by the dolerite-interspersed mudstones which form a broad NW-SE band that buffers areas around the towns of Bergville, Winterton, Estcourt and Mooi River (cf. **Figure 4.1** for locations of towns). Sandy shales constitute about 16.5% of the catchment. In the north, the shales contain extensive seams rich in coal. Basaltic outcrops are exposed as protruding spurs in the high altitude Drakensberg and isolated surrounding areas. Volcanic rocks that contain greenstones veined by granite with intercalations of sedimentary rocks occur in incised valleys in the lower Thukela. Other rocks in this area include limestones, schists, gneisses and amphibolites, as well as ultra-basic rocks such as gabbro, peridotite and serpentine with their metamorphosed derivatives (Council for Geosciences, 1999).

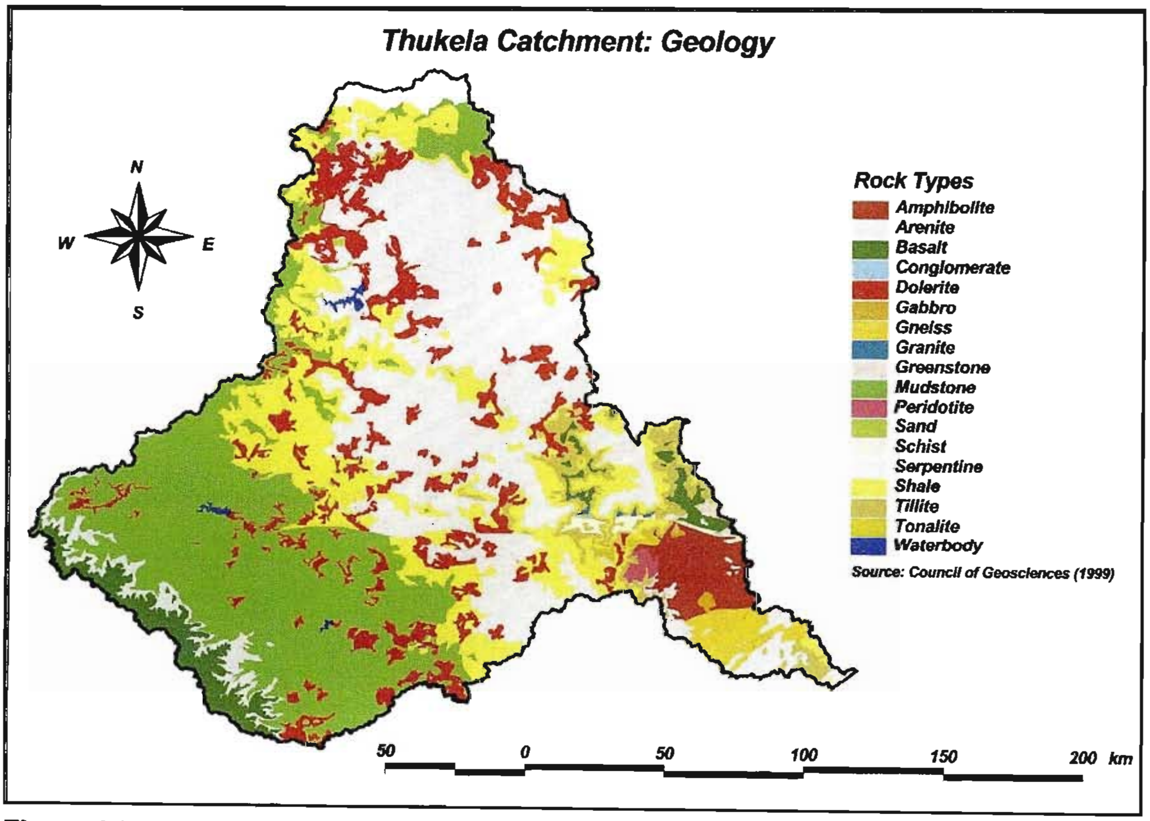


Figure 4.8 Major rock formations in the Thukela catchment (after Council for Geoscience, 1999)

4.1.4 Land Types and Soils Characteristics

A land type is an area that can be shown at 1 : 250 000 scale and that displays a marked degree of uniformity with respect to terrain form, broad soil patterns and climate (Land Type Survey Staff, 1986). In essence they are soil mapping units. The land types were mapped by superimposing a climate map on a pedosystem map. There are nine broad categories of land types in South Africa , of which seven are found in the Thukela catchment (**Figure 4.9**). The spatial distributions of selected hydrologically relevant characteristics of the soils found in these land types are shown in **Figure 4.10.** For hydrological modelling purposes, hydrological characteristics of soils are derived from a computer program AUTOSOIL (Pike and Schulze, 1995 and updates), which interrogates the soils databases of the Land Type Survey Staff (1986). The percentage distribution of the seven land types found in the Thukela catchment is given in **Table 4.10**.

Table 4.10 Descriptions and percentage distributions of broad categories of land types found in the Thukela catchment

Category	Description	%
A (b-e)	Red-yellow apedal, freely drained soils	23.1
B (a, b, d)	Plinthic catena: upland duplex and margallitic soils rare	13.5
Ca	Plinthic catena: upland duplex and/or margalitic soils common	12.8
D (b, c)	Prismacutamic and/or pedocutanic diagnostic soil horizons dominant	7.7
Ea	One or more of vertic, melanic, red structured diagnostic soil horizons	3.9
F (a-c)	Glenrosa and/or Mispah soil forms (other soils may occur)	37.4
I (a-c)	Miscellaneous land classes	1.6

The most common soil forms in the catchment are Glenrosas and Mispahs, which occur over 37.4% of the total area. These soils forms are predominantly found in an extensive area from the dry Interior Basins (cf. **Figure 4.3**) all the way down to the lower Thukela valley. In these regions, soils have a high content of lime and/or other bases.

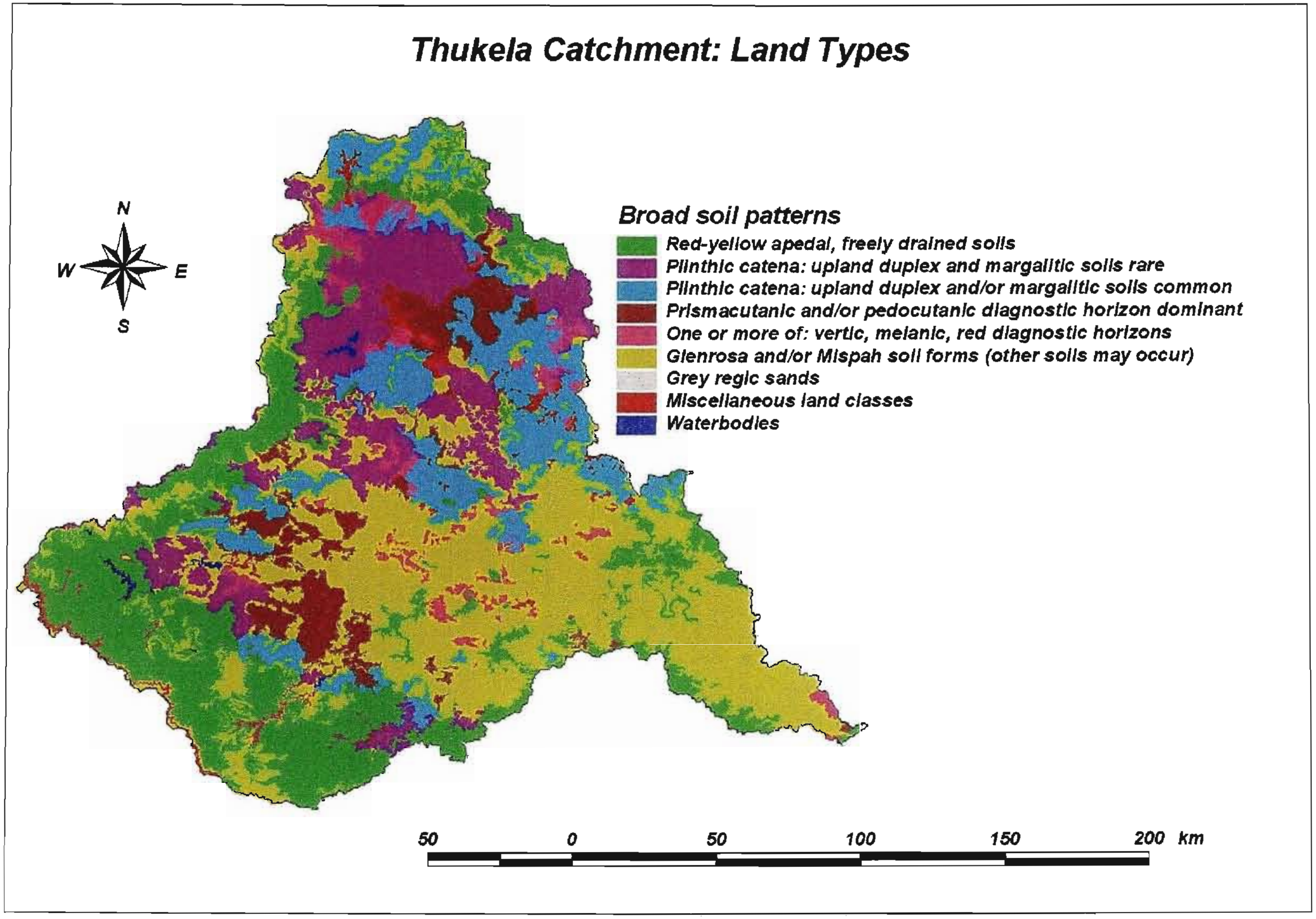


Figure 4.9 Distributions of land types in the Thukela catchment (after Land Type Survey Staff, 1986)

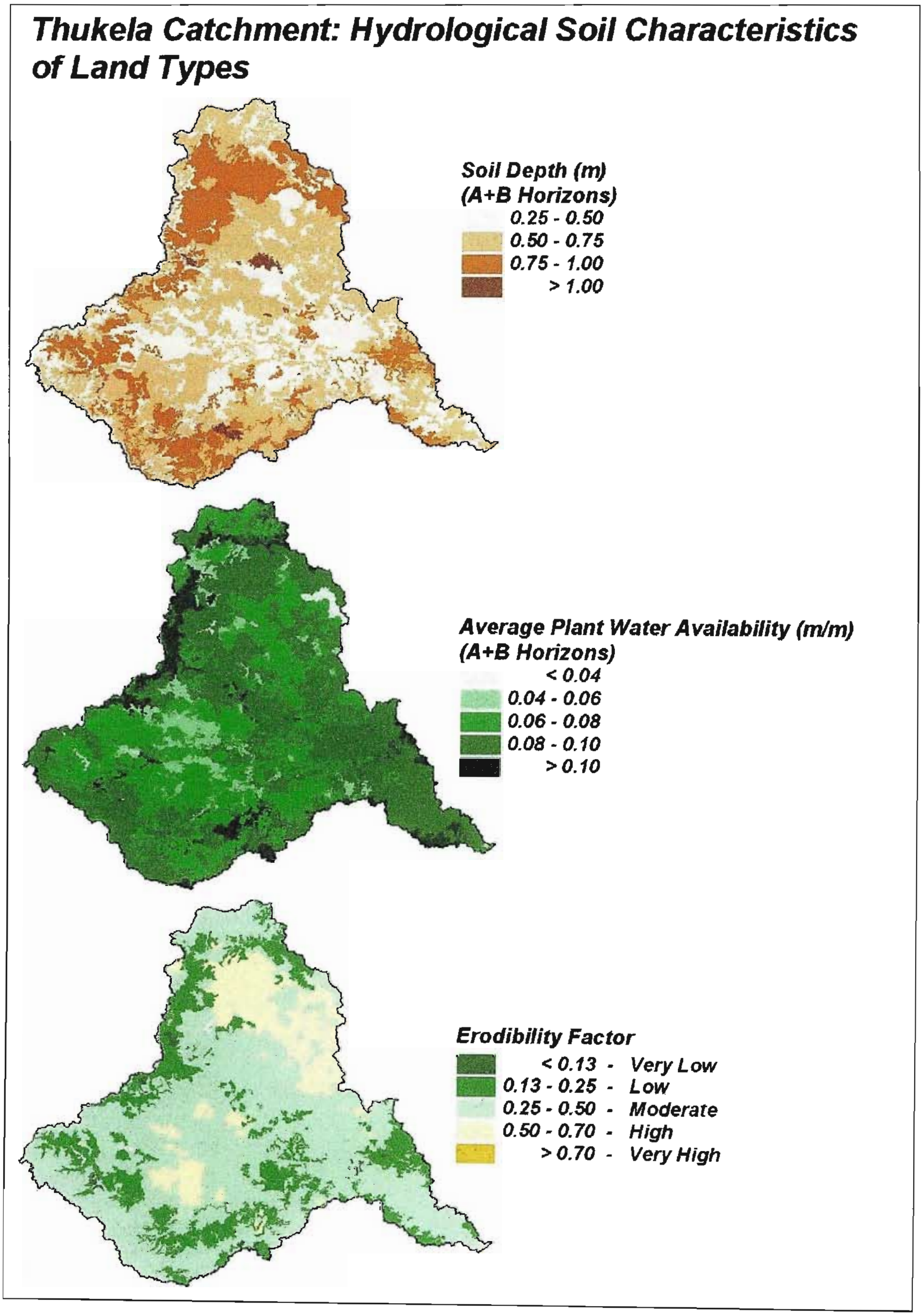


Figure 4.10 Distribution of selected soil characteristics in the Thukela catchment

The susceptibility of Glenrosa and Mispah soil forms to erosion ranges from moderate to high. Strongly leached variants of these soils exist in patches in the wet Highlands and Coast Hinterland, as well as the Moist Interior Basins. About 23.1% of the catchment is covered by red to yellow apedal soils that belong in one or more of the Inanda, Kranskop, Magwa, Hutton, Griffin or Clovelly soil forms. These soils tend to have a low base status (i.e. they are acidic), which reflects the combination of their free drainage characteristics and the wetter climates of the highland areas, where they are commonly found. The fertility of these soils is low owing to their low base status. However, their productive potential can be enhanced by heavy artificial fertilisation (van der Eyk, 1969). Erodibility is low in the uplands and moderate in the bottomland. Plinthic soil catenas represent about 26% of the landscape of the Thukela catchment, most of these being in the Moist Interior Basins. Soils found in these landscapes tend to have mottles and/or concretions which have resulted from localised accumulations of iron and manganese oxides (Macvicar *et al.*, 1977).

Within the Thukela catchment, the distribution of the mottled soils is about even in relation to those that are underlain, and those that are not underlain, by a hardpan. Other soils occurring in this region are those with prismacutanic, gleycutanic and/or pedocutanic diagnostic horizons. These are duplex soils with slightly acidic to acidic topsoils that are underlain by a neutral to alkaline claypan. Because of their extremely impermeable subsoils, claypan soils tend to be highly erodible. Hence ploughing and overgrazing, with their associated increases in runoff, often lead to severe sheet and rill erosion (Macvicar *et al.*, 1977). Within the Thukela catchment, claypan soils are found in an extensive area within the Colenso, Estcourt and Winterton triangle as well as around Ladysmith and northeast of Dannhauser (cf. **Figure 4.1**). Land type units with one or more of either dark coloured cracking (vertic) or non-cracking (melanic) soils and other red structured soils which do not fall within the other classes, occur over about 3.5% of the Thukela catchment, mainly in the dry parts of the Interior Basins. They tend to have high concentrations of bases and, like the claypan soil, they are highly erodible. Other land types that include rock outcrops, unconsolidated stones and boulders and other undifferentiated materials cover about 2% of the catchment.

4.2 Land Cover and Land Use

Land cover and land use are often used interchangeably. Schulze *et al.* (1995) make a distinction between these terms by defining land cover as natural vegetation, and land use as the anthropogenic activities that are undertaken on the land, such as urbanisation and/or cropping. Land cover can undergo transformations, some of which are natural, such as responses to season changes, while others are a result of the use and management practices that the land is put under. While land cover and land use play a significant and dynamic role in plant and soil water evaporation processes, as well as runoff generation mechanisms, the type of land cover and the type and extent of land use is frequently a reflection of the water availability in an area. For example, abundant water tends to promote vegetation growth, the expansion of cities and rapid conversion of natural cover into farmland (GLCF, 2005).

4.2.1 Natural Land Cover

Several attempts at mapping natural vegetation in southern Africa have been made in the recent past. A natural vegetation classification that is respected and scientifically accepted as a baseline land cover for hydrological purposes in South Africa is that by Acocks (1988) into 70 so-called "Veld Types" (Schulze, 2004). **Figure 4.11** shows the spatial distribution of the 14 veld types found within the Thukela catchment.

The Thukela catchment is dominated by Valley Bushveld, Southern Tall Grassveld, Natal Sourveld as well as Highveld Sourveld and Döhne Sourveld. Other notable veld types are the Ngongoni Veld and the Coastal Forest and Thornveld, the latter two found in the lower coastal end towards the east of the catchment.

The Acocks (1988) veld types are frequently used in hydrology as "baseline" or "benchmark" or "reference" land cover, with their attributes input into hydrological models when investigating the impacts of certain land uses or management practices on hydrological responses (e.g. Taylor, 1997; Dlamini, 2001; Taylor *et al.*, 2004). Schulze (2004) describes in detail a methodology of assigning hydrological attributes to the veld types. The hydrological attributes of the veld types that are found in the Thukela catchment are shown in **Table 5.1** in **Chapter 5**.

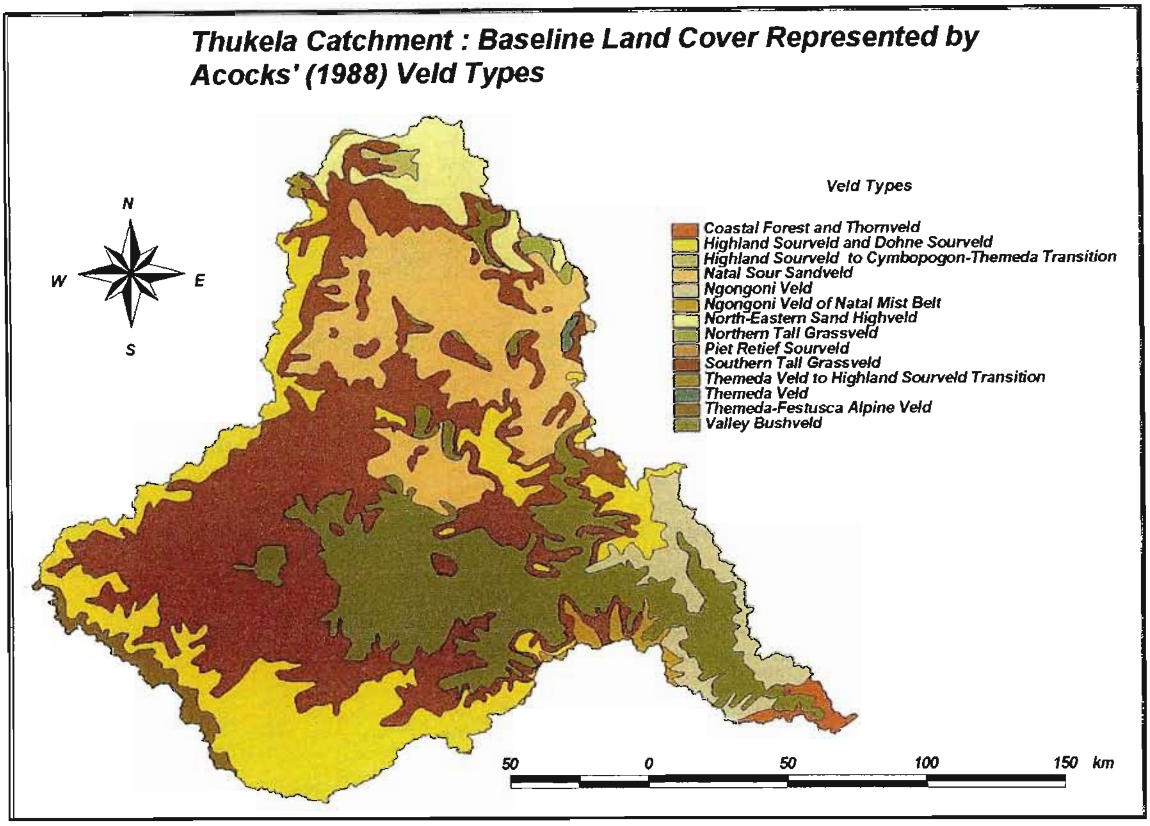


Figure 4.11 Baseline land cover in the Thukela catchment as represented by Acocks' (1988) Veld Types

4.2.2 Present Land Use

The Thukela catchment's natural land cover has undergone significant modifications as a consequence of the uses to which the land has been put. The distribution of "present" land cover and land use in the Thukela catchment **(Figure 4.12)** was derived from Thompson's (1996) interpretation and classification of 1996 LANDSAT TM satellite images. About three-quarters of the area within the catchment is occupied by modified near-natural vegetation which, according to Thompson's (1996) classification, consists of unimproved grasslands, scrubland and low fynbos, thicket and bushland, low forest and woodland and high forests. Commercial forest plantations, irrigated and dryland commercial agriculture, together with subsistence farming and improved grasslands or pastures cover slightly more than one eighth of the catchment. Exposed rock/soil and degraded areas (overgrazed veld) represent slightly less than one tenth of the catchment area.

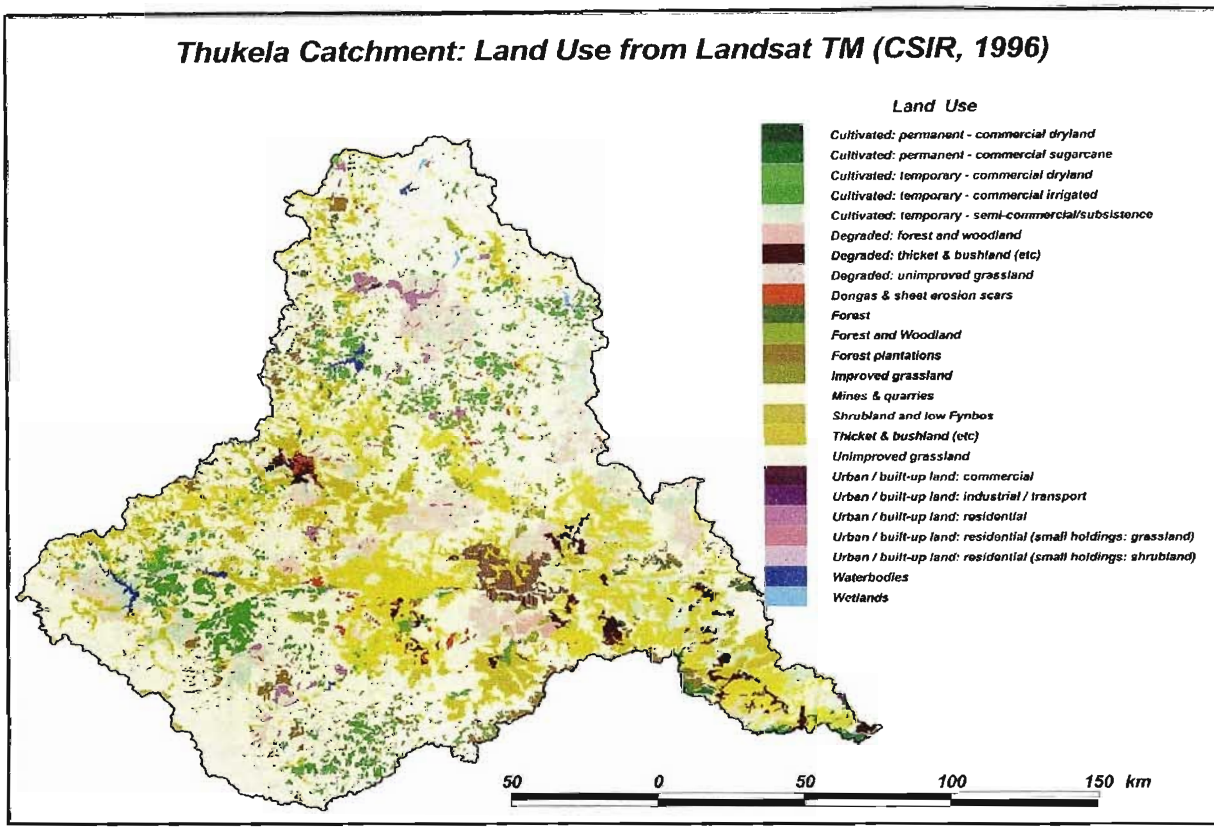


Figure 4.12 Present land use in the Thukela catchment (Source: CSIR, 1996)

Other types of land cover and land use which are found in the catchment include built-up areas in urban areas, mine and quarry sites and water bodies as well as wetlands, each of which covers less than 1% of the catchment area. The overall distribution (%) of present land cover and land uses in the catchment is presented in **Table 4.11**. Parts of the land that is under natural vegetative cover comprise nature reserves and other protected areas within the catchment. These, together with their respective areas and year of establishment, are listed in **Table 4.12**.

Table 4.11 Proportions of land cover and land uses, by percentage, in the Thukela catchment (after CSIR, 1996)

Modified Near Natural	%	Agricultural	%	Other	%
Grassland	53.00	Forest plantation	1.88	Built-up (urban)	0.93
Shrubland & low Fynbos	0.18	Commercial dryland	4.16	Mines & quarries	0.13
Thicket & bushland	19.65	Commercial irrigated	2.42	Degraded land	8.24
Woodland	0.75	Subsistence	7.11	Barren rocks	0.03
Forest	0.57	Pastures	0.28	Water bodies & wetlands	0.67
Total	74.15		15.85		10.00

Table 4.12 Nature reserves in the Thukela catchment (after Wilson, 2000)

Nature Reserve	Area (ha)	Year of Establishment
Chelmsford Dam	6845	1975
Moor Park	264	1967
Ncandu	1875	1925
Spioenkop	7283	1975
Thukela Drift	41	1973
Wagendrift	764	1973
Weenen Game Reserve	4183	1975
Cathedral Peak (partly within the catchment)	32246	1927
Giants Castle Game Reserve (partly within the catchment)	34638	1903
Royal Natal National Park	8094	1916

Within the context of water poverty, land cover and land use distributions in the catchment may be first indicators of a shortage of water in certain areas, for example overgrazed and degraded lands (Dlamini and Schulze, 2004). The fact that a large proportion (74.15%) of the catchment area is still under near-natural vegetative cover, albeit modified, may also be a signal of the possible shortage of the water that is required for desired land uses to be undertaken.

4.3 Historical Background

Before the arrival of the Bantu peoples in the fifteenth and sixteenth centuries, major parts of the Eastern Cape and KwaZulu-Natal (including the Thukela catchment) were occupied by large herds of wildlife and the San peoples, i.e. the Bushmen (Edwards, 1967). The human populations were small and their influences on the ecology were minimal. In the Thukela catchment, the Bantu settled almost entirely in the warmer ecological regions at altitudes below 1500 m altitude where grazing of the palatable so-called "sweet veld" was in abundance. As a result of warfare, the Bantu populations in the catchment decreased during the reigns of Shaka (1818-28) and Dingane (1828-1841), according to Edwards (1967). With many people fleeing KwaZulu-Natal as the result of the Mfecane wars, the Thukela was almost depopulated and inhabited only by roaming bands of fugitive clan remnants (Isaacs, 1936). A large-scale return of the Bantu to KwaZulu-Natal and the Thukela catchment occurred during the peaceful reign of Mpande (1841-1872), which coincided with the entry of the white settlers in many parts of the catchment (Edwards,1967). Between 1849 and 1869, the population doubled from about 100

000 to about 200 000. According to Edwards (1967), this era laid the foundation of the present rural settlement distribution because the influx of returning refugees "created problems" that led to the appointment of the Natal Native Commission of 1846-7. The Commission adopted a principle of dividing the land between Bantu and European by a system of Native Reserves or Locations (Brooks and Hurwitz, 1957), whose boundaries were maintained in substantially similar positions until recently.

4.4 Socio-Economic Profile

The socio-economic profile of the Thukela catchment includes an examination of present settlements and the demographic make-up of the catchment's population, its economic wellbeing and the levels of delivery of household services. Unlike most other parts of this chapter, which are based on reviews of existing material, the sections which follow are based on new work by the author. The socio-economic analysis was undertaken using data from the National Population Census databases (StatsSA, 1996; 2001). Both the datasets from the 1996 and the 2001 National Population Censuses are geographically referenced; hence, they were amenable to GIS manipulation and presentation. The smallest scale of aggregation of the 1996 census data was the enumerator area (EA), while that of the 2001 was the sub-place (SP). Before these data were analysed and presented as graphs and maps, they were aggregated into subcatchment values (cf. Chapters 4 and 5 for detailed descriptions of subcatchments), since the subcatchment was the working spatial unit selected for this study.

4.4.1 Present Settlements and Demography

The total population of the catchment in 2001 was just under 2.1 million (StatsSA, 2001). This shows an increase of about 400 000, or 32%, between 1996 and 2001. The present average population density, according to the 2001 population census, is slightly more than 70 persons per km^2. A majority of the population (56.45%) resides in historically tribal areas, while about a quarter of the total population (25.77%) lives in urban areas. The overall distribution of the population in the catchment, according to settlement types, is presented in **Table 4.13**. The spatial patterns of total population and population density (**Figure 4.13**) in the Thukela catchment suggest that the people in rural areas live dispersed over larger areas compared to those who live in nucleated urban areas. The population densities in the subcatchments in which towns are contained (e.g. Newcastle, Ladysmith, Estcourt, Dundee, Utrecht, Mandini) are in the excess of 80 persons per km^2, which is slightly higher than the catchment average of 71 people per km^2. The subcatchments in many rural or tribal areas such as Nqutu and Nkandla have moderate population densities in the range of 40-60 people per km^2. Other places such as Msinga are densely populated despite being predominantly rural. Those parts of the catchment that consist mostly of commercial farmlands have the lowest population concentrations, with fewer than 20 people per km^2. The areas that are still under natural vegetation (cf. **Section 3.2**) also have low population densities. Some of these are designated nature reserves. The fact that there was a significant increase in the overall population of the catchment between 1996 and 2001 has been alluded to, above. However, not all the areas exhibit this change, with population densities decreasing in some parts.

Table 4.13 Distribution of population, by settlement type, in the Thukela catchment

Settlement Type	Population	%
Sparse (10 or fewer households)	7 342	0.36
Tribal settlement	1 167 247	56.45
Farm	308 800	14.93
Smallholding	14 398	0.70
Urban	532 802	25.77
Informal	19 001	0.92
Recreational	2 363	0.11
Industrial	2 837	0.14
Institutional	10 125	0.49

The spatial trends of absolute and relative changes of population in the catchment, shown in **Figure 4.14**, indicate that the reduction occurs mainly in rural areas such as Msinga. Some catchments in urban areas also show a decrease in total population. About 60% of the overall population increase in catchment can be attributed to births, while the remainder can be attributed to immigration. Emigration and immigration are likely to have played a role in the reduction of population in rural areas and the increase in urban areas.

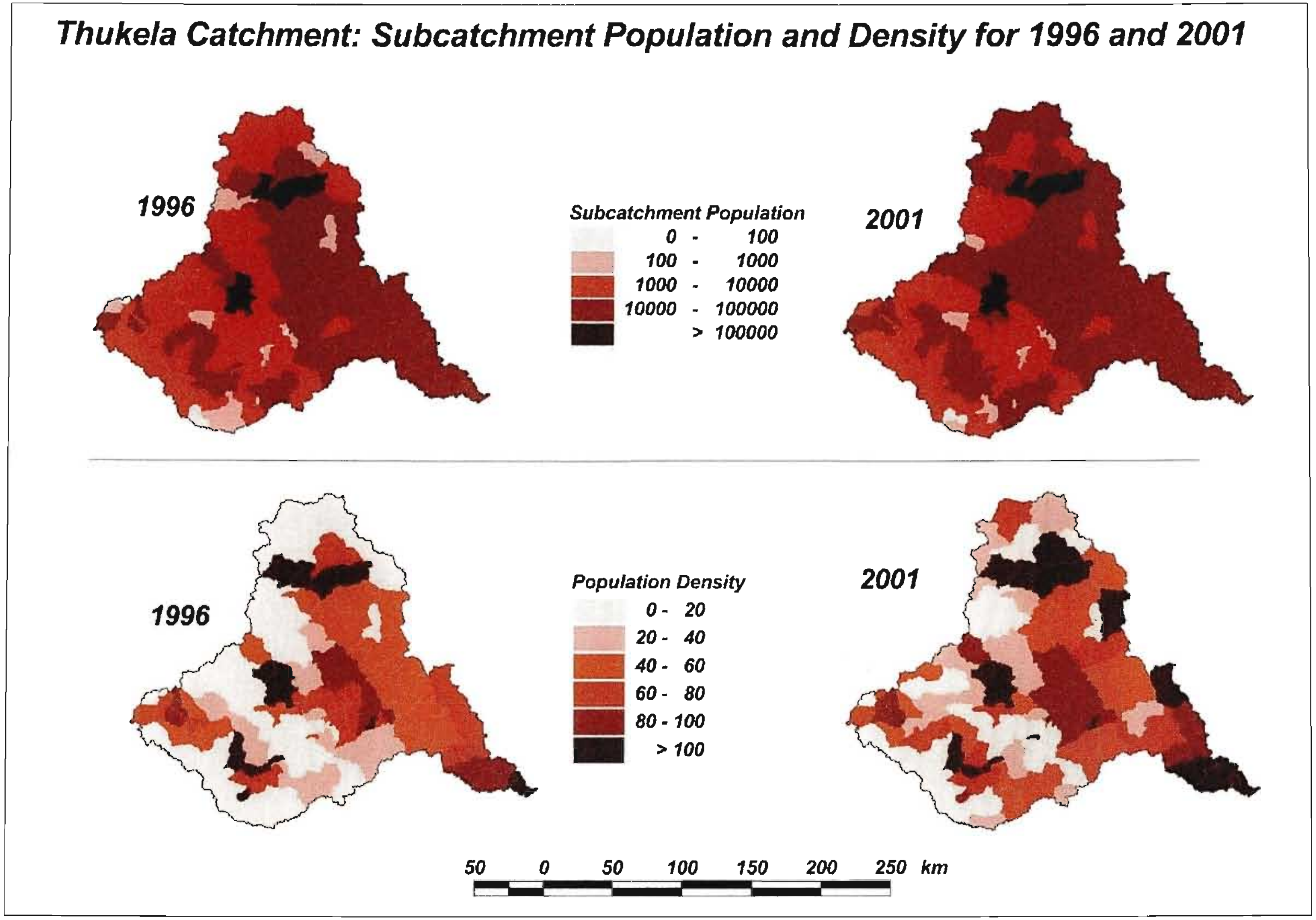


Figure 4.13 Spatial distributions of population and population density per subcatchment in the Thukela catchment for 1996 and 2001

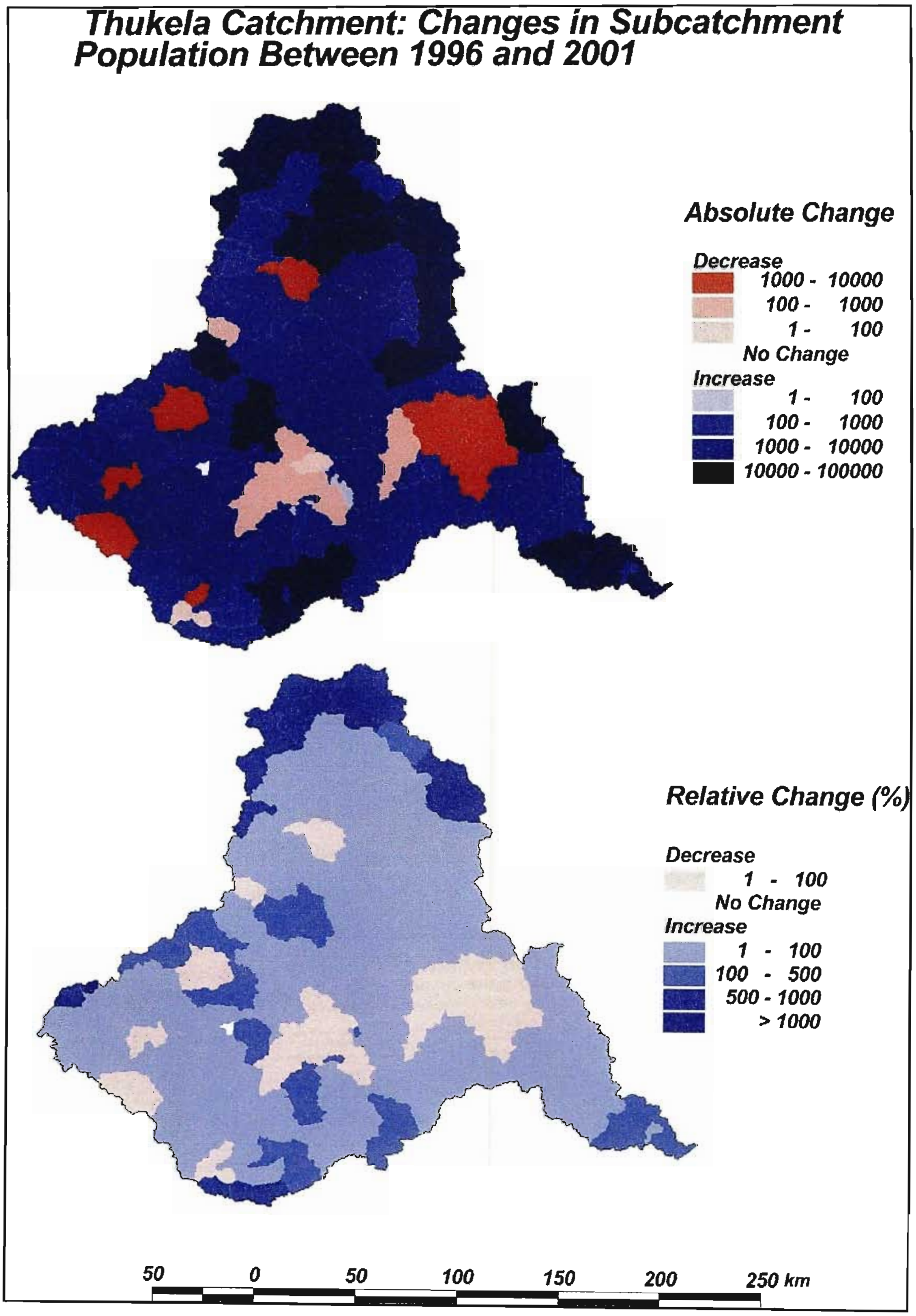


Figure 4.14 Population changes per subcatchment in the Thukela catchment between 1996 and 2001

About 120 000 (~6% of the total population) people who were born in the catchment before 1996 are not staying where they used to stay before 1996. **Figure 4.15** shows the spatial distribution of the immigrants. While immigrants are present throughout the catchment, more than 5 000 people are in urban subcatchments, particularly Ladysmith, Newcastle and Estcourt. In the rural areas, the immigration may represent people settling in areas which were not inhabited previously, such as new communities in the Drakensberg area. About 20% of the immigrants are from outside of the province of KwaZulu-Natal. However, it cannot be ascertained whether the remaining 80% are from the Thukela catchment or from elsewhere in the province.

4.4.2 Economic Wellbeing

Overall, the Thukela catchment is relatively poor, with people having low skills levels, while limited economic activity and low income levels prevail over large areas. Unemployment in 2001 stood at more than 35%, while in more than 20% of the adult population had never received a formal education. The average economic dependency ratio (defined as the total of the 0-14 and the 65+ age groups as a proportion of the overall numbers employed) is high at about ~3.7, which implies that each employed person is economically responsible for ~4 dependants. The breakdowns of employment status and highest levels of education reached are shown in **Figures 4.16** and **4.17**. Average per capita income is ZAR5 400 per annum, which is well below the national average of ZAR12 900 (Wilson, 2000).

The spatial patterns of average per capita annual incomes in the catchment (**Figure 4.18**) depict subcatchments in urban centres such as Newcastle, Ladysmith, Dundee and Estcourt as having the highest average annual incomes of more than ZAR10 000. About 41% (46 out of 113) of the subcatchments have relatively low per capita incomes of less than ZAR5 000 per annum. All the subcatchments in this income category are predominantly rural and located in magisterial districts such as Nkandla, Nqutu and Msinga, all of which were parts of the KwaZulu independent homelands prior to 1994.

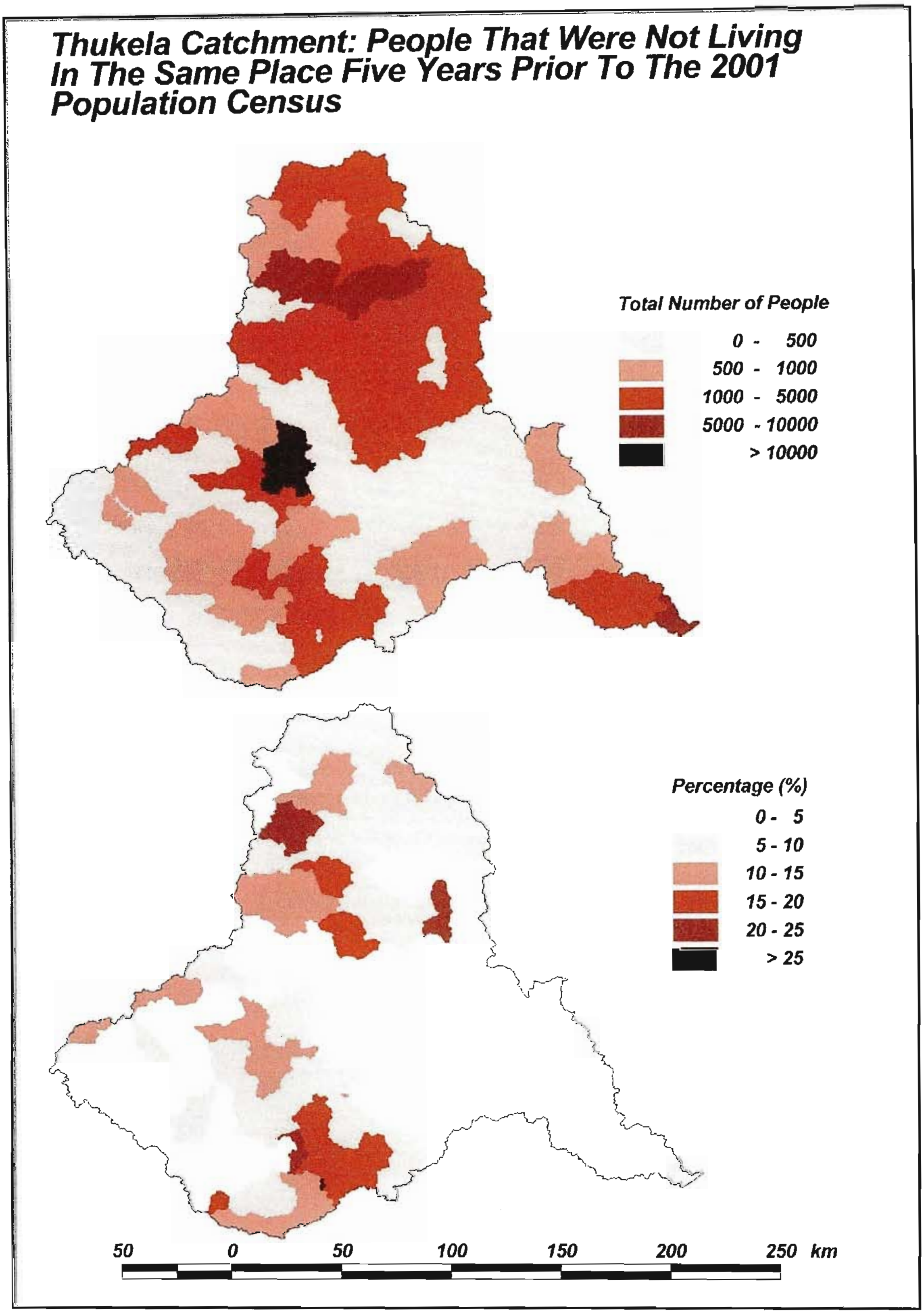


Figure 4.15 Patterns of migration per subcatchment in the Thukela catchment

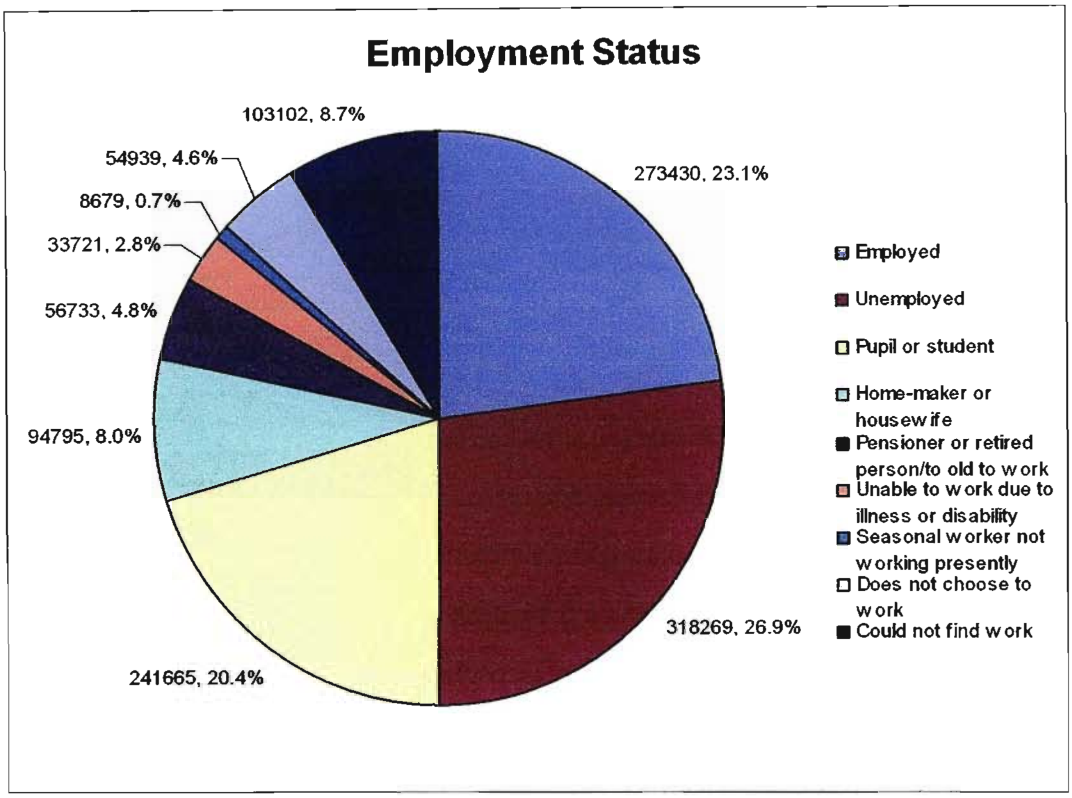


Figure 4.16 Subdivision of adult population in the Thukela catchment according to employment status

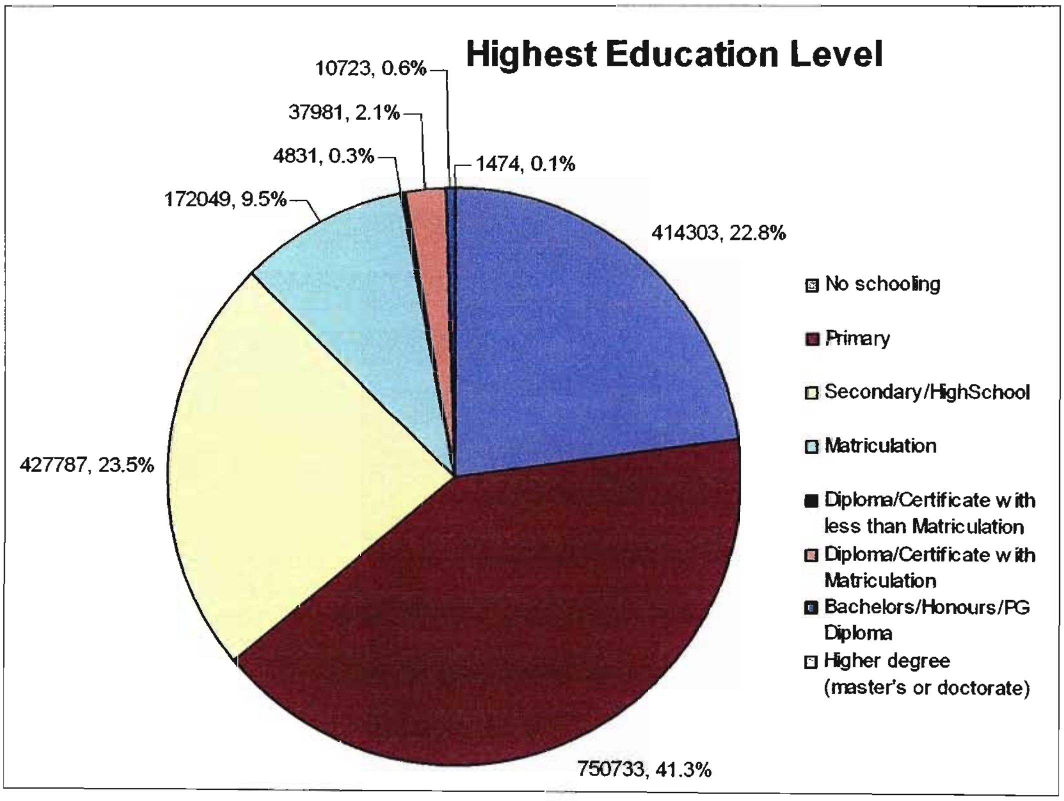


Figure 4.17 Subdivision of adult population in the Thukela catchment according to highest level of education attained

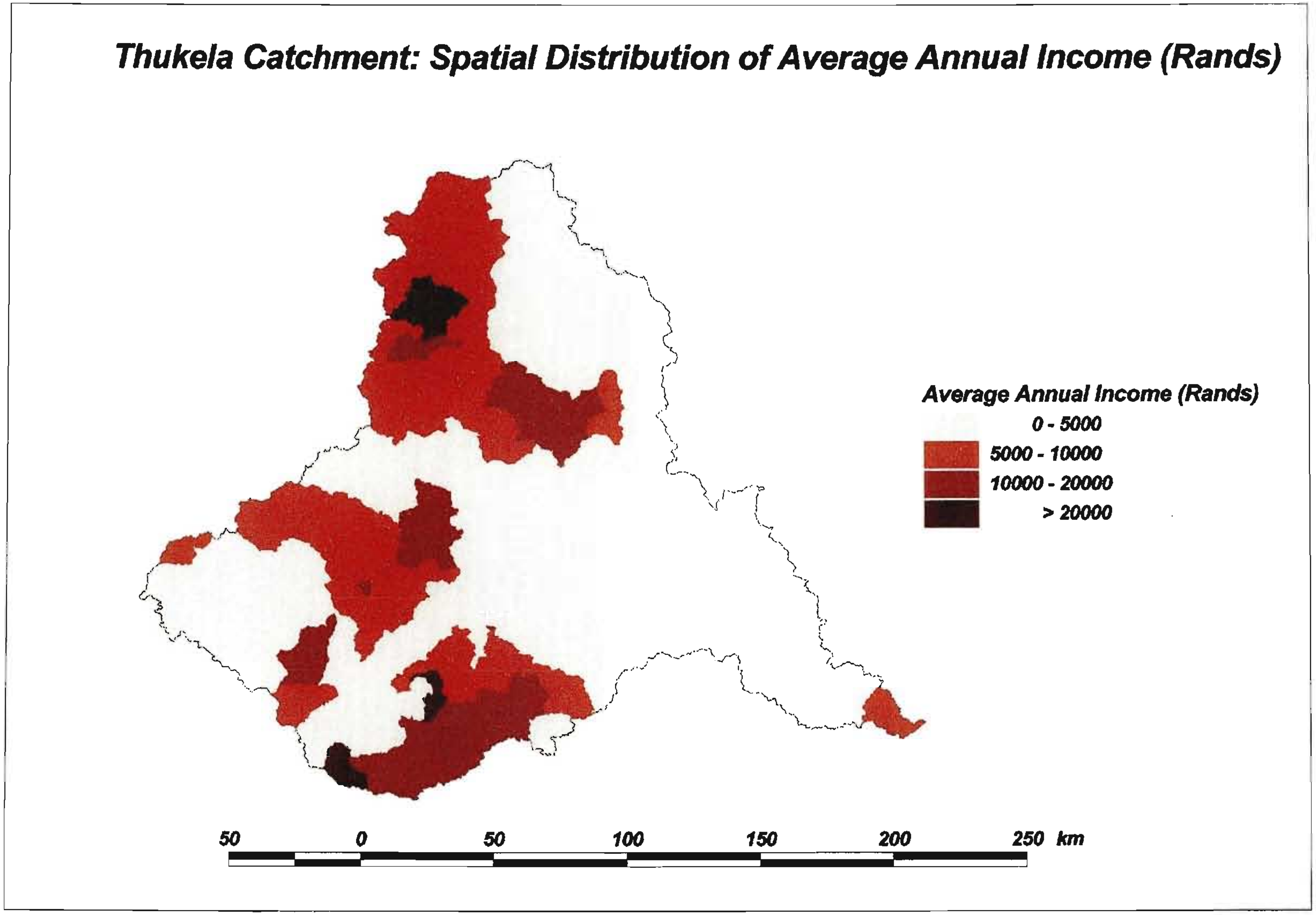


Figure 4.18 Spatial distribution in the Thukela catchment of per subcatchment of average annual individual income (ZAR)

Figure 4.19 shows that, in terms of income, the situation is more dire than it first appears, as more than 80% people in the low income categories actually have no income at all. The spatial patterns of socio-economic disadvantage in the catchment are further illustrated in **Figure 4.20** by the poverty index, a composite measure that takes into account the levels of literacy, essential service provision and economic dependency. Again, the levels of economic disadvantage appear to be related to the dominant types of settlements in a catchment.

The rural subcatchments tend to be the poorest. For example, Msinga, the poorest district in the catchment and in fact, in the whole of South Africa (Wilson, 2000), rates poorly according to this index. On the other hand, urban areas such as Newcastle are less disadvantaged.

4.4.3 Household Services

The levels of household services provision in the Thukela catchment exhibit sectoral and geographical variations. **Table 4.14** shows that about 48% of households are served with water in a manner that meets the minimum standards stipulated by the DWAF. In 2001, more than 100 000 households (24%) still collected water directly from dams, pools, stagnant water, springs, rivers and streams, which are often unprotected, while more than 3 500 households purchased water from vendors. The households that use unprotected water sources are susceptible to water-borne diseases. This susceptibility becomes a real concern when viewed in light of the 103 491 households without any form of sanitation, or the 82 049 who do not have access to organised refuse disposal facilities.

Access to electricity and reachable telephone communication facilities were 51% and 80% respectively according to the 2001 population census (**Table 4.14**). The spatial patterns of household services in the catchment indicate that the levels of delivery vary with the types of settlements (**Figure 4.21**). The subcatchments in rural areas tend to have the largest proportions of households using unprotected water sources, without proper sanitation, without electricity connections, or without reachable telephone facilities. On the other hand, the access levels in urban areas are relatively high (often more than 60%), irrespective of the type of service.

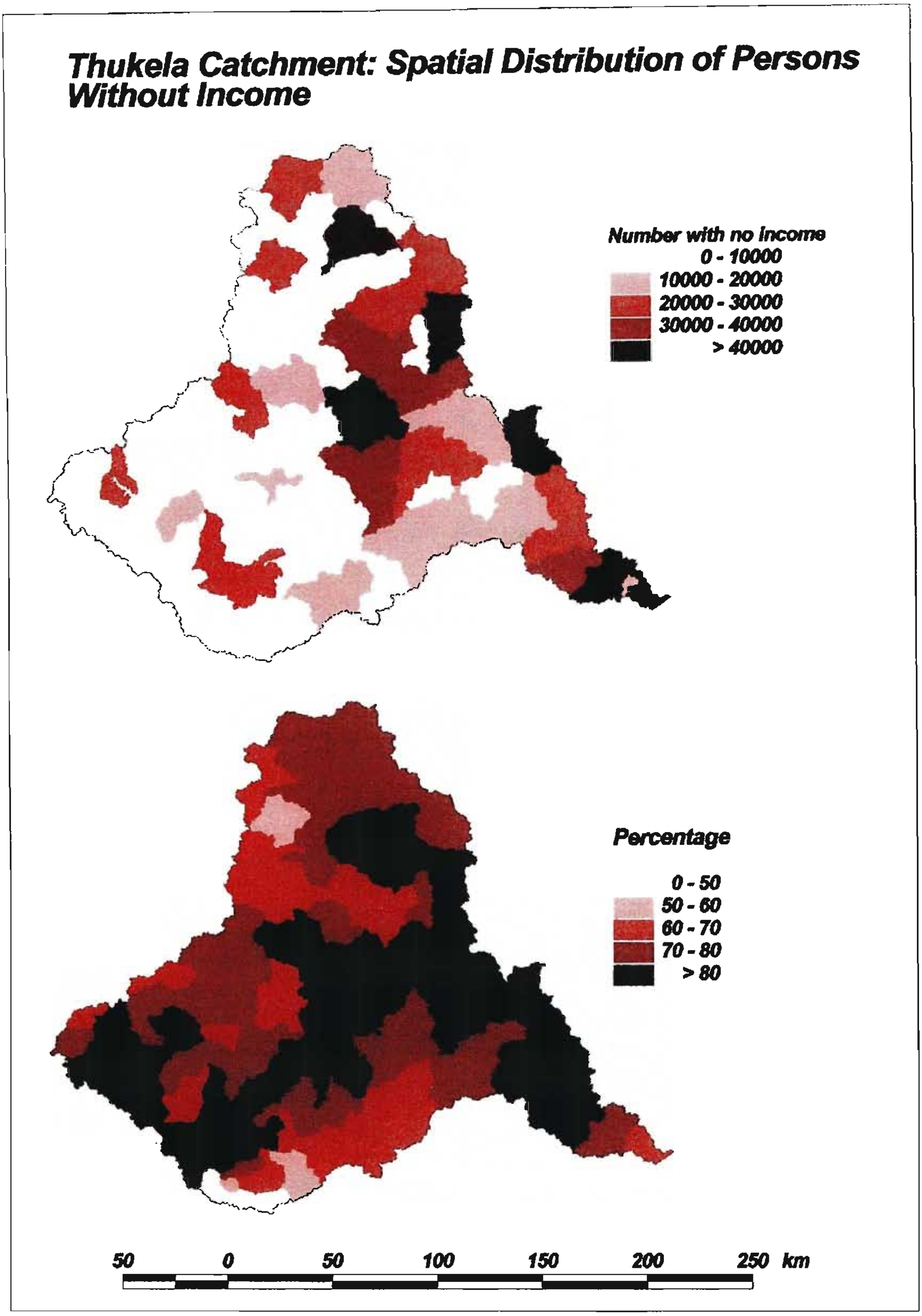


Figure 4.19 Spatial distribution, per subcatchment in the Thukela catchment, of people without regular monetary income

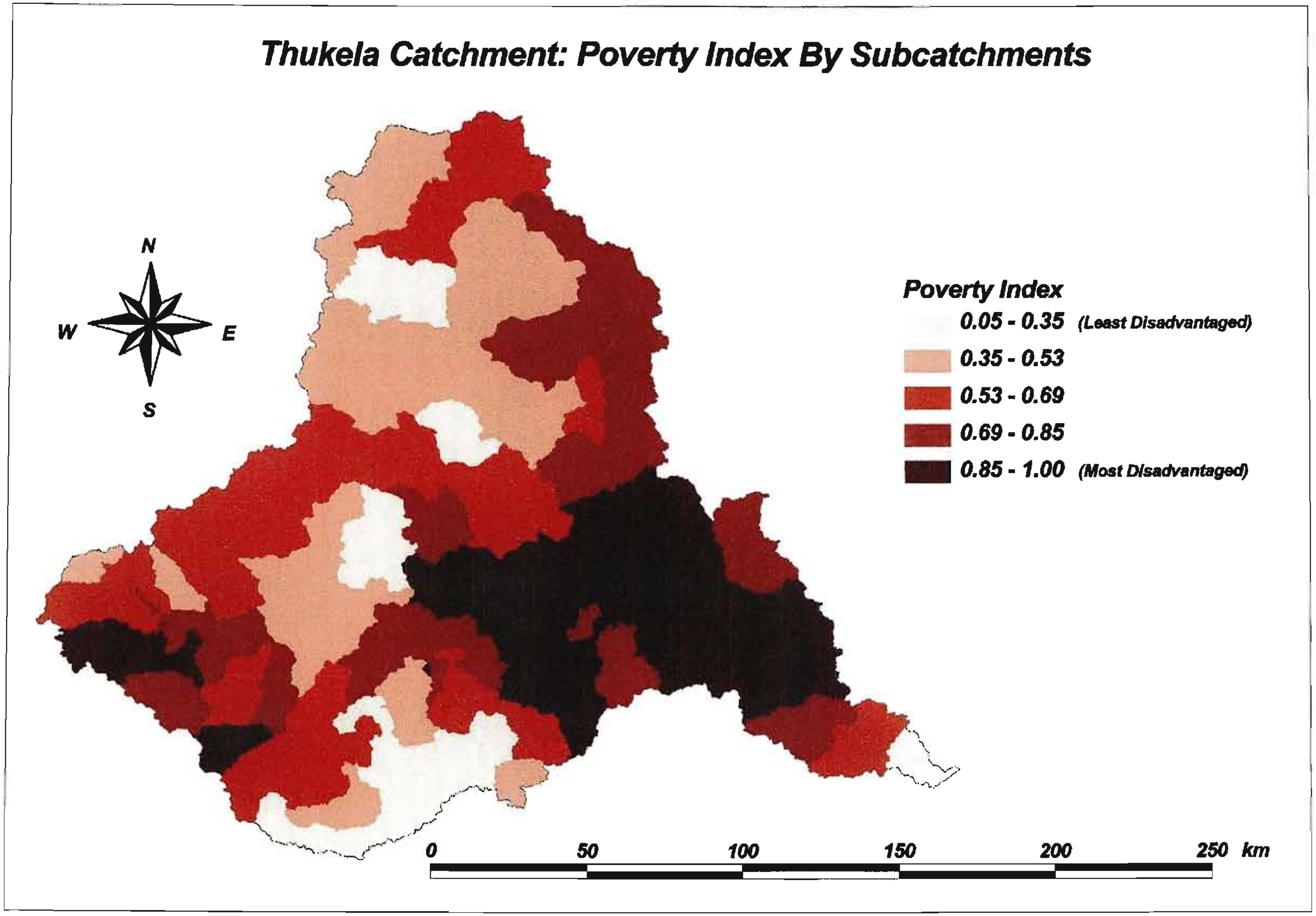


Figure 4.20 An overall index of poverty per subcatchment in the Thukela catchment (after Wilson, 2000)

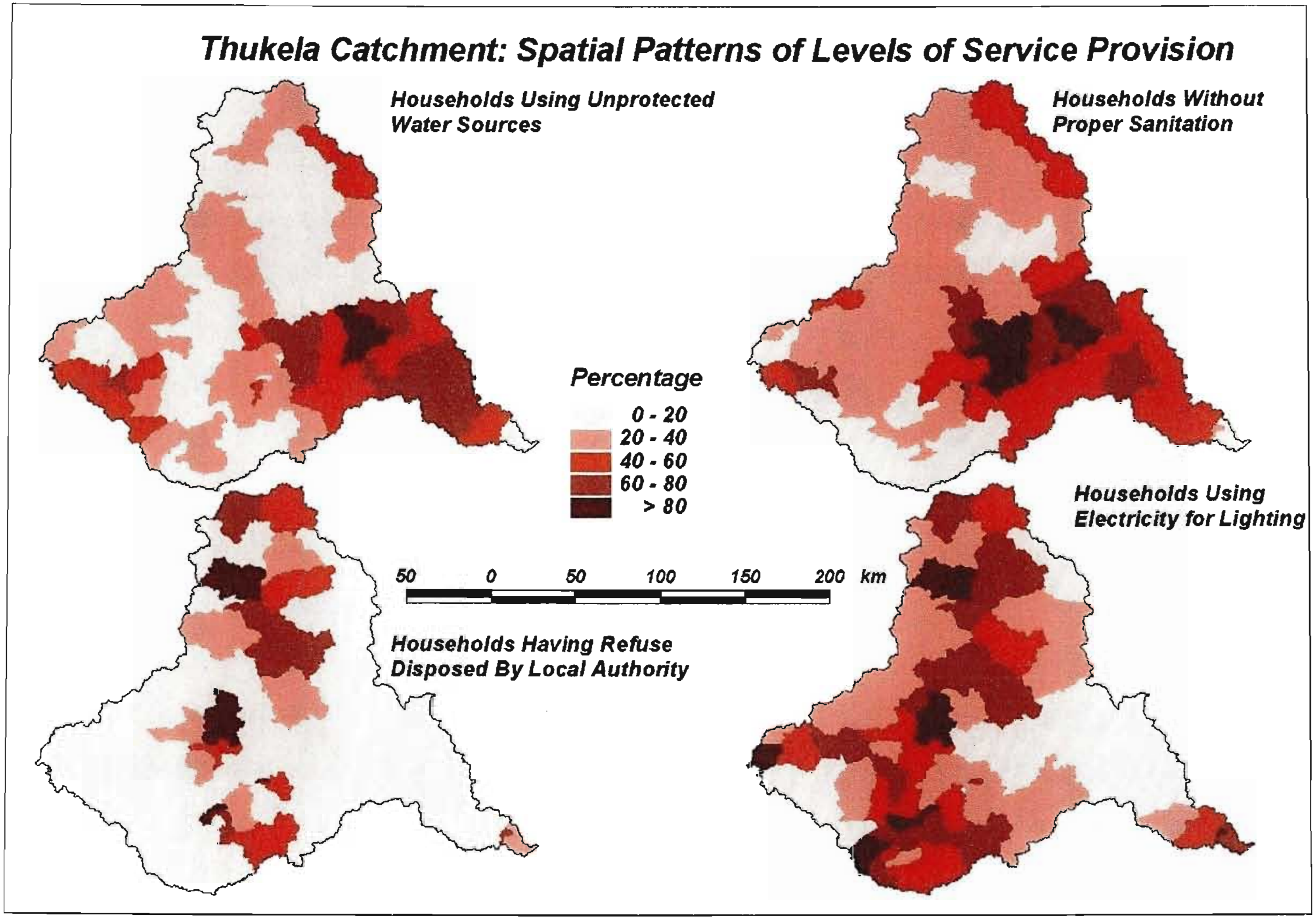


Figure 4.21 Spatial patterns, per subcatchment in the Thukela catchment, of the provision of selected services

Table 4.14 Distribution of household services in the Thukela catchment

Water Supply			Sanitation			Garbage Removal		
	Total	%		Total	%		Total	%
Piped water inside dwelling	72 659	16	Flush toilet (sewer)	124 099	28	Local authority at least weekly	132 277	30
Piped water inside yard	99 635	22	Flush toilet (with septic tank)	12 986	3	Local authority less often	4 168	1
Piped communal < 200m. from dwelling	45 228	10	Chemical toilet	16 544	4	Communal refuse dump	6 021	1
Piped communal > 200m. from dwelling	67 029	15	Pit latrine with ventilation (VIP)	44 187	10	Own refuse dump	223 398	50
Borehole	38 626	9	Pit latrine without ventilation	141 205	32	No rubbish disposal	82 049	18
Spring	25 488	6	Bucket latrine	5 397	1			
Rain-water tank	4 819	1	None	103 495	22			
Dam/pool/stagnant water	10 412	2						
River/stream	70 177	16						
Water vendor	3 663	1						
Other	10 177	2						
Total	**447 913**	**100**		**447 913**	**100**		**447 913**	**100**
Energy Source for Lighting			Telephone Facilities					
	Total	**%**		**Total**	**%**			
Electricity	226 429	51	Telephone in dwelling and cell-phone	32 143	7			
Gas	2 090	0	Telephone in dwelling only	32 024	7			
Paraffin	12 537	3	Cell-phone only	62 410	14			
Candles	203 475	45	At a neighbour nearby	46 453	10			
Solar	1 120	0	At a public telephone nearby	166 358	37			
Other	2 262	1	At another location nearby	21 367	5			
			At another location; not nearby	35 005	8			
			No access to a telephone	52 153	12			
Total	**447 913**	**100**		**447 913**	**100**			

Fieldwork for this study, which involved the author's traversing the catchment extensively and regularly between 1999 and 2004, showed that the rural hinterland was generally underdeveloped. It was also noted that many household units in the rural communities were scattered along ridge lines, an observation also made by Lenehan and Martin (1997). Associated with the poor access to services in the rural areas is the limited infrastructural development. The rugged terrain of large parts of the catchment (cf. **Figure 4.2**) and the tendency of the settlements to be scattered along ridge lines render infrastructural development both an engineering challenge and a prohibitively expensive undertaking (Mhlongo, 2001).

4.5 Water Resources and Management

The Thukela catchment is one of 19 Water Management Areas (WMA) which have been delineated in South Africa (cf. **Figure 4.1**). In future Catchment Management Agencies (CMAs) will be operating these WMAs, in conjunction with the Department of Water Affairs and Forestry (DWAF), and share the responsibility of managing water resources. The following subsections present a brief overview of the availability of water resources and key management issues in the catchment. A more detailed investigation of water resources in the catchment will follow in Chapter 5.

4.5.1 Availability of water resources

The brief analysis below is based on simulated streamflows, the derivation of which is described in detail in Chapter 5. The average mean annual runoff (MAR) for the catchment when assumed to be under baseline land cover conditions, is 136 mm, which is equivalent to 17% of mean annual precipitation. MAR values per subcatchment vary widely, from less than 25 to over 250 mm. High runoff values are simulated in the southwest and northern sections of the catchment, which make up parts of the high Drakensberg range of mountains (cf. **Figures 5.10** and **5.12**) characterised by high rainfall. Other areas of high runoff occur in the southeastern tail of the catchment along the Indian Ocean, which has a maritime climate again with high rainfall. Save for a few patches of MAR > 150 mm, values ranging from 25 to 150 mm are simulated in the relatively dry central parts of the catchment.

4.5.2 Major Impoundments

The water resources of especially the upper Thukela catchment have undergone relatively extensive development. Just under 10^9 m^3 of water are currently impounded in large dams on various tributaries across the catchment (**Table 4.15**), of which about 630.72 million m^3 can be transferred annually through the Thukela-Vaal scheme to supply the Gauteng region, the economic heartland of South Africa, when it requires the water (Wilson, 2000). Further water resources developments have been proposed (Jewitt *et al.*, 1999) for possible future inter-basin transfers to the Vaal River System. This system would be capable of transferring 15 $m^3.s^{-1}$ from two additional proposed impoundments with combined potential capacities of up to 2 909 million m^3 (**Table 4.15**).

Table 4.15 Current and proposed impoundments in the Thukela catchment, as well as their capacities and the tributary on which they are located (Wilson, 2000)

Impoundment	River	Capacity ($10^6 m^3$)
Spioenkop	Thukela	274.3
Wagensdrift	Bushmans	58.5
Chelmsford	Ngagane	199.1
Craigienburn	Mnyamvubu	23.5
Woodstock	Thukela	380.8
Kilburn	Thukela	35.7
Jana*	Thukela	1468 – 2483
Mielietuin*	Bushmans	284 – 426

* Proposed

Schemes located in the Thukela which transfer water to other WMAs include:

- The Mooi – Mgeni scheme, transferring water from the Mooi River into the Mgeni catchment;
- The Zaaihoek scheme, supplying Majuba Power Station and transferring water from the Buffalo catchment into the Vaal system;
- The Drakensberg Pump Storage scheme, transferring water from the upper Thukela into the Vaal system; and
- The Middledrift scheme, transferring water from the lower Thukela into the Usuthu to Mhlathuze WMA (Wilson, 2000).

This extensive development, particularly the facility to transfer substantial volumes of water out of the Thukela WMA, creates a real potential for water-related conflicts. This has led to negative social and cultural impacts, such as the resettlement of communities, loss of cultural artefacts, loss of sites of traditional resources for livelihood and sustenance, loss of recreational facilities (e.g. river rafting) after flooding of areas upstream of the dam wall (Wilson, 2000). From an economic perspective, the transfer of water to neighbouring catchments can deprive the catchment of a resource that would otherwise be available for potential development in the donor catchment. These developments also impact on the environment through the disturbance of the aquatic ecological balance that may lead to loss of biodiversity.

4.5.3 Water Sector Management

As a democracy, South Africa is faced with many challenges, including those that relate to redressing political injustices of the past. Among these is the need to redistribute and ensure equitable access to resources such as land and water. As with many sectors, the water sector has, since 1994, seen major changes in legislation that govern its resources operations and management. Two separate, but mutually supportive acts of parliament, *viz.* the Water Services Act (RSA, 1997) and the National Water Act, or NWA (RSA, 1998), guide water services and water resources management respectively. As has been the case in other catchments in South Africa, the Thukela has, in one way or the other, been affected by the new legislation.

On the one hand, the Water Services Act provides a legal framework to the constitutional right of access to basic water supply and sanitation and an environment not harmful to human health (Muller, 2002). The Community Water Supply and Sanitation Programme and the State's Free Basic Water Policy are the outcomes of this Act. The Free Basic Water Policy commits local government, as the Water Supply Authority (WSA) under the Municipal Structures Act (Act 110 of 2000), to provide all households with a minimum supply of 6 000 litres per month at no cost (DWAF, 2001a). Despite these national initiatives and the fact that the Thukela catchment is relatively richly endowed with water resources (cf. **Chapter 5**), some communities still do not have access to adequate safe water for both domestic and productive uses (Dlamini and Schulze, 2004). By July 2005 only 66 % of the total population and 63 % of the rural poor in KwaZulu-Natal were served with the Free Basic Water (DWAF, 2005). Infrastructural and institutional restructuring, as well as economic and political considerations, present practical challenges in relation to the implementation of the free basic water policy (Sheperd, 2001). In the Thukela Catchment, for example, Uthukela Water, which is an amalgamation of the Amajuba, Newcastle, Umzinyathi and Uthukela water services authorities, only started providing water and sanitation on 1 July 2004.

On the other hand, the National Water Act, among many other issues, does away with the concept of "private water" and instead recognises water as a "national asset"

(DWAF, 2003). It ensures the protection of both an ecological and basic human needs reserve, requires the registration of all water users for the purpose of licensing, and defines the structure for a significant devolution of power in water management through the development of Catchment Management Agencies (CMAs). Work on the establishment of the Thukela Catchment Management Agency is at an advanced stage, i.e. the process was already at a transitional period between the establishment and fully functional stages in the middle of 2003 (Karar, 2004). Together with DWAF, the Thukela Catchment Management Agency (CMA) will share the responsibility of managing water resources in this WMA.

4.6 Conclusions

The Thukela catchment is characterised by a wide diversity with respect to physiography, climate and (by extension) natural vegetation as well as, land use, demography, culture and economy. These physical, biochemical and socio-economic characteristics and their distribution have a bearing, in isolation or in concert, on water poverty, or water scarcity, in the catchment. Large parts of the catchment are semi-arid in climate, have steep-sloped terrain, have low plant water availability and soils that display high erodibility potential. This points to a natural susceptibility to water poverty. The socio-economic situation is no better. Many communities, a high percentage of which occupy the naturally high risk areas, have low skills levels, high proportions of unemployed people, low or no income and low services delivery. This implies a vulnerability in that the capacity to cope with any water scarcity is low. Infrastructural development, which should improve service delivery, is made prohibitively expensive by the difficulty of the terrain.

The high rainfall in the Drakensberg and western highland regions, much of which is converted to runoff, makes the Thukela catchment one of the most water-rich basins in South Africa. This abundance of water in the catchment is of strategic importance nationally because it enables vast amounts of water to be transferred to Gauteng, the economic hub of South Africa. The fact that the Thukela catchment is water rich, yet a large percentage of its population is still using unprotected water sources, is a paradox that highlights the need to address water resources management issues in terms of further development of the resource and the improvement of access to adequate and clean water.

As is the case with other catchments in South Africa, the Thukela is experiencing institutional restructuring subject to the policy reforms endorsed by, and enshrined in, the two mutually supplementary pieces of water legislations, *viz.* the Water Services Act of 1997 and the National Water Act of 1998. These Acts have laid the foundation for the establishment of structures and the formulation of policies (e.g. the Free Basic Water initiative), which are aimed at addressing the needs of the water poor. The encouraging levels of delivery with respect to the Free Basic Water Initiative, the advanced stage at which the establishment of the Thukela CMA is, and the coming into being of Uthukela Water, are early positive signals of the progress made with respect to the water sector in the catchment. However, the impact of these reforms on the general wellbeing of the affected communities is not known yet.

This general description of the Thukela catchment has highlighted the socio-economic situation and the way in which it is affected by biophysical characteristics of the catchment. However, the description does not provide a holistic assessment of the water-poverty link, results of which can be more useful in water-based development planning and policy evaluation than the mere description of the catchment. Therefore, the next chapters progress towards a quantitative evaluation of this link. In **Chapter 5**, which follows, a comprehensive and quantitative assessment of the annual renewable water resources in the Thukela catchment is made using traditional hydrological techniques and indicators.

5 PRIMARY WATER AVAILABILITY AND ITS IMPLICATIONS ON WATER POVERTY IN THE THUKELA CATCHMENT

5.1 Introduction

Water availability may mean "different things to different people". In this study, it refers to the amount of renewable and non-renewable freshwater resources that a particular location has over a specific period. A distinction is made between an area's natural, or primary, freshwater endowment (Sullivan *et al.*, 2002), which is the focus of the analysis in this chapter, and total water availability, with the difference being the origins of the water and extent of human interventions. The former consists only of the water that is generated within a region when that region is subjected to a minimum of human impacts, while the latter includes (in addition to the locally generated water under baseline, or reference land cover conditions) external sources of water such as engineered inter-basin transfers, desalinized sea water and any other source on the water resource through catchment land use or channel manipulations.

An assessment of natural water availability can give a first indication of the potential for water poverty, or water scarcity, in relation to the natural endowment as a result of prevailing climatic and physiographical conditions, before demand on and use of the resource are even considered. Natural endowment with respect to water poverty is associated with a region's aridity, or proneness to droughts. Several methods such as frequency analyses or evaluations of temporal and spatial variability of precipitation, streamflows, evapotranspiration, groundwater and soil moisture are commonly used to assess natural water availability. Therefore, this chapter presents a detailed assessment of the natural water resources of the Thukela catchment. Ideally, such an assessment should involve the analysis of sufficiently long historical hydroclimatic data dating back to periods before significant anthropogenic impacts occurred. However, such data are seldom available. Therefore, surrogate methods have to be used. Models, be they statistical, physical or simulation, are often used to generate surrogate information for analysis. In hydrology, simulation modelling is a well established field of study with numerous tested and accepted methods and tools available for use. Among other reasons, the integrative nature of streamflows, which reflects the combined effects of prevailing conditions in the catchment (Jewitt, 1998; Katz *et al.*, 2002), dictated that the focus of this assessment be on renewable surface water resources. While its importance in water scarcity/poverty analysis is acknowledged, the consideration of groundwater in this study is confined to a broad overview as a result of data limitations.

5.2 The Hydrological Modelling System

Hydrological modelling can be a challenging undertaking. The first hurdle is to choose which model to use. In light of the multitude of hydrological models from which to choose (cf. Beven, 2000), this is not an easy task, and it is often complicated further by conflicting modelling ideologies, institutional stereotypes, and vigorous marketing (Schulze, 1998). The *ACRU* agrohydrological modelling system (Schulze, 1995; Smithers and Schulze, 1995; Schulze, 2001; 2004) was selected for the simulation of the baseline hydrological responses of the Thukela catchment. The soundness of its conceptual and structural framework (discussed in detail later), its practical suitability for this particular study with respect to input data availability, available in-house expertise, computing resources and the timeframe of research are all factors contributing to the decision to use the *ACRU* model. The *ACRU* model has been developed, tested and applied extensively and successfully in many diverse catchments in developed and developing countries (Schulze, 2004b). The Thukela catchment is one of the catchments the hydrological responses of which have been verified and simulated using this model for other studies (e.g. Schulze and George, 1987; Jewitt *et al.*, 1999; Dlamini and Schulze, 2004).

5.3 The *ACRU* Agrohydrological Modelling System

ACRU is a daily time step, physical-conceptual and multi-purpose agrohydrological modelling system (Schulze, 1995; 2004) with options to output, *inter alia*, daily values of stormflow, baseflow, peak discharge, reservoir status, recharge to groundwater, sediment yield, as well as irrigation water supply/demand on a catchment basis and, additionally, having the facility to output seasonal yields of selected crops, either with or without irrigation, and at any location within the catchment (**Figure 5.1**).

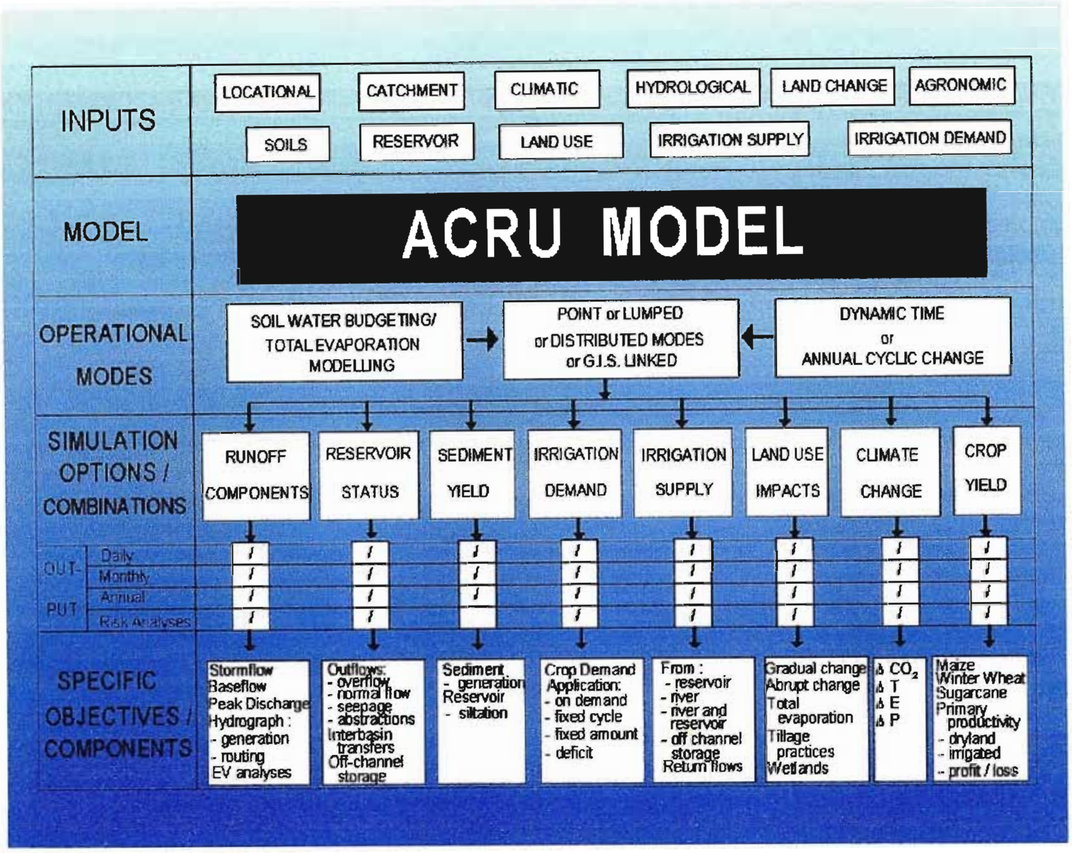


Figure 5.1 The ACRU agrohydrological modelling system: Concepts (Schulze, 1995)

The model revolves around multi-layer soil water budgeting concepts (**Figure 5.2**). It is structured to be hydrologically sensitive to impacts of different catchment land uses such as urbanisation and afforestation and changes thereof, and also to the impacts of reservoir operations, run-of-river abstractions, irrigation practices and of enhanced greenhouse gas induced climate change on catchment streamflows and sediment generation.

For large areas, or where complex land uses and/or hydrologically variable soils occur, or where streamflows in the channel have been modified by reservoirs/abstractions, the catchment is discretised into relatively homogeneous response zones, and *ACRU* then operates as a hydrologically cascading, distributed cell-type model. The *ACRU* model requires input of known and measurable spatial and temporal variables which characterise the catchment's hydrological behaviour. Catchment information required may be grouped into:

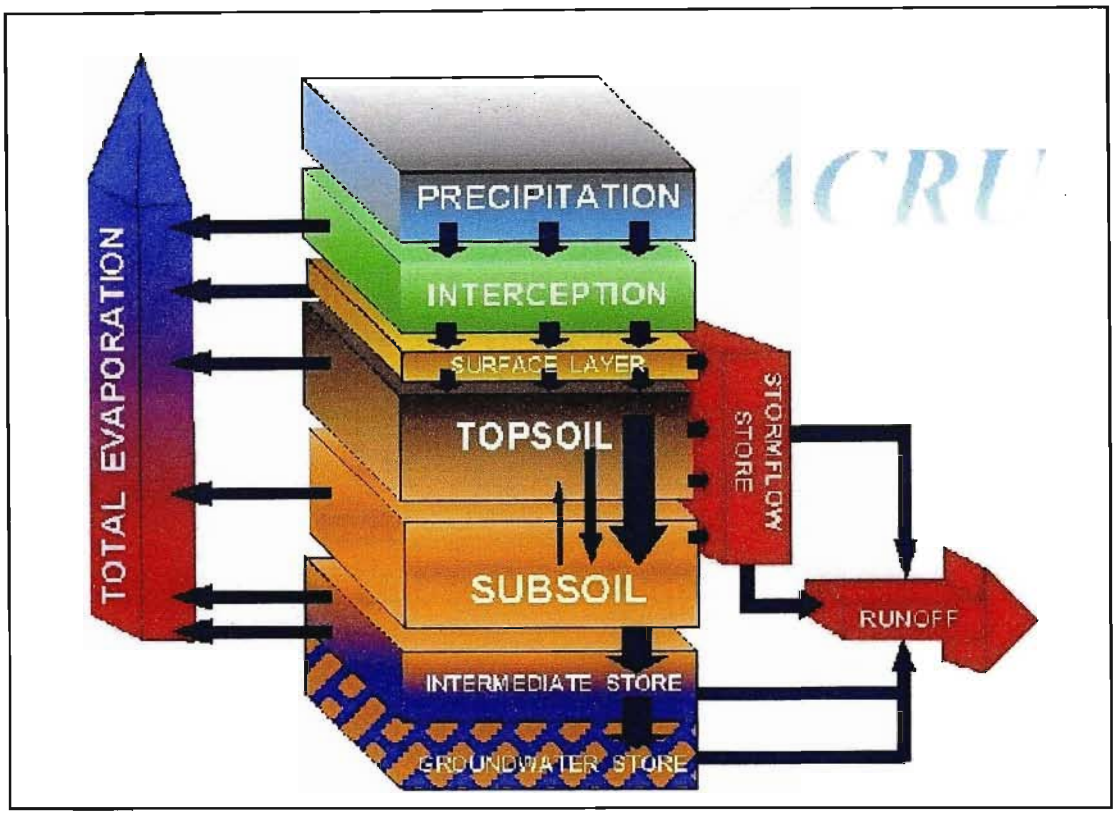


Figure 5.2 The ACRU agrohydrological modelling system: Structure (Schulze, 1995)

- climatic, e.g. daily rainfall, temperature, potential evaporation;
- physiographic, e.g. area, slope, hydrological soil properties;
- biophysical, e.g. baseline land cover and present rainfed land uses and their
- hydrological properties; and other
- land use/management-related practices, including irrigation demand and supply, as well as domestic, industrial and livestock water abstractions from either river runoff or from reservoirs, and return flows.

Within the *ACRU* model the input information is transformed to produce the eventual hydrological responses through algorithms which represent the processes of each sub-system of the hydrological cycle (e.g. the rainfall, interception, infiltration, stormflow generation, groundwater recharge or sediment yield sub-systems) and the manner in which they interact with one another through feedforwards and feedbacks and are linked. The model also calculates thresholds at which catchment responses occur.

5.4 Preparation of *ACRU* Model Input and Sources of Information

5.4.1 Layout and Configuration of the Thukela Catchment System for Simulation Purposes

At 29 036 km^2, the Thukela catchment is a large river system with marked spatial and hydrological heterogeneity (Dlamini and Schulze, 2004). For simulation modelling purposes, the catchment was therefore discretised into 113 hydrologically relatively homogeneous subcatchments (**Figure 5.3**) on the basis of the Department of Water Affairs and Forestry (DWAF) delimitation of operational Quaternary Catchments (QC), which use topography as well as land uses and the location of water engineering structures such as major reservoirs and water off-take points as the main criteria for delineation. DWAF's initial official subcatchment delimitation of 86 QCs within the Thukela was extended by Jewitt *et al.* (1999), who considered Instream Flow Requirement (IFR) monitoring sites, critical reach sites as well as other points along the channel, for example, where water abstractions points take place or dams are proposed in the future and where streamflows may thus be significantly modified; hence the 113 subcatchment outlets used in this study. The manner in which the subcatchments are arranged and configured such that the simulated runoff can be routed through the system in a downstream direction is illustrated in **Figure 5.4**.

5.4.2 Climatic Variables

Minimum climatic information required by the *ACRU* model for each subcatchment is a time series of daily rainfall values together with monthly means of daily maximum and minimum temperatures as well as monthly totals of reference potential evaporation. Rainfall stations in, and adjacent to, the Thukela catchment, with long records of daily rainfall were selected from the climate databases maintained in the School of Bioresources Engineering and Environmental Hydrology (SBEEH) for an initial assessment of those data to "drive" the catchment's hydrological responses. Using a recently developed sophisticated Expectation Maximisation Algorithm technique (Smithers, 1998), missing daily records were in-filled at each of the rainfall stations before the values were further screened using the *CALCPPTCOR* utility (Pike, 2004) to choose the most appropriate so-called "driver" station for each subcatchment.

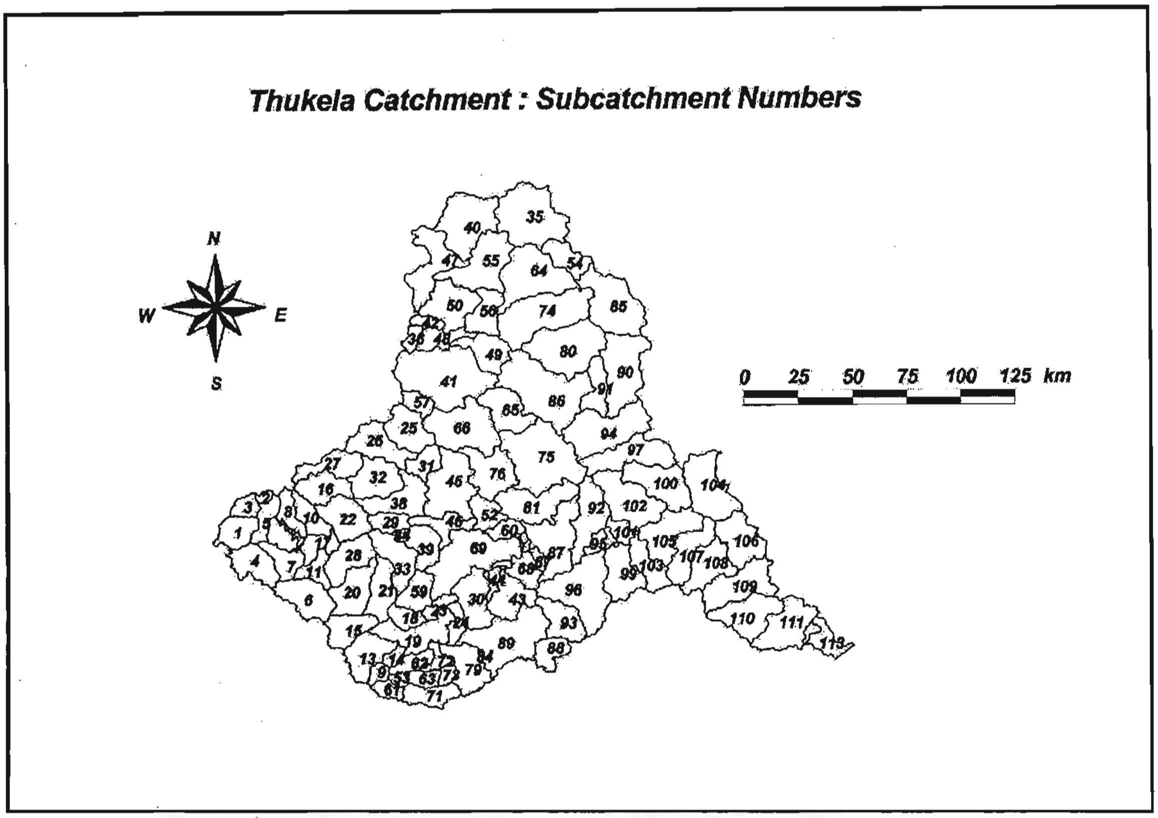


Figure 5.3 The 113 subcatchments delimited within the Thukela catchment and their numbering system (after DWAF and Jewitt *et al.*, 1999)

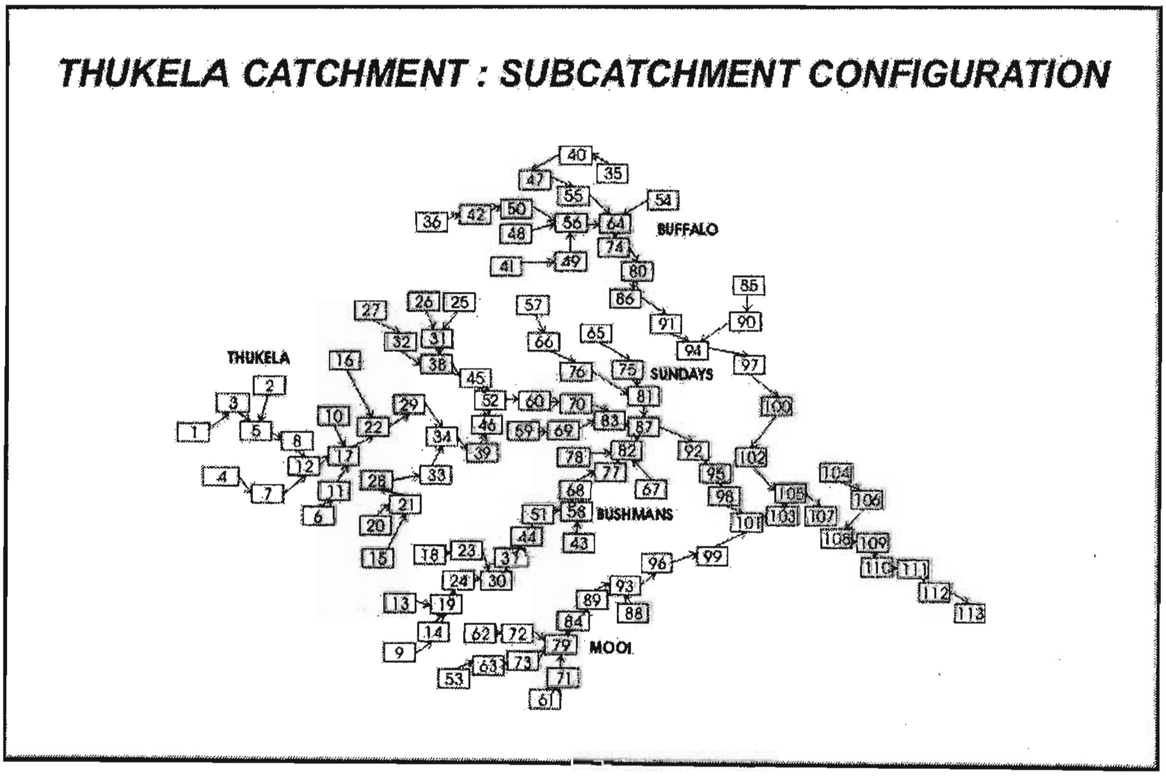


Figure 5.4 Subcatchment configuration and the routing of flows within the Thukela catchment (modified, after Jewitt *et al.*, 1999)

The *CALCPPTCOR* utility also calculates a precipitation adjustment factor which, when applied as a multiplier with the driver rainfall station's daily rainfall, is used to estimate a representative daily areal rainfall for each subcatchment. Using this selection procedure, 57 driver stations were eventually assigned to the 113 subcatchments (**Figure 5.5**), implying that many of the rainfall stations selected will "drive" the hydrological responses of more than one subcatchment, albeit with a different daily adjustment. For each subcatchment, representative values of monthly A-pan equivalent reference potential evaporation (cf. **Figures 4.7**) and monthly means of daily minimum and maximum temperatures were determined, based on gridded values generated at one minute latitude by one minute longitude (Schulze, 1997). These monthly values are converted to daily values within the model by using a Fourier Analysis, with potential evaporation then further perturbed on the basis of whether or not a threshold rainfall occurred on a given day (Schulze, 1995).

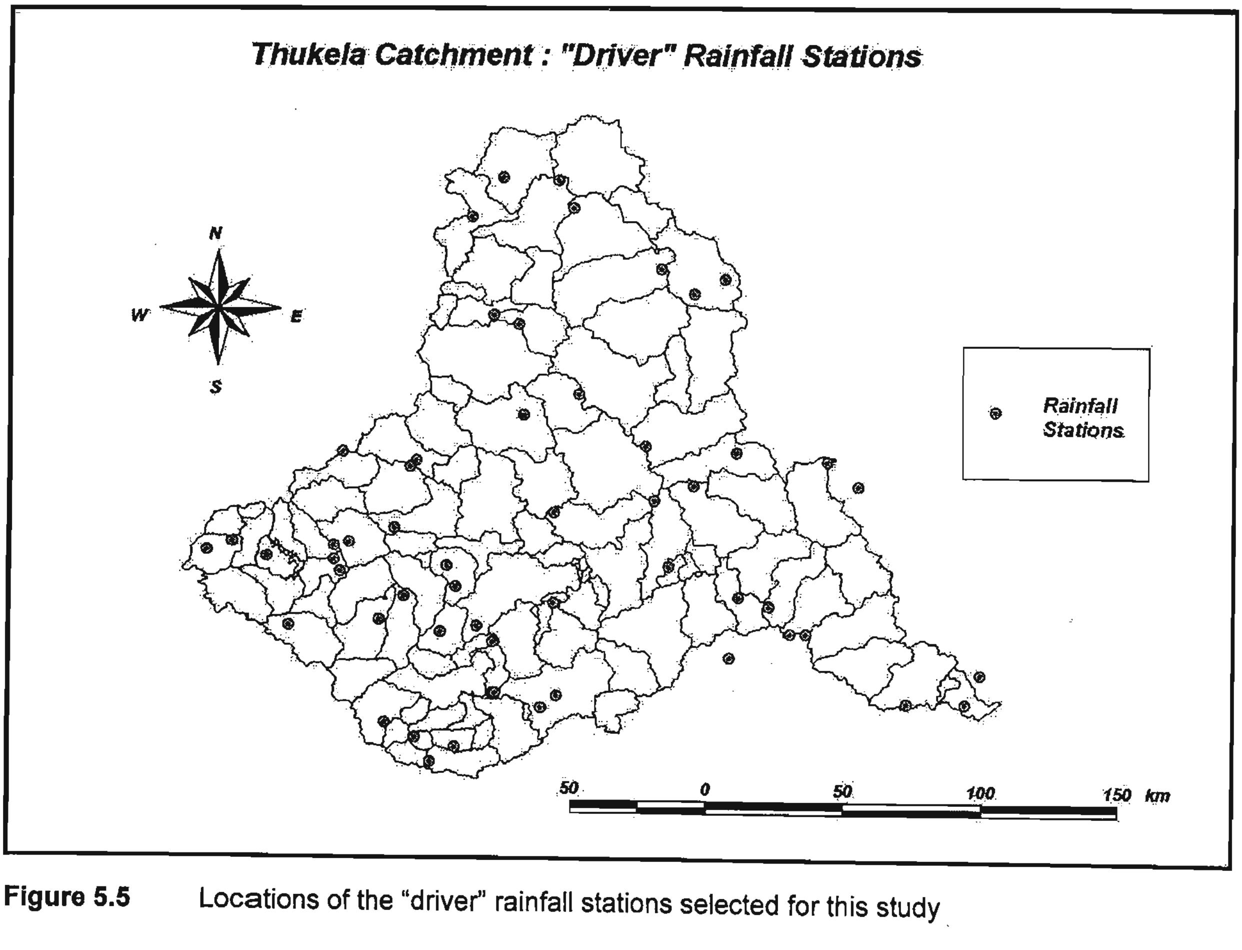


Figure 5.5 Locations of the "driver" rainfall stations selected for this study

5.4.3 Soils Information

Soils play an important role as regulators of the rate, and the manner in which, a catchment responds, hydrologically, to a rainfall event by

- influencing the rate of infiltration, thus dictating the timing and rate of stormflow generation;
- providing storage for soil water, which may become available for evapotranspiration;
- redistributing soil water, both within and out of the soil profile;
- controlling rates of the soil water evaporation and transpiration processes; and
- influencing rates and amounts of drainage beyond the root zone and eventually into the intermediate/groundwater zone, which feeds baseflows.

A GIS coverage of soil mapping units, i.e. the land types (cf. **Figure 4.9**), was obtained for the Thukela catchment from the Institute of Soil, Climate and Water (ISCW). The coverage provides detailed information on percentages of soil series making up individual terrain units within a land type, together with certain physical characteristics (e.g. clay content, profile thickness) for each land type.

Using the *AUTOSOILS* soils decision support system (Pike and Schulze, 1995 and updates), the soil attributes from the land types were translated into hydrological variables for a two-horizon soil profile (cf. **Figure 4.10**), as required by *ACRU* (e.g. horizon thickness, critical water retention constants, drainage rates and saturated overflow areas).

5.4.4 Land Cover Information

Like soils, land cover and land use/management systems can have profound influences on hydrological responses through seasonally variable canopy and litter interception amounts, surface water detention, evapotranspiration rates, provision of protective cover against soil particle detachment and soil losses from direct raindrop impact, as well as extraction of soil water by plant roots. For this WPI study, hydrological modelling is undertaken to evaluate streamflows under baseline land cover conditions to enable the estimation of primary water endowment, i.e. natural water availability, per subcatchment. Acocks' (1988) so-called Veld Types (cf. **Figure 4.11**), which are assumed to represent natural vegetation classes, have become the *de facto* standard land cover used for baseline hydrological studies in South Africa (Schulze, 2004a). The *ACRU*-related attributes of the Veld Types have been determined by Schulze (2004a). The hydrological variables and associated values for the Veld Types found in the Thukela catchment are given in **Table 5.1**. Monthly values corresponding to each Veld Type were weighted according to the percentage areas of the Veld Types found in each subcatchment. For this WPI study, therefore, no land and water resources development was assumed to have taken place in the catchment, and hence the impacts of land uses on streamflows were not considered, nor were and abstractions/return flows of water from/to streams and reservoirs.

5.5 Verification and Validation Studies of Streamflow Responses

To engender confidence in the *ACRU* model's output of hydrological responses from baseline land cover conditions, verification studies have been undertaken on catchments under pre-development land cover conditions. An example from the Cathedral Peak hydrological research station's Catchment 2 (1.94 km^2), under natural grassland, is given in **Figure 5.6**.

However, owing to the unavailability of observed streamflow data from other catchments in the Thukela under baseline land cover conditions, a validation task (as distinct from verification) was undertaken to visually check the overall plausibility of the model output. The results are illustrated in **Figure 5.7**, in which simulated mean annual runoff, MAR, is plotted against MAP for each of the 113 subcatchments.

In accordance with hydrological theory, MAR increases curvilinearly with increasing mean annual rainfall. The trend is clearly evident in **Figure 5.7**. A map of subcatchments' rainfall-runoff ratios in **Figure 5.8** further highlights the above curvilinear trend. The trends in this validation are in accord with results from other studies conducted in the Thukela catchment (e.g. Schulze, 1979; Jewitt *et al.*, 1999). The above results are interpreted as an indication that representative results are produced by the *ACRU* model, thus lending credibility to the conclusions drawn from the simulation results.

Table 5.1 Hydrological attributes of the Acocks' (1988) Veld Types, which represent baseline land cover in the Thukela catchment (Schulze, 2004a)

Veld Type	Variable	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Coastal Forest and Thornveld	CAY	0.85	0.85	0.85	0.85	0.75	0.65	0.65	0.75	0.85	0.85	0.85	0.85
	VEGINT	3.10	3.10	3.10	3.10	2.50	2.00	2.00	2.50	3.10	3.10	3.10	3.10
	ROOTA	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
	COIAM	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Ngongoni Veld - Zululand	CAY	0.70	0.70	0.70	0.65	0.55	0.50	0.50	0.55	0.60	0.65	0.65	0.70
	VEGINT	1.40	1.40	1.40	1.40	1.30	1.20	1.20	1.30	1.40	1.40	1.40	1.40
	ROOTA	0.90	0.90	0.90	0.95	1.00	1.00	1.00	1.00	0.95	0.90	0.90	0.90
	COIAM	0.20	0.20	0.25	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.25	0.20
Highland Sourveld and Döhne Sourveld	CAY	0.70	0.70	0.70	0.50	0.30	0.20	0.20	0.20	0.50	0.65	0.70	0.70
	VEGINT	1.60	1.60	1.60	1.40	1.20	1.00	1.00	1.00	1.30	1.60	1.60	1.60
	ROOTA	0.90	0.90	0.90	0.95	1.00	1.00	1.00	1.00	0.95	0.90	0.90	0.90
	COIAM	0.15	0.15	0.25	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.20	0.15
Natal Mist Belt Ngongoni Veld	CAY	0.70	0.70	0.70	0.50	0.35	0.25	0.20	0.20	0.55	0.70	0.70	0.70
	VEGINT	1.50	1.50	1.50	1.30	1.10	1.10	1.10	1.10	1.40	1.50	1.50	1.50
	ROOTA	0.90	0.90	0.90	0.94	0.96	1.00	1.00	1.00	0.95	0.90	0.90	0.90
	COIAM	0.15	0.15	0.20	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.20	0.15
Themeda Veld or Turf Highveld	CAY	0.65	0.65	0.65	0.50	0.40	0.20	0.20	0.20	0.35	0.55	0.65	0.65
	VEGINT	1.20	1.20	1.20	1.10	1.00	0.90	0.90	0.90	1.10	1.20	1.20	1.20
	ROOTA	0.90	0.90	0.90	0.95	0.95	1.00	1.00	1.00	0.95	0.90	0.90	0.90
	COIAM	0.15	0.15	0.25	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.25	0.15
Turf Highveld to Highland Sourveld Veld Transition	CAY	0.60	0.60	0.60	0.52	0.40	0.20	0.20	0.20	0.35	0.50	0.60	0.60
	VEGINT	1.30	1.30	1.30	1.20	1.00	0.90	0.90	0.90	1.10	1.20	1.30	1.30
	ROOTA	0.90	0.90	0.90	0.95	0.95	1.00	1.00	1.00	0.95	0.90	0.90	0.90
	COIAM	0.15	0.15	0.25	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.25	0.15
North-Eastern Sandy Highveld	CAY	0.62	0.62	0.60	0.50	0.35	0.20	0.20	0.20	0.35	0.50	0.62	0.62
	VEGINT	1.30	1.30	1.30	1.20	1.00	1.00	1.00	1.10	1.20	1.30	1.30	1.30
	ROOTA	0.90	0.90	0.90	0.95	0.95	1.00	1.00	1.00	0.95	0.90	0.90	0.90
	COIAM	0.15	0.15	0.20	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.25	0.15
Piet Retief Sourveld	CAY	0.70	0.70	0.70	0.55	0.45	0.20	0.20	0.20	0.50	0.60	0.70	0.70
	VEGINT	1.30	1.30	1.30	1.30	1.10	1.00	1.00	1.00	1.20	1.30	1.30	1.30
	ROOTA	0.90	0.90	0.90	0.90	0.95	1.00	1.00	1.00	0.95	0.90	0.90	0.90
	COIAM	0.15	0.15	0.25	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.20	0.15
Southern Tall Grassveld	CAY	0.75	0.75	0.75	0.50	0.40	0.20	0.20	0.20	0.55	0.70	0.75	0.75
	VEGINT	1.60	1.60	1.60	1.60	1.50	1.40	1.40	1.40	1.50	1.60	1.60	1.60
	ROOTA	0.90	0.90	0.90	0.95	0.95	1.00	1.00	1.00	0.95	0.90	0.90	0.90
	COIAM	0.15	0.15	0.20	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.20	0.15
Natal Sourveld	CAY	0.75	0.75	0.70	0.50	0.35	0.20	0.20	0.20	0.50	0.65	0.70	0.75
	VEGINT	1.80	1.80	1.80	1.80	1.60	1.40	1.40	1.40	1.50	1.70	1.80	1.80
	ROOTA	0.90	0.90	0.90	0.95	0.95	1.00	1.00	1.00	0.95	0.90	0.90	0.90
	COIAM	0.15	0.15	0.20	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.25	0.15

Legend:
- CAY = water use (i.e. crop) coefficient
- VEGINT = canopy interception (mm/rainday)
- ROOTA = fraction of roots in the topsoil horizon
- COIAM = coefficient of initial abstractions (i.e. infiltrability index)

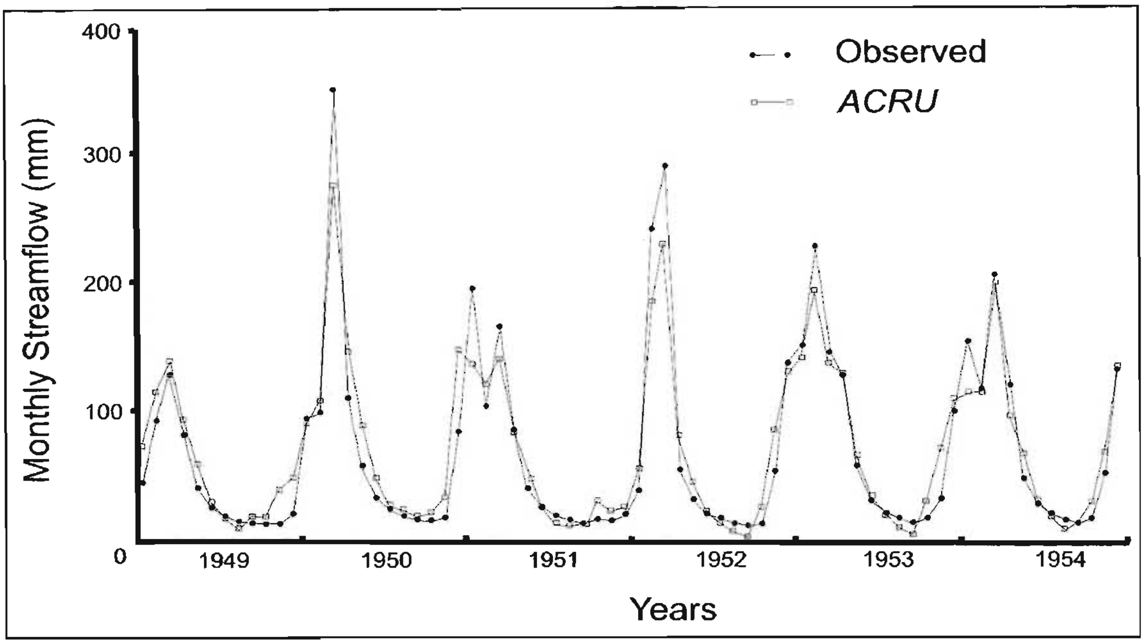


Figure 5.6 *ACRU* model verification from Catchment 2 at the Cathedral Peak hydrological research station (after Schulze and George, 1987)

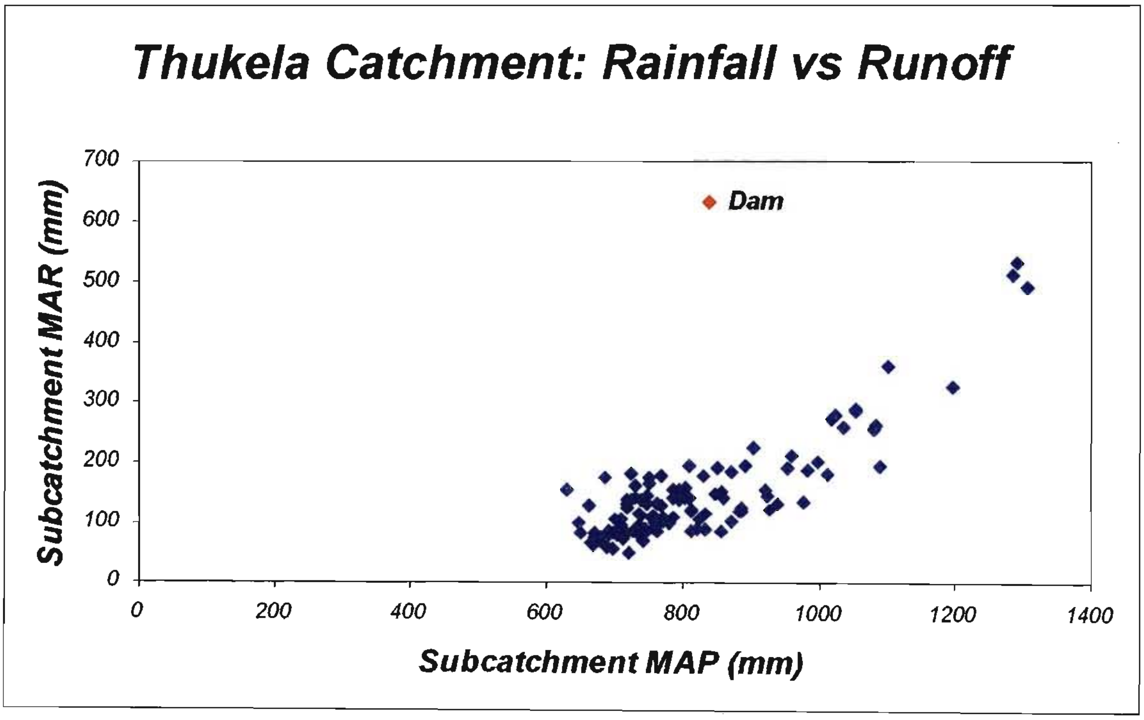


Figure 5.7 Relationship between *ACRU* model simulated MAR (mm) and MAP (mm) for individual subcatchments in the Thukela basin

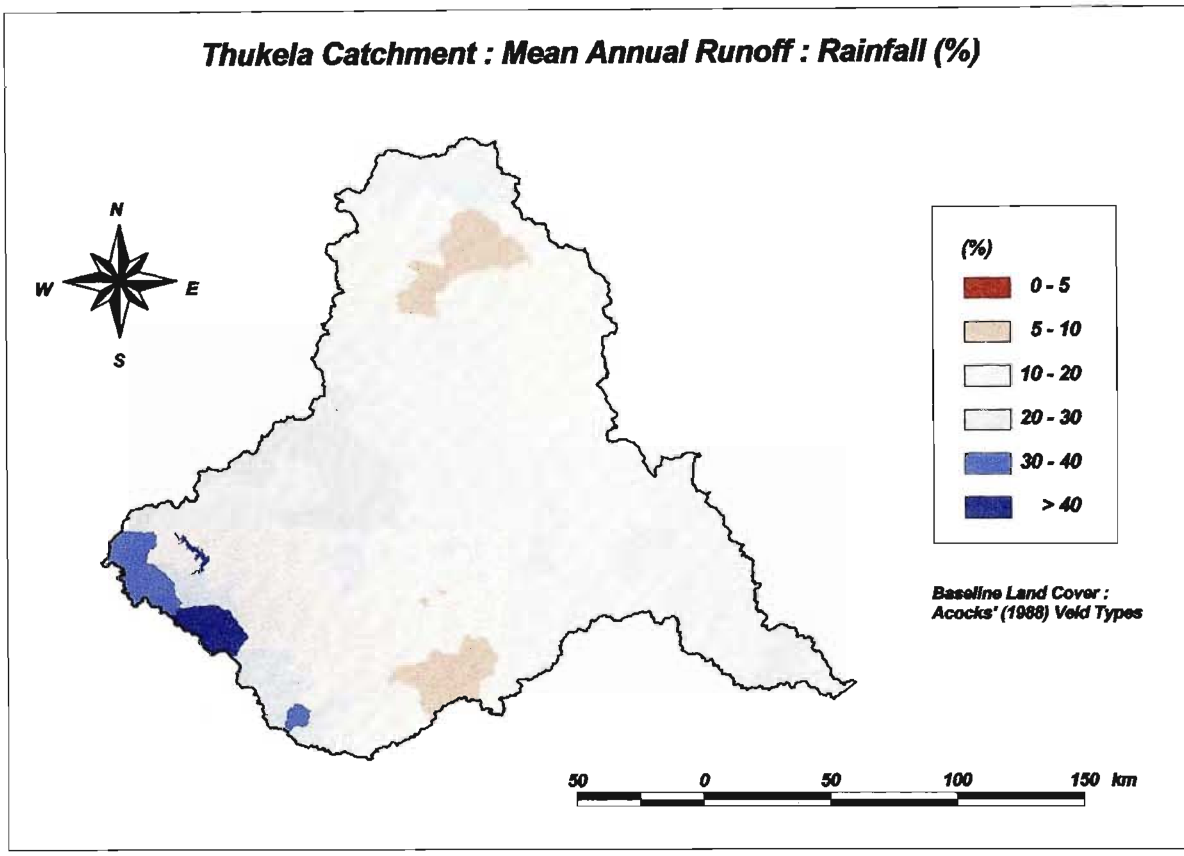


Figure 5.8 *ACRU* model simulated subcatchment MAR (mm) as a percentage of MAP (mm)

5.6 Spatial Variation of Streamflow Characteristics Within the Thukela Catchment

The success of the verification and validation studies presented in **Section 5.5** provides the all-important confirmation of the *ACRU* model's output being considered realistic under baseline land cover conditions. The results of this study are presented in two broad sections. Analyses of baseline streamflow characteristics in the Thukela catchment in its entirety are presented first, followed by an assessment of baseline streamflow at selected locations in the catchment, *viz.* at Keates Drift and Wembezi, the selection of which will be discussed in detail later.

5.6.1 Spatial Variations of Subcatchment MAR within the Thukela Catchment

Figure 5.9 shows the spatial variations of individual subcatchment MAR within the Thukela catchment. The average simulated MAR for the catchment is 136 mm. Simulated MAR values per subcatchment vary widely, from less than 25 to over 250 mm. High runoff values are simulated in the southwest and northern sections of the catchment, which make up parts of the high Drakensberg range of mountains characterised by high rainfall (cf. **Figure 4.4**) Other high values occur in the southeastern tail of the catchment along the Indian Ocean, which has a maritime climate. Save for a few patches of MAR > 150mm, values ranging from 25 to 150 are simulated in the relatively dry central parts of the catchment.

Patterns of subcatchment MAR have important implications on water resources development and water poverty. With most of the streamflows generated in the high altitude, rugged and sparsely inhabited western fringes, and less being produced in the lower lying plains and valleys which contain most of the farmlands, towns and especially the poor rural communities, it has become imperative that the mountain-fed main streams be impounded, also as a result of the strong seasonal nature of the flows, to ensure year-round sustained water supplies. Implications on rural communities will be discussed in the section outlining results at the two specific locations.

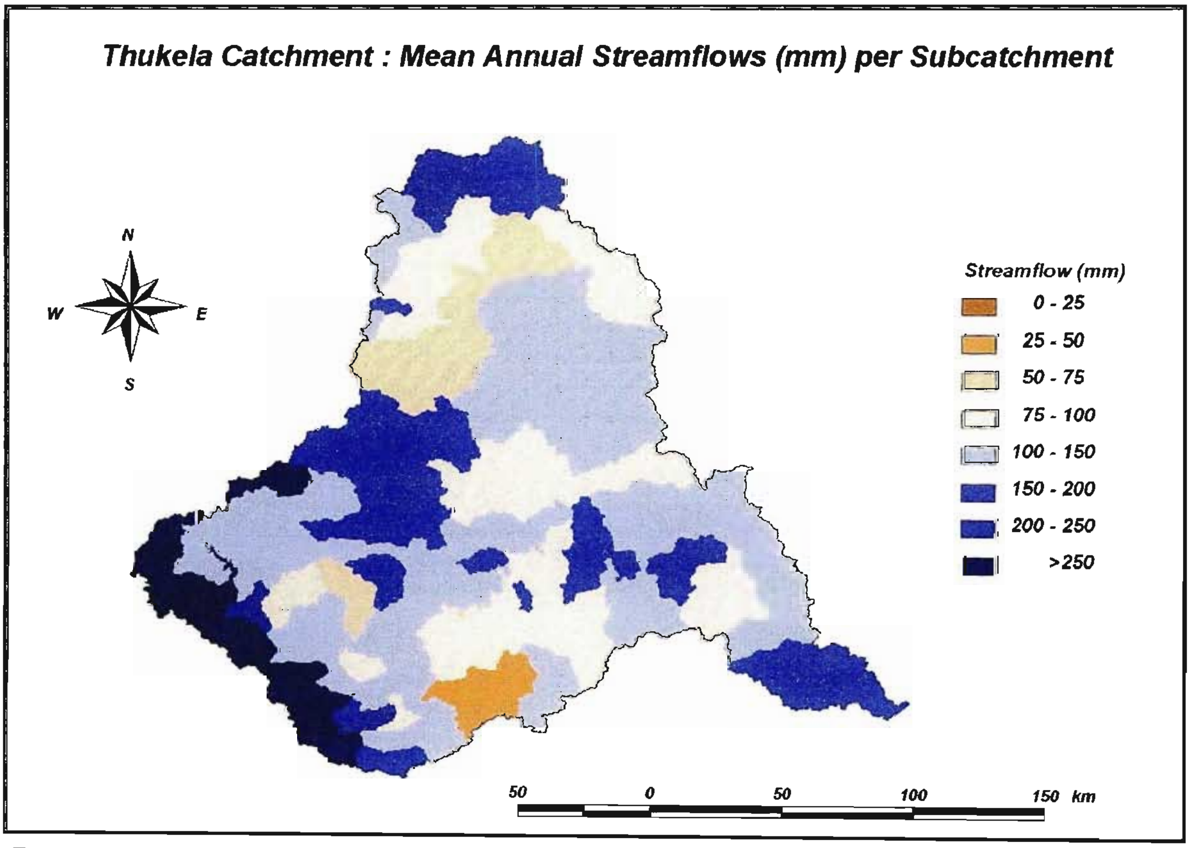


Figure 5.9 Simulated subcatchment MAR (mm) in the Thukela catchment under baseline land cover conditions

5.6.2 Inter-Annual Coefficients of Variation (CVs) of Streamflows from Individual Subcatchments

Low CV values depict relatively small year-to-year variations of annual runoff from the mean while the converse holds for high CVs. The spatial patterns of the CVs in the Thukela catchment (**Figure 5.10**) inversely mimic those of MAR, i.e. subcatchments in the Mountains, Highlands and the moist Interior Basins ecological regions (cf. **Figure 4.3**) with high simulated MAR values portray correspondingly low CV values of less than 50%, while the subcatchments in the drier Valleys have high inter-annual CV values ranging from 70% to 200%. The coastal stretch is an exception, as values of both MAR and CV are high. The high CVs of annual streamflows present a major challenge to planners in poor communities, of which many are, as yet, without any reticulated water. The above prognosis of high inter-annual variability is exacerbated by the facts that

- most of the rural poor communities within the Thukela catchment live in those areas with high CVs (cf. **Chapter 4**),
- both intensification and extensification of land uses have been shown to amplify streamflow variabilities in the Thukela catchment (Schulze *et al.*, 1997; Schulze, 2000; Dlamini and Schulze, 2004), and
- the CVs depicted in **Figure 5.10** are of the "mildest" form because CVs of streamflows for individual months are several times higher than those of annual flows (Dlamini and Schulze, 2004).

5.6.3 Spatial Variations of Mean Annual Accumulated Streamflows

Figure 5.11 shows means of annual accumulated streamflows in the Thukela catchment, where accumulated flows incorporate the (usual dampening) effects of all upstream flows, in addition to the flows from the subcatchment under consideration.

High accumulated streamflows are, once again, simulated in the Drakensberg region and also along the so-called internal subcatchments, i.e. those subcatchments that receive streamflow contributions from upstream subcatchments.

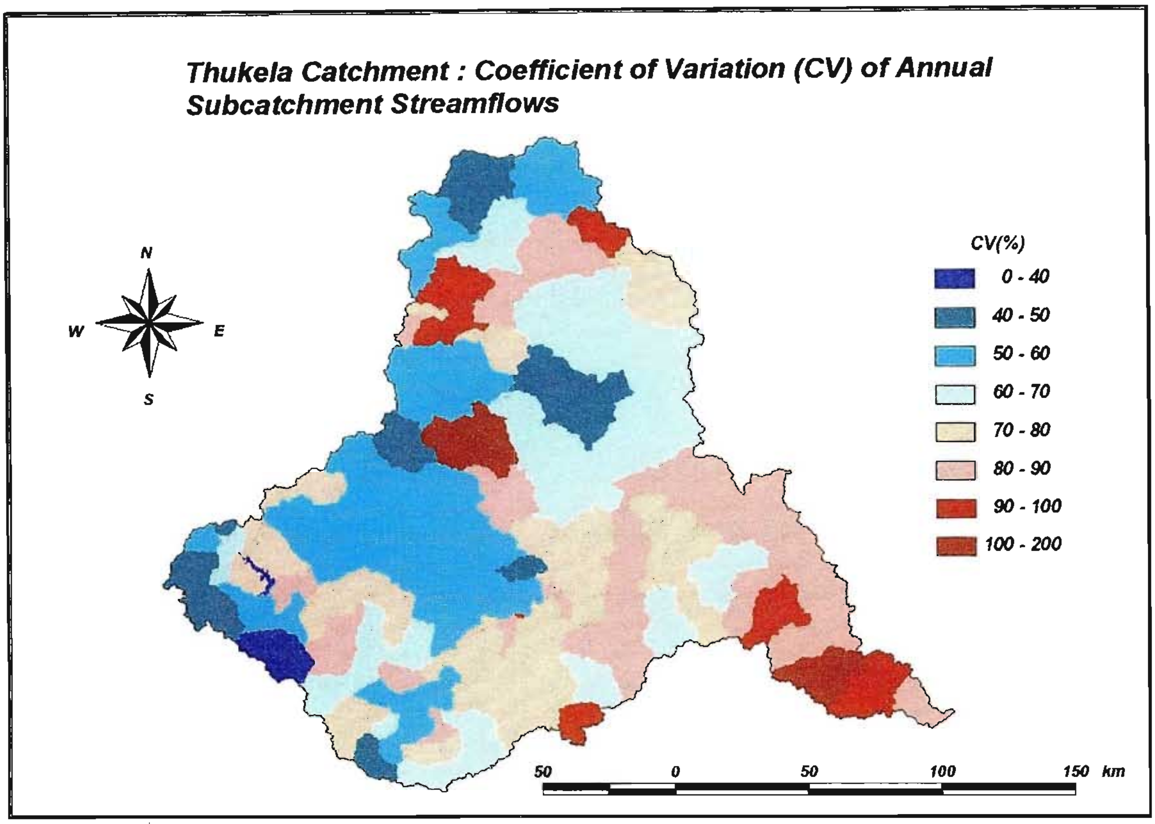


Figure 5.10 Inter-annual coefficients of variation (CV%) of streamflows in individual subcatchments within the Thukela catchment

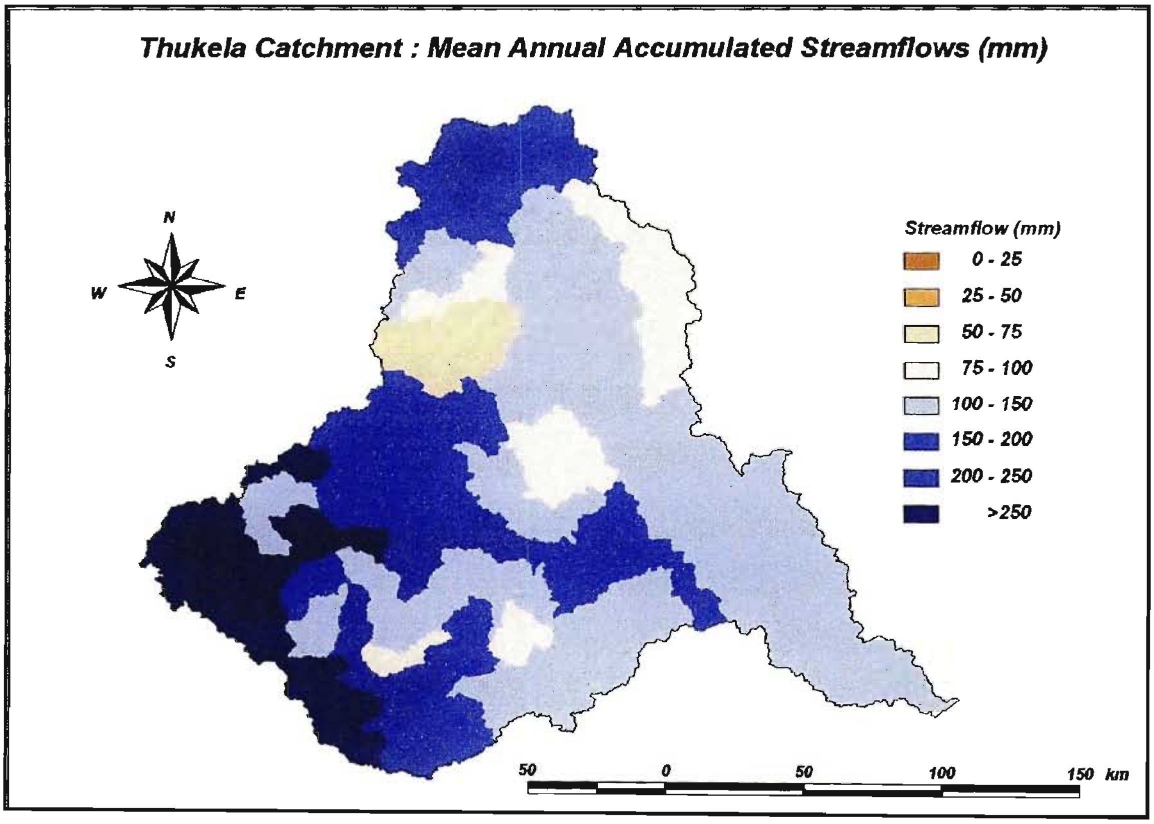


Figure 5.11 Accumulated MAR (mm) in the Thukela catchment

These high runoff internal subcatchments are clearly those along the mainstem of the Thukela River and its major tributaries such as the Mooi, Sundays, Bushmans and Buffalo rivers (cf. **Figure 4.1**). Other than in the Drakensberg, external subcatchments (i.e. those with no other upstream flows contributing), generally have the lower streamflow values than internal ones.

The implication of this pattern is that, although the Thukela catchment appears to have abundant available water on an annual basis, most of that water is concentrated along the major tributaries and the mainstem Thukela itself. It should, furthermore, already be noted at this juncture that most of the rural poor communities do not, however, live along mainstem rivers with high accumulated flows. There is a further constraint to indigenous rural communities not having ready access to available water, other than not being located adjacent to internal/mainstem rivers, and that is that within a subcatchment the communities/households tend to be located close to watershed boundaries where their supply of surface water would come from first order headwater streams which are frequently ephemeral in their flow regime, rather than from higher order streams which display more consistent flows.

5.6.4 Inter- Annual Coefficient of Variation of Accumulated Streamflows

The inter-annual CVs of accumulated flows (**Figure 5.12**) once again display inverse patterns to those of the accumulated flows themselves. Low CVs of less than 70% occur along the main channel and major tributaries, while high values of up to 200% occur in external subcatchments. The low CVs indicate that annual streamflows along the major tributaries are, in general, neither too large nor too low relative to MAR, while the high CVs indicate that both higher and lower extreme values of annual streamflows are not uncommon along the low order streams. This observation once again highlights the fact that water users who rely on the major tributaries are generally assured of more consistent supply than those who are dependent on low order streams. This is of particular relevance in water poverty studies when considering that many rural communities with no formal water supply schemes laid on as yet are located in the external subcatchments. Even those which are in the internal subcatchments are not in close proximity of the major tributaries, but rather reside on valley slopes (cf. **Chapter 4**).

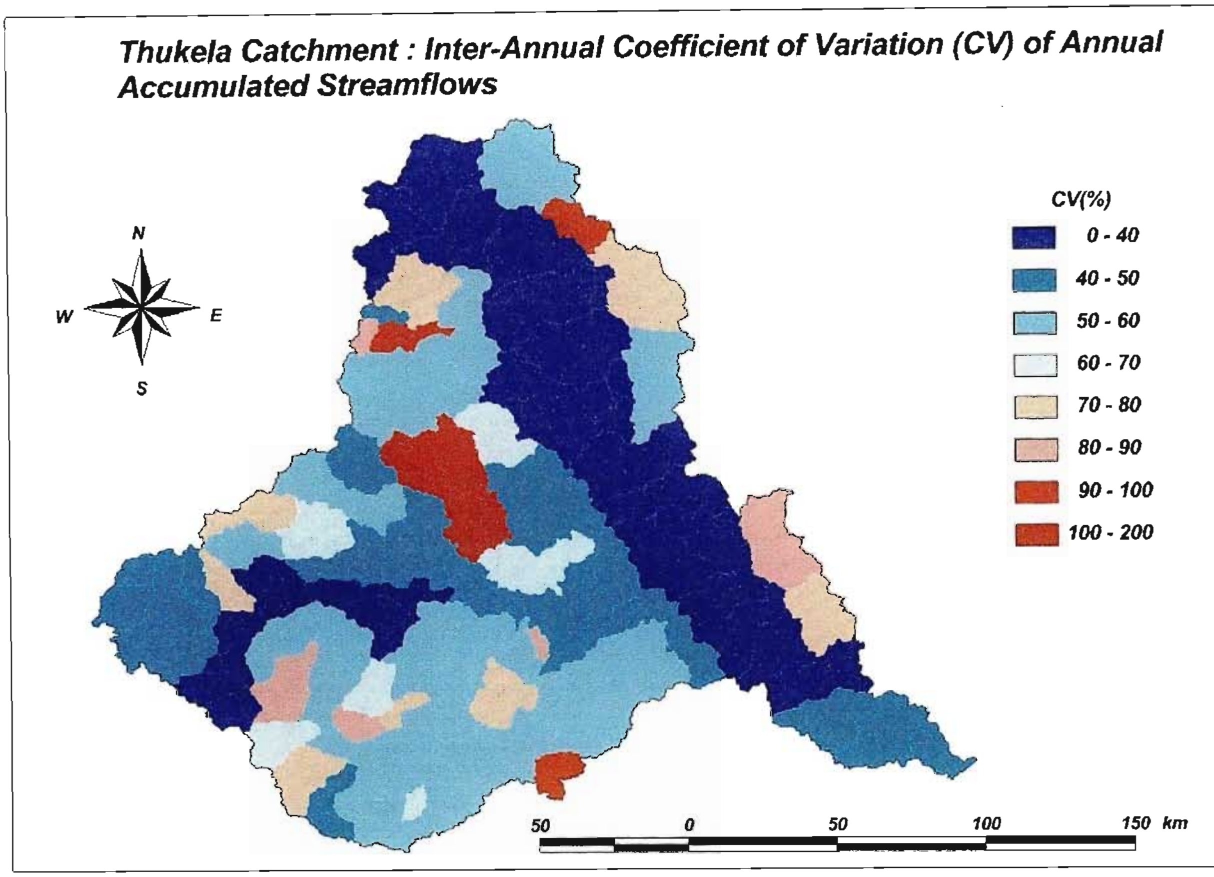


Figure 5.12 Inter-annual coefficients of variation (CV%) of accumulated streamflows within the Thukela catchment

5.7 Streamflow Characteristics at Specific Locations in the Thukela Catchment

The previous sections have presented an overview assessment of the spatial distributions of renewable surface water resources and their inter-annual variation in the Thukela catchment. In the following sections, attention shifts towards two specific case study locations within the Thukela catchment, *viz.* Keates Drift and Wembezi **(Figure 5.13)**. Keates Drift and Wembezi are locations in which water use surveys were undertaken during the testing phase of the project to develop a Water Poverty Index (Sullivan *et al.*, 2002). The purpose of these sections is to assess the natural water availability and variability at local community scale. This assessment intends to highlight the degrees and frequencies of water shortage as well as their implications on access and utilisation of water shortage at these locations, especially to those communities without reticulated potable water supplies.

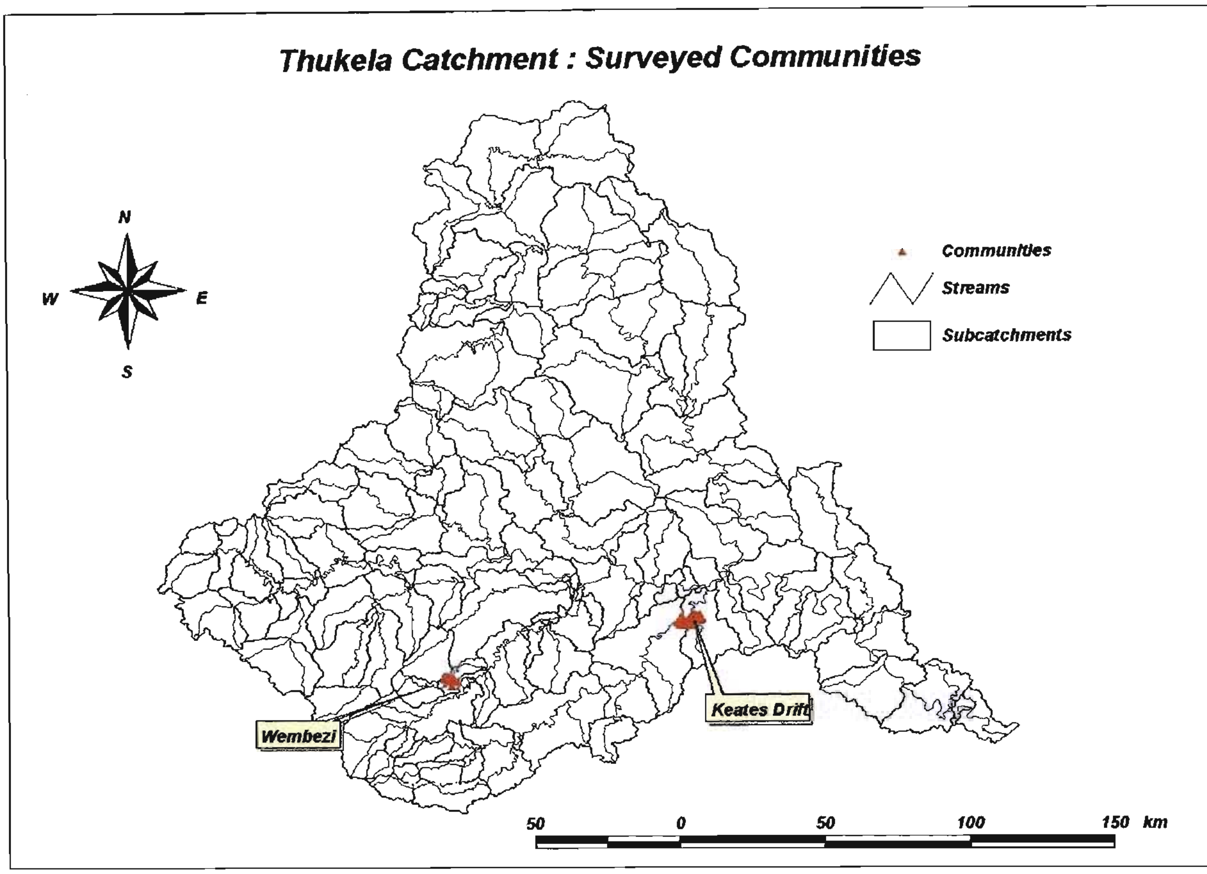


Figure 5.13 Locations of surveyed communities in the Thukela catchment

The survey information was used in this study when the upscaling water use component of the WPI from household to subcatchment scale (cf. **Chapter 7**). In the following sections, the outlets of the subcatchments in which these two places are located were used as points for localised hydrological analysis. The objectives of these localised hydrological analyses are

- to present and interpret output statistics of simulated baseline flows, including flow variability, on a month-by-month basis rather than only as annual totals,
- to interpret time series of streamflows in order to establish patterns of flows, particularly during low flow months,
- to evaluate flow duration curves for total, high flow month and low flow month conditions in order to establish flow patterns at critical threshold occurrences, and
- to distinguish between respective contributions of stormflows and baseflows to total streamflows.

5.7.1 Keates Drift

Keates Drift was selected to represent a poor rural indigenous community consisting of scattered non-nucleated households, where one section of the community, *viz.* Ethembeni, already has access to potable water from a pre-paid token (akin to debit card) system at scattered water points, while the other section of the community, at KwaLatha, has no water service provision as yet and water has to be collected from rivers and springs. The Keates Drift communities are located close to the Mooi River along the Greytown-Dundee road (cf. **Figure 4.1**) at latitude 28°51'S, longitude 30°30'E and altitude around 700 m. The subcatchment in which these communities are located is SC99 (**Figure 5.3**), which has an area of 309.77 km^2, while the accumulated upstream area of the Mooi River at Keates Drift is 2880.22 km^2.

5.7.2 Wembezi

Wembezi was selected to represent peri-urban township conditions. One section of the township, *viz.* at Depot, has its population living in formal housing with running water while the other, poorer community, Section C, lives more under shack conditions with no individual household water supply, but with communal standpipes approximately 150 m apart. Wembezi is a satellite township near Estcourt. Located at 29°03'S, 29°47'E and at an altitude of 1400 m, Wembezi flanks the Bushman's River. The subcatchment in which it is located is SC23 (**Figure 5.3**), with an area of 77.86 km^2, with the total catchment area upstream of Wembezi being 195.55 km^2.

5.8 An Overview of Streamflow Statistics

This overview presents frequently used streamflow statistics as indicators of physical water shortage, the aspect of water scarcity which is imposed by the natural hydrological system. The statistics which follow in **Tables 5.2** to **5.9** have mm equivalent flows as the unit rather than m^3, in order to represent flow equivalents per unit of area. The 10th percentile of flow exceedance represents flows in the driest month (or year) in 10, the 20th percentile the driest in 5, the 90th percentile the wettest in 10, and so forth. Also note that monthly percentile flows are computed for that particular month only and that the 12 monthly totals of percentile flows therefore do not add up to the annual total, which is computed separately. Furthermore, note that because the *ACRU* model simulates a specific subcatchment's stormflows and baseflows explicitly (i.e. without recourse to baseflow separation curves), the statistics on stormflow and baseflow are available only for flows of an individual subcatchment and not for accumulated flows from upstream, in which case mixing of these two streamflow components has already taken place.

Table 5.2 Statistics on monthly and annual simulated total streamflows generated under baseline land cover conditions from the individual subcatchment SC23 at Wembezi

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean	17.5	19.2	12.0	3.8	1.8	0.7	0.7	2.7	9.3	7.5	9.5	16.0	100.7
Std. Deviation	18.8	22.4	14.1	4.6	2.7	0.9	1.3	5.7	28.0	12.2	9.6	15.7	75.5
CV (%)	107.8	116.8	117.5	121.4	149.9	131.2	176.4	210.6	302.2	161.0	101.4	98.1	75.0
Skewness Coef.	1.6	1.9	2.5	2.0	2.3	1.8	4.5	2.7	5.0	2.7	1.9	1.7	1.9
Kurtosis Coef.	2.3	3.8	7.0	3.9	5.1	2.9	24.8	6.7	27.2	7.6	4.4	2.9	5.4
10th Percentile	1.7	1.5	1.5	0.3	0.0	0.0	0.0	0.0	0.1	0.5	1.0	3.1	22.3
20th Percentile	3.1	2.5	2.1	0.6	0.1	0.0	0.0	0.1	0.2	0.9	2.7	3.3	46.3
50th Percentile	10.1	10.3	8.7	2.3	0.9	0.3	0.3	0.4	0.6	2.5	6.4	12.7	83.3
80th Percentile	29.8	37.1	18.1	6.2	2.3	1.1	1.2	2.6	7.9	10.3	15.2	24.7	147.0
90th Percentile	41.6	47.1	22.8	12.1	5.0	2.1	1.7	10.2	22.7	22.8	22.0	33.9	178.0

Table 5.3 Statistics on monthly and annual simulated total streamflows generated under baseline land cover conditions from the accumulated area upstream of Wembezi

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean	18.1	18.6	11.0	4.5	1.9	1.1	1.2	1.8	7.1	6.5	7.9	14.9	94.6
Std. Deviation	19.9	19.5	11.7	4.5	2.6	1.9	2.5	3.2	21.0	11.3	7.3	13.3	72.9
CV (%)	110.0	104.9	106.3	99.9	137.0	172.6	216.3	173.3	296.7	172.5	92.2	89.5	77.1
Skewness	2.1	1.7	1.8	1.2	1.9	3.5	4.5	2.7	4.9	3.2	1.5	1.4	1.7
Kurtosis Coef.	5.5	3.1	2.9	0.3	3.3	16.0	23.3	7.4	25.6	11.0	1.6	1.8	3.3
10th Percentile	2.7	1.7	1.8	0.7	0.0	0.0	0.0	0.1	0.2	0.7	1.0	2.5	23.1
20th Percentile	4.0	3.3	2.3	1.0	0.1	0.0	0.0	0.1	0.2	0.9	2.1	4.0	39.8
50th Percentile	9.4	15.1	6.3	2.3	0.9	0.4	0.4	0.5	0.6	2.0	6.4	10.9	80.6
80th Percentile	28.4	28.0	18.9	9.2	3.8	2.1	1.6	2.0	6.6	8.3	10.6	24.3	132.1
90th Percentile	43.2	42.6	24.4	11.6	5.6	3.0	2.7	6.6	15.0	13.3	18.9	35.8	194.5

Table 5.4 Statistics on monthly and annual simulated stormflows generated under baseline land cover conditions from the individual subcatchment SC23 at Wembezi

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean	16.0	17.4	9.8	2.1	0.8	0.1	0.4	2.4	8.2	4.9	7.6	14.5	84.3
Std. Deviation	18.4	20.8	12.2	3.8	1.8	0.2	1.2	5.4	26.3	7.0	7.4	15.1	58.0
CV (%)	115.2	119.6	124.6	178.5	221.7	158.1	316.5	229.6	319.0	143.2	97.4	103.7	68.8
Skewness Coef.	1.7	1.8	2.2	3.1	2.9	2.2	5.6	2.8	5.2	2.2	1.9	1.8	1.9
Kurtosis Coef.	2.8	3.6	5.3	10.4	8.7	5.0	34.1	7.5	29.3	4.1	4.0	3.2	5.9
10th Percentile	1.5	1.4	0.7	0.1	0.0	0.0	0.0	0.0	0.1	0.4	1.0	1.9	21.8
20th Percentile	2.5	2.0	1.2	0.3	0.0	0.0	0.0	0.0	0.1	0.7	2.6	3.2	40.6
50th Percentile	9.4	8.3	5.2	0.6	0.1	0.0	0.0	0.2	0.4	1.8	4.7	8.1	75.1
80th Percentile	28.2	30.8	15.9	3.0	0.5	0.2	0.3	1.9	4.5	7.6	11.3	24.6	129.2
90th Percentile	37.9	42.4	22.8	4.5	3.0	0.3	0.8	9.9	22.7	14.8	19.3	29.4	140.2

Table 5.5 Statistics on monthly and annual simulated baseflows generated under baseline land cover conditions from the individual subcatchment SC23 at Wembezi

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean	1.4	1.7	2.2	1.7	1.0	0.6	0.4	0.4	1.0	2.7	1.8	1.5	16.4
Std. Deviation	2.6	3.0	4.1	3.0	1.6	0.9	0.6	0.7	2.9	8.3	4.7	2.7	24.1
CV (%)	183.3	173.8	184.8	177.2	158.3	154.6	154.6	191.6	275.1	313.4	252.7	185.4	146.5
Skewness Coef.	2.4	2.6	2.7	2.7	2.1	2.0	1.9	4.0	3.5	4.1	3.6	2.9	2.4
Kurtosis Coef.	5.9	8.3	6.9	7.4	4.6	3.4	3.3	19.8	11.7	17.3	13.2	9.1	5.8
10th Percentile	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20th Percentile	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
50th Percentile	0.1	0.2	0.5	0.3	0.2	0.1	0.1	0.1	0.0	0.1	0.1	0.1	7.8
80th Percentile	1.7	3.2	3.3	2.5	1.6	1.0	0.6	0.6	0.5	0.4	2.2	2.4	22.5
90th Percentile	5.2	6.0	4.8	4.2	3.5	2.1	1.3	1.0	3.6	7.1	4.3	4.0	43.5

Table 5.6 Statistics on monthly and annual simulated total streamflows generated under baseline land cover conditions from the individual subcatchment SC99 at Keates Drift

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean	28.7	24.4	15.9	4.2	3.3	0.9	1.8	4.2	9.4	9.1	10.1	19.6	131.5
Std. Deviation	34.0	33.6	21.6	7.0	11.3	1.8	5.0	9.4	36.2	14.8	12.0	28.4	82.4
CV (%)	118.7	137.8	136.1	166.5	343.0	197.7	281.2	224.1	386.6	162.3	118.6	145.3	62.7
Skewness Coef.	2.2	2.8	2.2	2.8	5.7	2.7	4.1	2.6	5.8	3.7	1.5	5.0	1.2
Kurtosis Coef.	4.3	9.5	4.9	8.8	34.8	6.9	17.7	5.5	36.0	16.6	1.4	28.8	2.0
10th Percentile	3.0	1.0	0.7	0.2	0.0	0.0	0.0	0.0	0.0	0.3	0.6	2.4	47.1
20th Percentile	6.5	4.3	1.2	0.3	0.1	0.0	0.0	0.1	0.1	0.6	1.2	5.8	66.6
50th Percentile	18.0	10.9	5.4	1.1	0.5	0.1	0.2	0.3	0.6	5.7	4.8	13.3	108.9
80th Percentile	38.5	41.4	25.2	5.9	2.1	1.1	1.2	2.8	7.8	13.2	18.0	25.4	201.0
90th Percentile	85.0	58.4	49.3	12.4	4.5	3.2	4.3	22.9	12.2	23.6	29.4	29.8	228.6

Table 5.7 Statistics on monthly and annual simulated total streamflows generated under baseline land cover conditions from the accumulated area upstream of Keates Drift

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean	20.8	18.1	14.5	5.5	3.4	1.7	1.2	2.7	7.2	7.6	10.2	18.5	111.4
Std. Deviation	14.3	13.2	12.6	4.7	4.5	2.5	1.5	4.3	24.2	12.1	7.6	9.7	62.0
CV (%)	68.7	72.9	87.1	85.3	134.7	145.3	128.4	158.5	335.2	158.7	74.8	52.5	55.6
Skewness Coef.	1.2	1.1	2.3	2.1	3.2	3.9	2.9	2.9	5.9	3.3	1.3	1.2	2.1
Kurtosis Coef.	1.0	1.2	7.3	5.1	12.8	18.7	10.6	10.0	36.8	11.6	1.5	1.3	5.1
10th Percentile	7.5	4.4	3.8	1.6	0.4	0.2	0.1	0.3	0.3	1.3	2.5	7.4	59.1
20th Percentile	8.8	5.7	5.0	2.2	0.7	0.5	0.2	0.3	0.4	1.7	3.3	11.5	67.3
50th Percentile	16.5	15.3	11.0	4.2	1.9	1.1	0.6	1.2	1.0	3.3	8.7	15.6	95.3
80th Percentile	32.0	29.7	22.3	8.2	4.8	1.9	1.9	3.5	4.8	8.6	13.8	24.6	128.7
90th Percentile	44.4	37.9	27.5	10.4	8.8	4.9	3.1	8.2	12.6	13.5	20.0	31.3	175.4

Table 5.8 Statistics on monthly and annual simulated stormflows generated under baseline land cover conditions from the individual subcatchment SC99 at Keates Drift

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean	27.4	23.1	14.8	3.2	2.4	0.3	1.2	3.6	8.1	6.5	8.0	18.0	116.6
Std. Deviation	33.5	33.5	20.8	6.3	10.5	1.4	3.8	8.7	35.1	8.3	10.6	26.8	68.7
CV (%)	122.1	145.0	141.3	198.3	430.4	394.8	326.0	245.1	435.5	127.2	133.0	148.8	59.0
Skewness Coef.	2.1	2.8	2.3	3.0	5.7	4.8	3.6	2.7	6.0	2.6	2.0	4.8	1.0
Kurtosis Coef.	4.0	10.1	5.6	10.0	34.7	22.9	12.1	6.8	38.0	9.0	4.0	26.9	1.6
10th Percentile	2.8	0.9	0.6	0.1	0.0	0.0	0.0	0.0	0.0	0.3	0.5	2.2	41.1
20th Percentile	5.3	2.6	1.0	0.2	0.0	0.0	0.0	0.0	0.0	0.6	0.7	5.6	65.1
50th Percentile	16.2	9.9	5.2	0.6	0.1	0.0	0.0	0.2	0.3	4.0	3.1	10.8	97.1
80th Percentile	38.5	40.4	24.8	3.8	0.4	0.2	0.2	1.4	3.3	10.3	14.0	24.1	164.9
90th Percentile	84.8	54.5	44.9	10.7	4.0	0.4	1.2	17.8	8.1	14.7	22.1	28.8	204.9

Table 5.9 Statistics on monthly and annual simulated baseflows generated under baseline land cover conditions from the individual subcatchment SC99 at Keates Drift

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annua
Mean	1.2	1.3	1.1	1.0	0.9	0.6	0.6	0.6	1.3	2.6	2.1	1.6	14.9
Std. Deviation	2.9	2.6	2.1	2.0	1.6	1.3	1.6	1.6	3.0	7.3	5.4	3.6	23.0
CV (%)	229.8	206.6	182.5	194.2	190.4	220.6	266.6	252.6	233.2	283.4	253.1	230.2	154.0
Skewness Coef.	3.6	2.9	3.1	3.4	2.4	3.6	4.7	3.4	2.5	4.1	3.5	2.9	2.1
Kurtosis Coef.	14.8	9.7	12.7	14.4	5.1	15.0	25.8	10.6	5.1	19.0	13.6	8.0	4.7
10th Percentile	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20th Percentile	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
50th Percentile	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.5
80th Percentile	1.7	2.0	1.9	1.9	1.4	0.8	0.7	0.6	0.8	2.5	3.1	2.0	24.5
90th Percentile	4.4	4.2	3.9	3.4	2.7	1.6	1.6	1.3	5.0	7.1	5.7	4.8	48.8

The following may be gleaned from **Tables 5.2** to **5.9**:

- A strong seasonality of flows is evident at both sites, with very low winter month flows (June – August) compared with high summer month flows (November – February).
- Total streamflow is dominated by stormflows (83.7% of the total flows at Wembezi, 88.7% at Keates Drift), indicative of the episodic and pulsar nature of rainfall events in the Thukela, which often occur as thunderstorms.
- Streamflow variability from year to year for any given month is very high. For the individual subcatchments, at Wembezi 11 of the 12 months have CVs > 100%, at Keates Drift it is 12 out of 12 months.
- It is notable that median monthly flows (i.e. 50th percentile) are markedly lower than mean monthly flows, particularly in the low flow months (e.g. at Wembezi in August: 0.4 mm vs 2.7 mm). This non-normality of the flow distribution manifests itself in very high coefficients of skewness, and it indicates that the mean flows are dominated by a few relatively high flows.
- While baseflows only make up 16.3% of the annual flows in the Wembezi subcatchment, and 11.3 % at Keates Drift, they do play an important role in the low flow season. For the period June to August, for example, baseflows make up 34 % and 26 % respectively of total flows at Wembezi and Keates Drift.
- According to the *ACRU* model simulations, baseflows are not generated at all during the driest year in 5 in any month of the year, or under conditions drier than that in the Wembezi subcatchment, and in the driest year in 2 or drier in the Keates Drift subcatchment.
- Where a total upstream catchment area is large, as is the case at Keates Drift, CVs of monthly (and annual) flows are considerably lower than those from an individual subcatchment. For example, CVs are < 100 % in 6 of 12 months for accumulated flows vs 0 out of 12 months for individual subcatchment flows at Keates Drift. This is not the case with the small total area upstream of Wembezi, however, where accumulated flows are more variable than those of the local subcatchment.

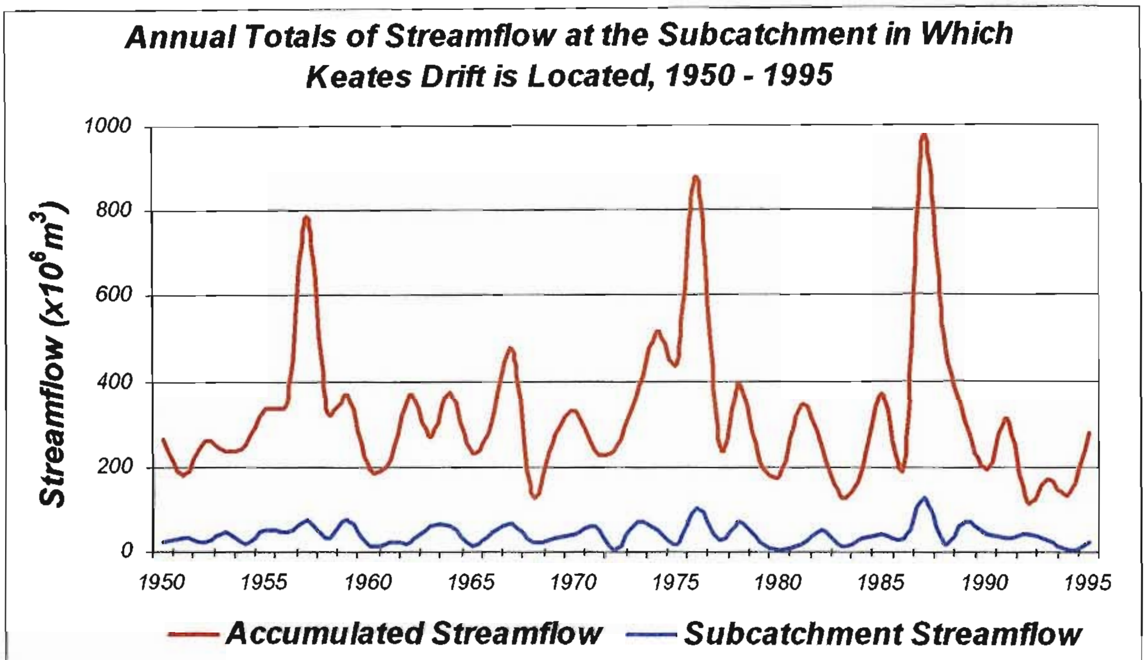
5.9 Interpretation of the Time Series of Streamflows

Visual interpretation of the time series of annual streamflows in the subcatchments in which Keates Drift and Wembezi are located (**Figures 5.14**) highlights the following:

- There is a high inter-annual variability of flows.
- More importantly from a water poverty perspective is that, in addition to isolated years with very high flows (e.g. 1957, 1976, 1987 at Keates Drift), sequences of persistent annual high flows occur, as do sequences of years of persistent low flows. The persistent low annual flows of the early 1960s, 1980s and especially 1990s have well documented associations with strong El Ninõ events.
- Neither the isolated high annual flows nor the consecutive years of lows necessarily occur at the same time or with the same strength at the two locations, which are only 75 km apart. For example, the sequence of low annual flow totals at Wembezi in the early 1990s is much stronger than at Keates Drift.
- The implications of persistent low annual flow sequences for water poverty are quite profound, in that any storage of water will have to be large enough to withstand hydrological droughts of several years' duration.

More significant for communities which depend on local surface water supplies are the patterns of the flow sequences in the low flow months, *viz.* June to August (**Figure 5.15**). The following may be observed:

- Inter-annual comparisons for the specified low flow months display a much more jagged pattern than for annual flows, particularly in the late low flow season (July to August).
- Prolonged hydrological droughts, i.e. when all three months have below average flows for several successive years, can be pronounced, as in the early 1960s, late 1960s and the decade 1975 to 1985 at Wembezi.
- Again, differences occur in the low flow season persistencies at the two locations.
- The time series analyses highlight the necessity for monthly to seasonal streamflow forecasting to be tested and applied as a planning and operational tool for water poor areas.



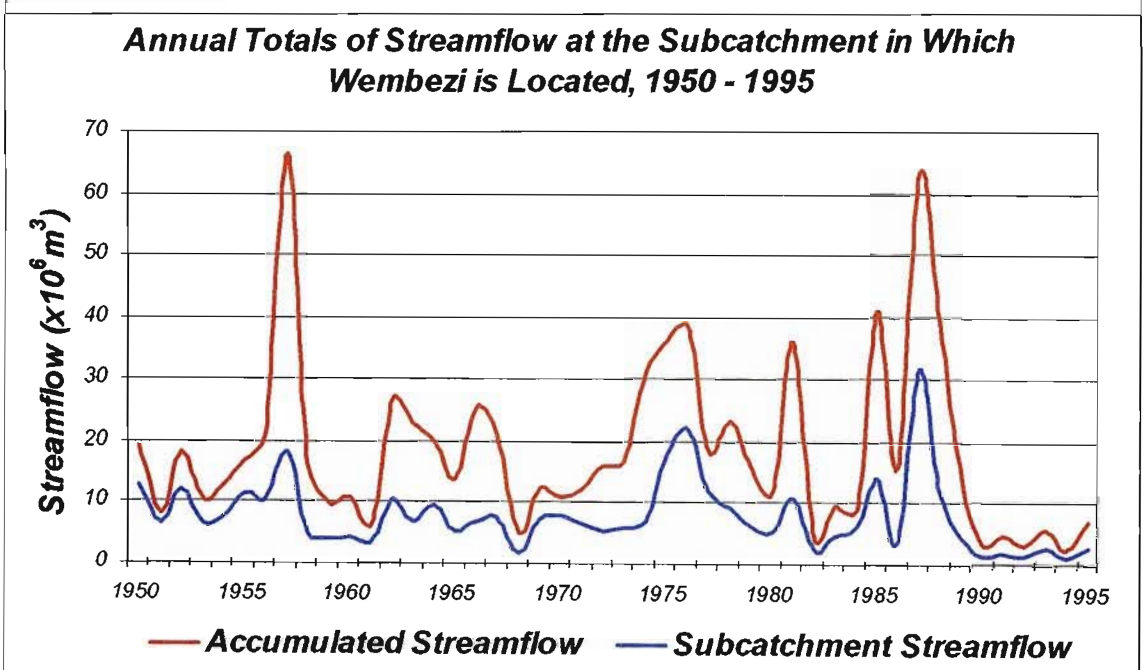


Figure 5.14 Time series of annual streamflows in the subcatchments in which Keates Drift and Wembezi are located

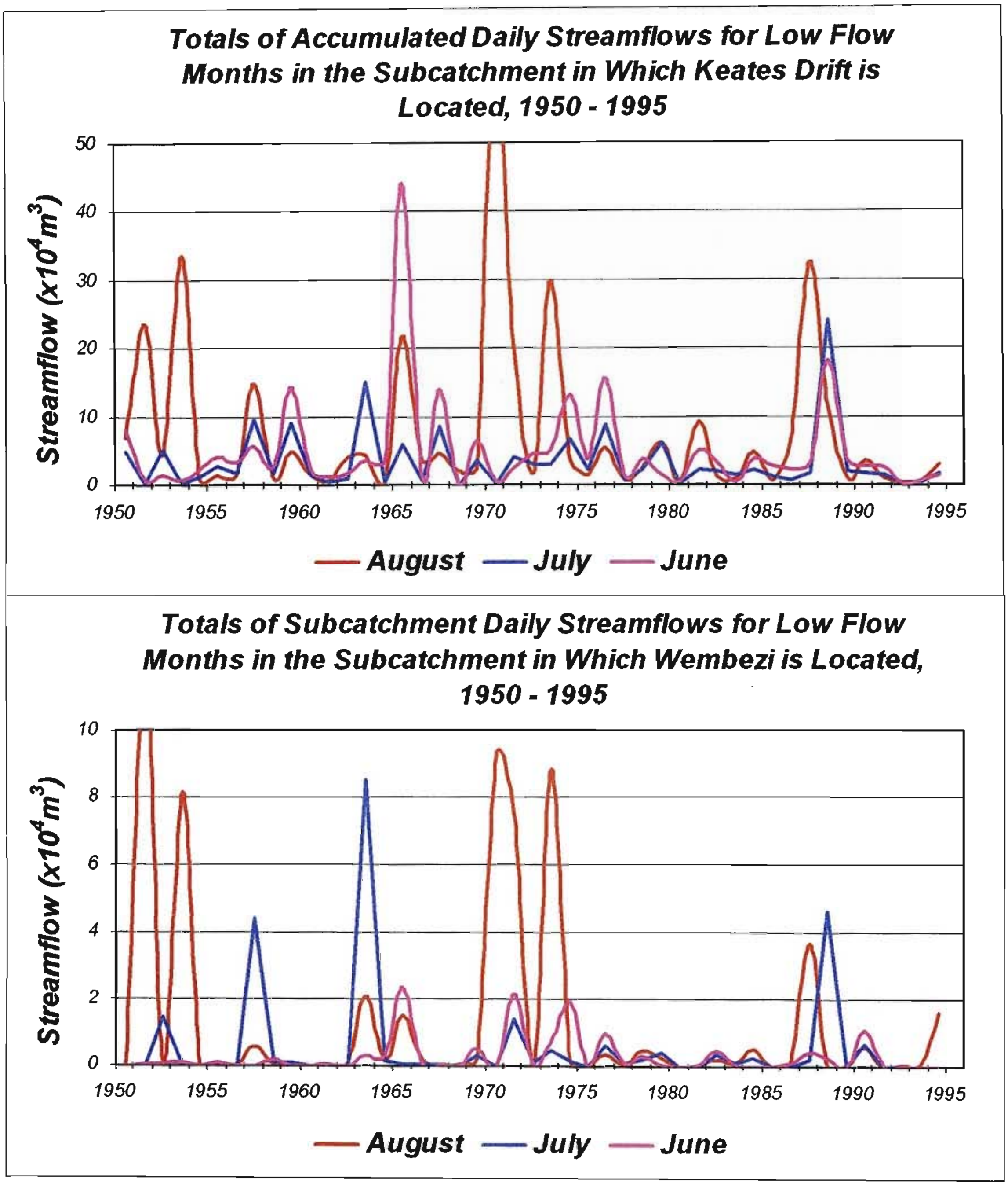


Figure 5.15 Time series of monthly flows of the low flow months June to August in the subcatchments in which Keates Drift and Wembezi are located

5.10 Evaluation of Flow Duration Curves for Year Round Flows and for High and Low Flow Months

Flow duration curves (FDCs) show the percentage of time that a specified flow is exceeded or not. When evaluated together with a population or development-driven water demand, a FDC can be used as an indicator of the proportion of time that water stress occurs, either in regard to too much water (low percentage exceedance) or too little water (high percentage exceedance). **Figures 5.16** and **5.17** illustrate the following:

- In absolute terms (i.e. $m^3.s^{-1}$ of water available), the proximity of a mainstem river commanding a large upstream catchment area (as at Keates Drift) provides a much more sustained water availability than a smaller catchment would (**Figure 5.16** top vs **Figure 5.17** top). Unfortunately, the rural poor do not always have access to water from rivers with large upstream catchments.
- Secondly, sustained water yield above a critical threshold of flow in months with high streamflows, e.g. January, is just so much more readily available than in months with low flows, e.g. July (**Figure 5.16** bottom vs **Figure 5.17** bottom).
- While being informative on percentage exceedances of flows of a given magnitude, the FDC does not, however, address the issue of persistent sequences of high or low flows.

For the purposes of comparing streamflow generation from large vs small catchments, FDCs may be expressed in terms of a unit area, i.e. $m^3.s^{-1}.km^{-2}$. Such a comparison is made in **Figure 5.18**. While results look deceptively similar, close scrutiny shows that in relation to water poverty, i.e. at the low end of streamflow generation for which flows are exceeded frequently:

- a unit of area upstream of Keates Drift generates considerably more streamflow than upstream of Wembezi and
- in an individual subcatchment, a trend may be reversed when its flows are compared with those of the accumulated flows of the total upstream catchment, as is the case at Wembezi for high flows occurring less frequently than 7 % of the times.

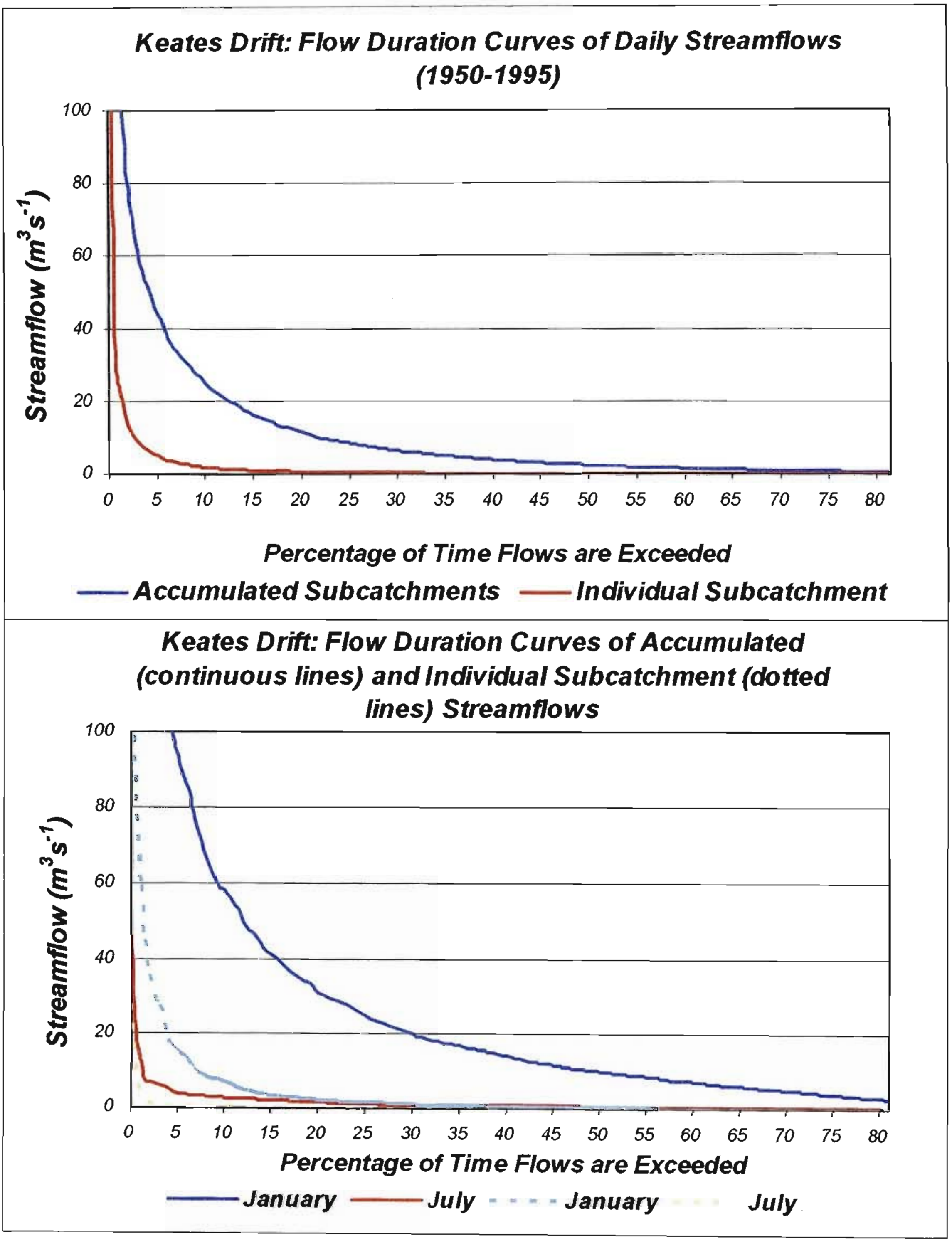
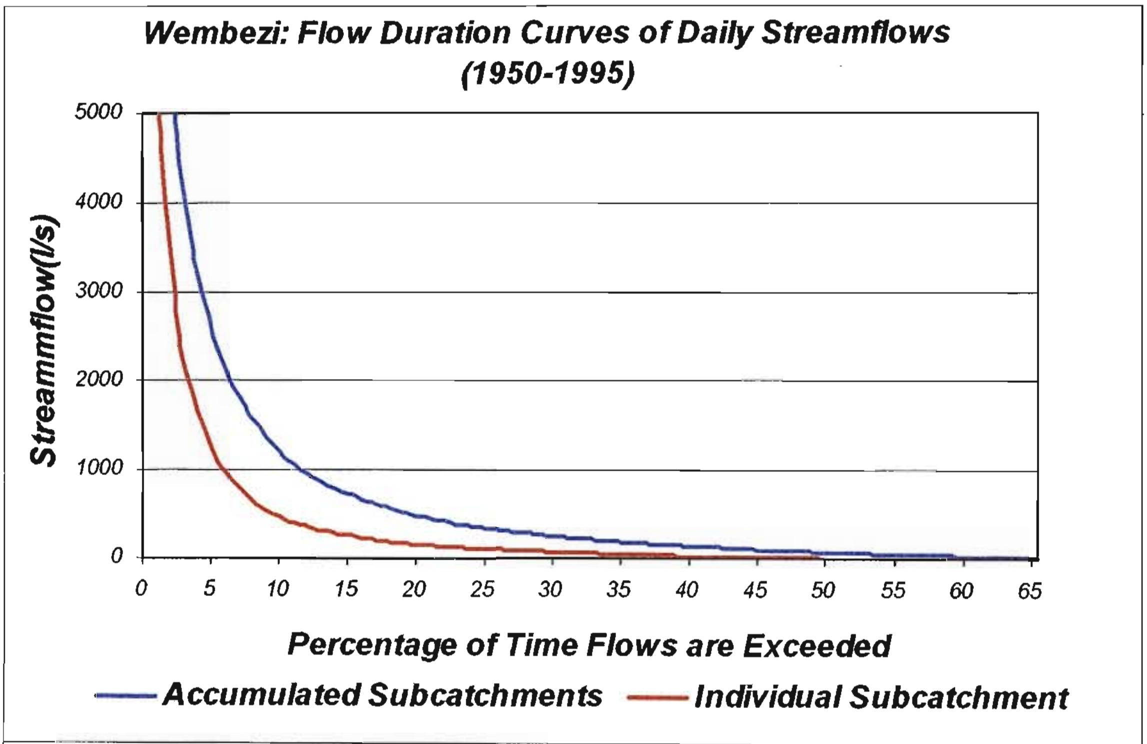


Figure 5.16 Flow duration curves for total flows as well as for high flows (January) and low flows (July) months at Keates Drift



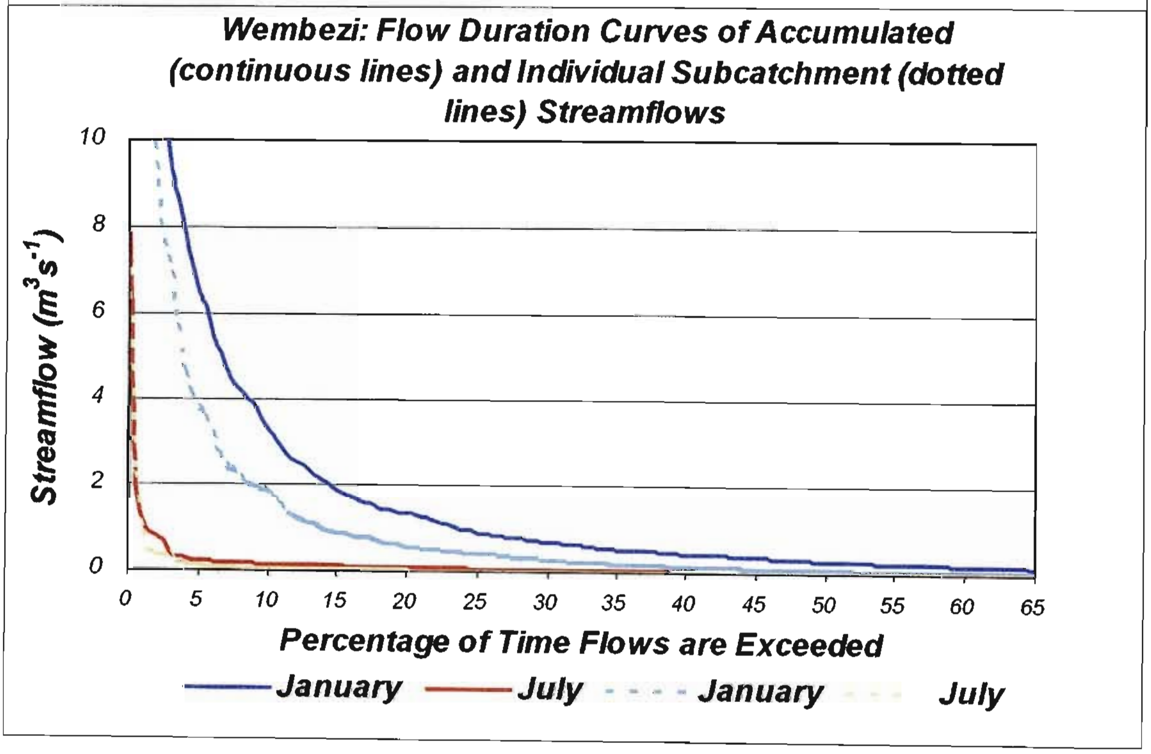


Figure 5.17 Flow duration curves for total flows as well as for high flows (January) and low flows (July) months at Wembezi

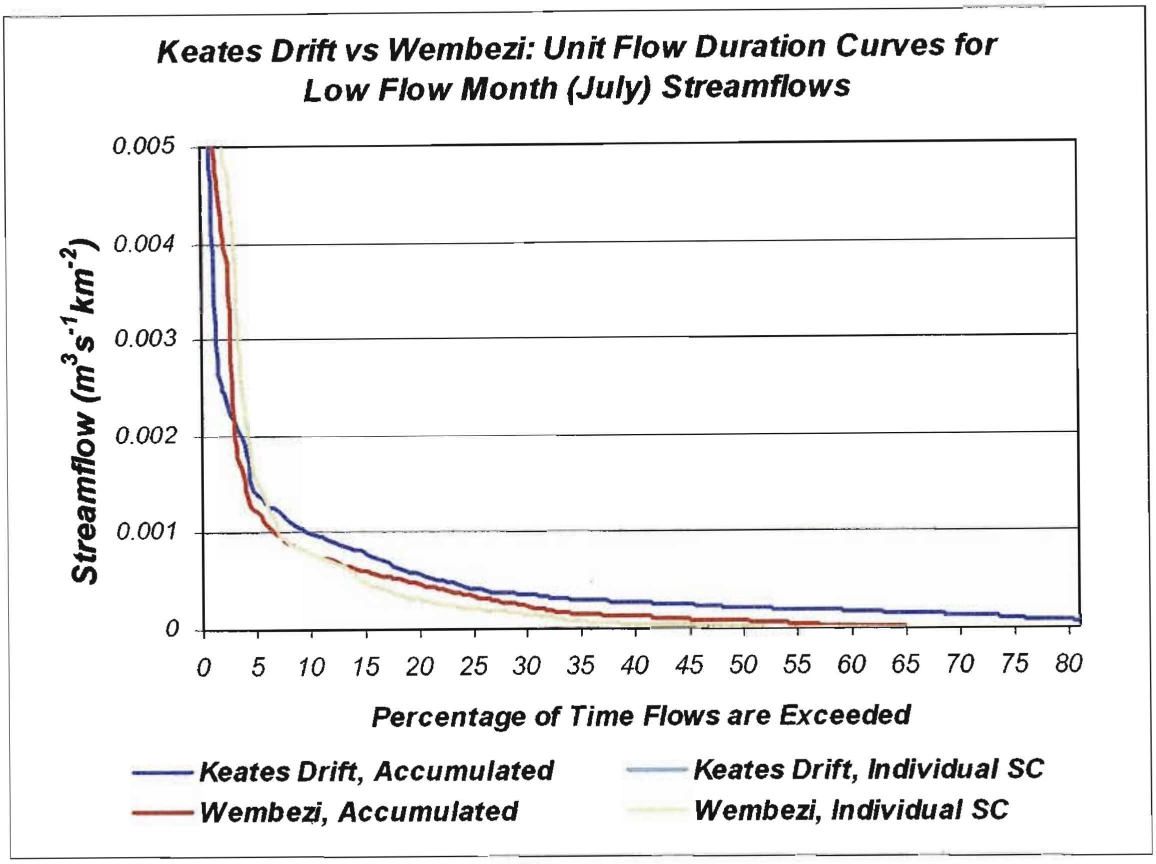


Figure 5.18 Flow duration curves per unit area ($m^3.s^{-1}.km^{-2}$) at Keates Drift and Wembezi

5.11 Contributions of Stormflows and Baseflows to Total Streamflows

The respective contributions to total flows of stormflows (Q_s) and baseflows (Q_b) are a reflection not only of the type of runoff generating mechanism in a region, but have an influence also on water quality. For example, high stormflows are commonly associated with high sediment and phosphorus yields; high baseflows have bearing on nitrate concentrations of streamflows.

The dominance of stormflows at both Keates Drift and Wembezi has already been emphasised. This is borne out graphically for the two case study locations in **Figures 5.19** (top) and **5.20** (top). In relative (percentage) terms, the middle diagrams of **Figures 5.19** and **5.20** show that only in June at Keates Drift and only from May to July at Wembezi, do baseflows contribute more to total flows than stormflows do.

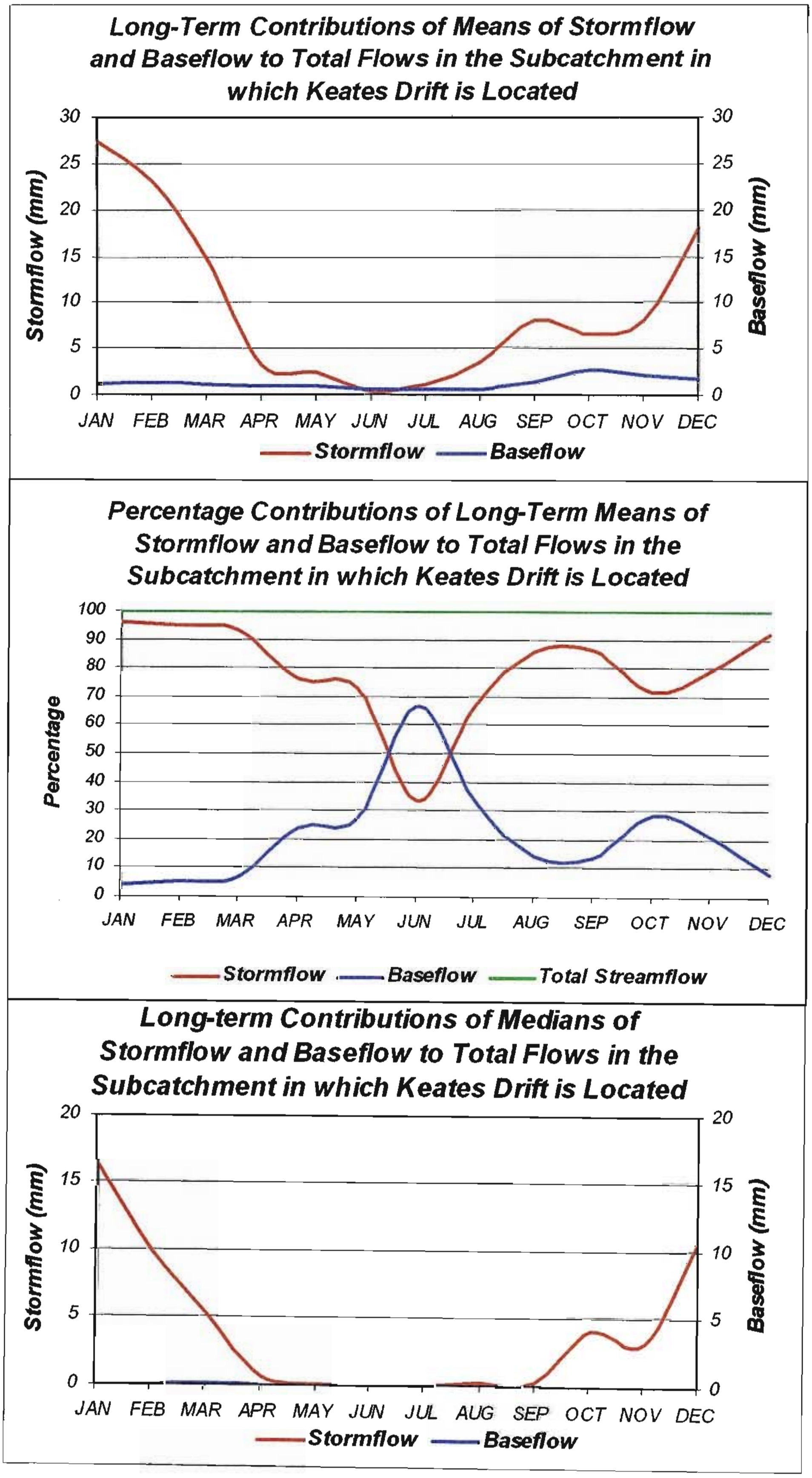


Figure 5.19 Contributions of stormflows and baseflows to total streamflows at Keates Drift

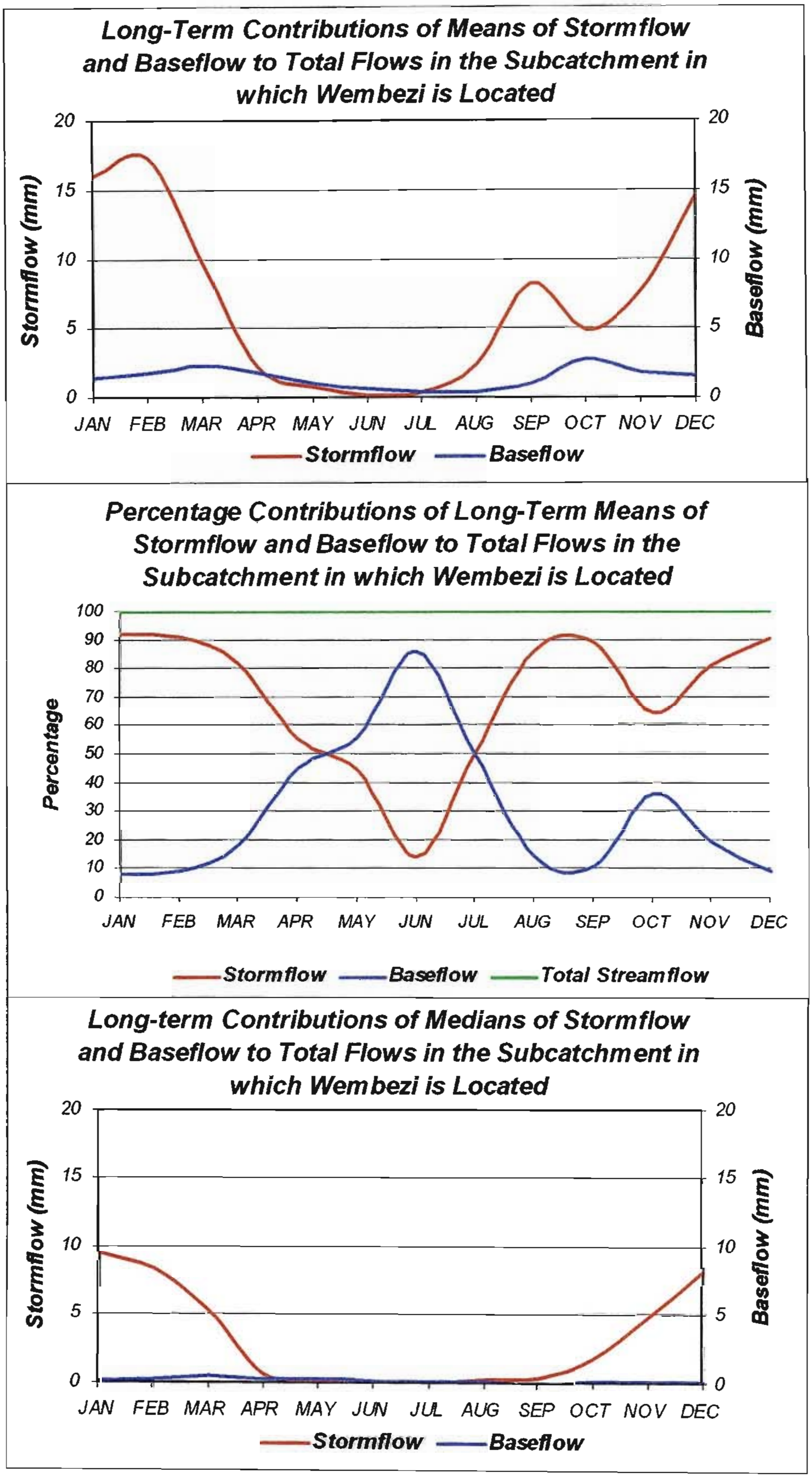


Figure 5.20 Contributions of stormflows and baseflows to total streamflows at Wembezi

The bottom diagrams of **Figures 5.19** and **5.20** illustrate that for median flows, the dominance of Q_s over Q_b is even greater than for means, because the means are influenced by extreme events which simultaneously tend to produce relatively higher baseflows.

5.12 Further Discussion of Results and Conclusions with Respect to Water Poverty

This assessment has established that the Thukela catchment is richly endowed with renewable surface water. However, considerations of the distribution of the water in space and time in relation to locations of water utilisation points reveal some important issues.

Most runoff is generated in the high rainfall, high altitude, rugged western parts of the catchment (cf. **Figure 5.9**). However, those areas are sparsely inhabited (cf. **Figure 4.13**). Most of the human populations, as well as agricultural regions and industries which require the water are found in the lower and drier parts of the catchment (cf. **Figure 4.12**).

The streamflows in the catchment are highly variable, both intra- and inter-annually (cf. **Figures 5.9** and **5.11**). This becomes evident when considering the flows which are generated within individual subcatchments and excluding those flows which are contributed from upstream. This is of particular importance within a perspective of water poverty because it represents the main sources of water for those rural communities which neither have reticulated potable water supplies, nor are adjacent to main tributaries. Many poor rural communities in the Thukela (and probably in many other catchments in South Africa) have, for historical and in the more recent past for political reasons, settled in the parts of the catchment with rough terrains and away from the mainstems of rivers with the more consistent flows (cf. **Chapter 4**). The high variability of flows implies low reliability of the water sources and hence greater vulnerability to water stress for these communities.

The mainstem rivers and large tributaries generally produce higher and more sustained flows and have a dampening effect on flow variability when compared with flows from individual subcatchments (cf. **Figure 5.10**). However, the rural poor in the Thukela catchment tend not to live close to the large rivers. In fact, they often live close to watershed boundaries where the streams are more prone to be ephemeral rather than permanently flowing (cf. **Chapter 4**).

The time series analyses of the 46 year period of simulation display frequent long sequences of low flows, both for annual flows and those in low flow months (cf. **Figure 5.14**). These long sequences of low flows highlight a further dimension of the natural vulnerability to water stress in the Thukela catchment, which also places a heavy burden on water poor communities.

It is apparent from the above discussion that certain areas in the Thukela catchment may be experiencing varying degrees of water stress, despite the catchment's being water-rich. However, the analysis presented in this chapter is not sufficient to draw comprehensive conclusions about water poverty.

- First, the inferences presented above are based only on characteristics of surface flows from a baseline, or reference, land cover without relating the quantities of the baseline water resource to demand, use or levels of pollution.
- Secondly, the simulated streamflows on which the analyses are based did not take into account the impacts of present land use and inter-catchment transfers on the availability of water resources.
- Thirdly, water scarcity and water poverty both have a social dimension (Ohlsson, 1998) which relates to the capacity to adapt to the natural vulnerabilities discussed above and to diminishing water resources as a result of increased demand. This was also not addressed because it was outside of the scope of this chapter.

Therefore, a more detailed investigation of the water scarcity in the Thukela catchment is presented in **Chapter 7**. Preceding that, however, the possibility of using multidisciplinary indices (such as the WPI), which take into account both the physical and socio-economic aspects of water scarcity, to measure levels of water stress at meso-catchment scale are assessed in **Chapter 6**.

6 THE APPLICABILITY OF MULTI-DISCIPLINARY WATER POVERTY INDICES AT MESO-CATCHMENT SCALE

6.1 Introduction

Indices of water stress and water poverty tend to be developed for, and applied at, either macro-scale level (i.e. country or large river basin) or, on the other hand, at the micro-scale level (i.e. individual rural communities) (Dlamini and Schulze, 2004). At the macro-scale little or no indication is given as to where, when, how often, or for what duration water stress occurs at a given point of interest within the country or river basin, while at community scales in-depth studies tend to be undertaken, often in isolation of broader operational water resources issues. Indices at neither of these "extreme" scales are applicable at the meso-catchment scale, i.e. at catchments in the range of 10s to 100s km^2 in area, yet it is at this scale that differences in streamflow responses can be identified meaningfully (i.e. the where, when, how frequently or how persistently water is available at a location of interest) and at this scale at which water resources planners operate and make decisions in South Africa. In South Africa, the meso-catchments may be equated to the so-called Quaternary Catchments of the Department of Water Affairs and Forestry, i.e. the 4th level of catchment discretisation, or sub-units thereof.

This chapter contains an analysis of the suitability of physically/hydrologically derived spatial units such as catchments to investigate water wellbeing at meso-scale using multi-disciplinary indices such as the WPI, which is the focus of this study. The rationale for selecting the WPI is presented in **Sections 2.6** and **2.9**. This is *Objective C* of the study (cf. **Table 1**). The analysis in this chapter starts with a review of the concept of a catchment as the recommended spatial unit for holistic water resources management, focussing also on the definition of the catchment and the concerns regarding the assessment of socio-economic issues within catchments. The review is followed by a discussion of classic concepts such as the Modifiable Areal Unit Problem, MAUP, (Openshaw, 1977) and contemporary hydrological practices in relation to the use of physical/hydrological units to study socio-economic phenomena. Statistical analysis of correlations between pairs of socio-economic variables at different spatial scales and the computation of a purely socio-economic index in both catchments (hydrological units) and magisterial districts (historical/administrative units) provides practical illustrations of the MAUP. The focus of the illustrations is on socio-economic issues because they are the ones for which the quantification in hydrological spatial units such as catchments is contentious.

6.2 The Catchment

A catchment (elsewhere in hydrological literature also described as a river basin, or watershed) refers to the entire area that is drained by a stream or river and includes all the land through, or over, which its waters move (DWAF and WRC, 1996). Catchment boundaries are demarcated by the points of highest altitude in the surrounding landscape (Hutchinson, 1957; Reid and Wood, 1981; DWAF and WRC, 1996). Catchments may be presented as a hierarchical structure from lower stream order to higher stream order, such as the Quaternary to Tertiary to Secondary to Primary delimitations in southern Africa, with the smaller units nested within the larger ones. This hierarchy is useful for moving up and down the spatial scale depending on the type and scale of the managerial problem to be solved (Water Quality 2000, 1992; Maxwell *et al.*, 1995; Session *et al.*, 1997; Jewitt, 1998).

A catchment integrates processes, fluxes and states relevant to the entire hydrological cycle, including atmospheric moisture (quantity, quality and distribution of precipitation), subsurface water (soil moisture and groundwater reserves), surface water (rivers, lakes, wetlands and impoundments), the estuary and the coastal marine zone. DWAF and WRC (1996) describe the catchment as a "living ecosystem" which consists of a large interactive network of land, water, vegetation, structural habitats and biota, all of which are dynamically linked by physical, chemical and biological processes.

The catchment ecosystem is continually changing over space (vertically, laterally and longitudinally) and time (Minsall, 1988; Ward, 1989). Under undisturbed conditions, the catchment is a complex system that is difficult to manage. Introducing a human dimension which perturbs the natural system can compound its management significantly. The recognition of the interconnectedness of components between and within systems, and hence benefits of managing them in a holistic manner, has led to the concept of integrated catchment management (ICM). With respect to the comprehensive assessment of water poverty, which can be viewed as an element of ICM, the catchment provides a suitable spatial unit which encompasses the physical aspects of water scarcity as well as the impacts of socio-economic activities on water resources.

Integrated catchment management represents an approach to managing resources of a catchment by integrating all environmental, economic and social issues within a catchment into an overall management philosophy, process, practice and plan (DWAF and WRC, 1996). It is aimed at obtaining an optimal mix of sustainable benefits for current and future generations, while protecting the natural resources, particularly water, and incurring minimum impedance of social and economic development (DWAF and WRC, 1996). ICM may be viewed as managing the catchment for sustainable development, especially where water is a limiting resource (Walmsley, 2002). While ICM is a conceptually sound notion and is promoted globally (Johnson, 1993), cases of its successful implementation are limited (Schulze, 2004), owing to a number of "barriers". The dearth of information is one of many impediments to effective implementation of ICM. DWAF and WRC (1996) identify appropriate assessment of the diverse, interacting components of catchment processes and the resource management actions and their impacts as one of the critical success factors for ICM. A systematic approach to the assessment of ICM should include (DWAF and WRC, 1996):

- Analysis of aspects of the catchment system that affect use and condition of the water resource;
- Assessment of the prevailing environmental, economic and social values, together with values arising from beneficial uses of the water resource and related impacts of management actions; and
- Monitoring of the environmental conditions and related socio-economic factors.

Such a systematic approach provides the basis for a management information system for catchments. The WPI could be useful in the assessment of ICM in two ways. First, WPI is a holistic tool that takes into account the physical water resource base, the capacity to develop and manage the resource, access to the resource, the ways by, and extents to, which the resource is used, as well as the condition of the aquatic environment. Second, the WPI can generate useful information which can be used to evaluate water-related development policies by utilising data from existing and planned water-related monitoring programmes and information systems (cf. **Chapter 3**), and hence add value to these systems. Other indicators and indices, particularly those of sustainable development, can be invaluable when implementing this systemic assessment of ICM. Despite the apparent convergence of the sustainable development and ICM concepts, the use of sustainability indicators in catchment management is still at its infancy (Walmsley, 2002). Lack of resources, lack of understanding of the use of indicators in catchment water resources management and the complexity of developing indicator sets for international catchments are cited by Walmesly *et al.* (2001) as some of the reasons for this slow uptake of ICM.

6.3 Concerns over the Use of Catchments as Spatial Units for Multi-Disciplinary Indices

Because the delimitation of catchments is based on characteristics of river networks and other physical features important in water management (e.g. dams or water abstraction points), they tend to intersect both political and administrative boundaries. Thus catchment boundaries may dissect and/or group within themselves different cultures and different levels of development (Newson *et al.*, 2000). They therefore may not always be appropriate for explaining trends and dynamics of social phenomena such as poverty. However, it should be noted that the concept of the catchment as a spatial unit is not always useful even for the explanation of the distributions and behaviours of some biophysical entities such as air, wildlife and vegetation because, unlike water, these are not confined to catchment boundaries (Griffin, 1999). As an organising spatial domain, the catchment is not entirely suitable unless the focus is solely on the management of water systems rather than on ecosystems or socio-economic entities. Catchments suit water management better than socio-economic issues because they are natural hydrological units. Therefore, on the basis of the above discussion, it would appear as though catchments are not necessarily suitable for the evaluation of multi-disciplinary indices such as the WPI, which have strong socio-economic components.

However, the evaluation of water poverty indices is not intended exclusively for water systems management, but can also be a useful decision making aid in relation to broader socio-economic and development issues. Hence, for these indices to be a useful, consistent and trusted measure, its validity should be assured at each scale of application. In this study, it is proposed that the validity of the water poverty indices at catchment level be ascertained by determining the nature of trends and relationships of social phenomena (e.g. poverty, literacy levels, provision of services) known to prevail at other spatial scales. Since the water poverty indices combine physical, socio-political, environmental and economic indicators, and only the physical indicators are usually studied on catchments, it is the measure of the human dimension of water poverty that requires validation at catchment level. From the available literature and the discussion above, the unsuitability or inadequacy of the catchment as a unit for studying or observing socio-economic issues is based entirely on individual experts' insights and intuitions, without experiment- or observation-based investigations. Inasmuch as insight and intuition are traits of the astute mind, they may at times not be sufficient as basis for important generalisations, particularly where rigorous investigations are both possible and feasible. Therefore, this analysis follows the scientific approach in order to establish whether the meso-catchment is a suitable spatial unit and scale for water-related socio-economic assessments.

Some water resources management and hydrological research practices such as the subdivision of catchments into sub-units on the basis of social, political or economic characteristics have gained broad acceptance. These will be reviewed in order to obtain an understanding of their implications on the acceptability of the catchment as a spatial scale for the assessing water poverty. Therefore, this chapter is attempting to establish whether known, or expected, relationships and trends of social phenomena are preserved in data such as those collected in the National Population Census enumerator areas, and then aggregated to meso-catchment scale units. This should, in turn, create a scientific foundation for accepting or rejecting the approach of evaluating the multi-disciplinary indices at the meso-scale catchment scale. This investigation includes the assessment of trends and associations between socio-economic variables in the Thukela catchment in South Africa using simple statistics such as correlation coefficients. To place findings in a spatial context, throughout this chapter, the reader is referred to the detailed description of the Thukela catchment which was presented in **Chapter 4.**

6.4 Methodology

An approach that combines a statistical analysis of correlations between pairs of socio-economic variables at different spatial scales, a review of contemporary hydrological practices and an assessment of the use of weightings when computing indices, was adopted for the assessment of the validity of representing socio-economic indicators at meso-catchment scale. A general poverty index was also computed for all the magisterial districts and meso-catchments in the entire KwaZulu-Natal province (cf. **Figure 4.1**) in order to illustrate the possibility of representing socio-economic variables, indicators and multi-disciplinary indices in physical spatial units and to assess the implications of evaluating these.

The statistical analysis commences by determining a spatial unit within which statistical relationships could be accepted as being valid. It is assumed that this will enable setting the relationships in that particular spatial unit as the standard, or control, against which the relationships between the same variables, but for different spatial units, can be compared. Magisterial districts (MDs) satisfied these criteria because they are historical administrative spatial units, the demarcation of which has had socio-political-economic connotations (De Visser, 1999). They today are still used as spatial aggregation/disaggregation units in the assessment of socio-economic-political phenomena (cf. Wilson, 2000). Therefore, if correlation coefficients between pairs of socio-economic variables in MDs are retained in the other spatial units then, as in the case of the MDs, these units may be considered to be suitable to quantify/aggregate and study socio-economic variables and their relationships and, hence, render it credible to compute the socio-economic indices therein.

The other four spatial units within which the correlation coefficients between selected pairs of socio-economic variables were computed are the

- Population Census's enumerator area,

- place names,
- sub-Quaternary catchments, and
- Quaternary catchments.

These are listed and described in **Table 6.1**. A graphical comparison of their geographical distributions and areal extents relative to the meso-catchments of the Thukela are presented in **Figure 6.1**.

Table 6.1 Selected spatial units and some of their characteristics within KwaZulu-Natal (KZN)

Unit	Abbr.	Function	Avg. Size (km^2) in KZN	No. in KZN
Enumerator Area	EA	National census land units; Survey area for an enumerator	7.4	13000
Place Name	PN	Local government sub-units	34	2741
Quaternary and Sub-Quaternary Catchment	SQ	Localised hydrological studies; Water resources assessments	*	*
Quaternary Catchment	QC	Water resources operational units	304	304
Magisterial District	MD	Magisterial jurisdiction	1800	51
* Spatial units are not standard, i.e. delimitations and hence sizes/areas may change, subject to objectives of individual studies				

Numerous socio-economic variables were selected for the construction of a correlation matrix in order to determine the existence and intensity of bi-variate relationships at the five spatial scales described in **Table 6.1**. Since the purpose of the matrix is to test a concept, rather than analysing the trends and distributions in the Thukela catchment, there was no stringent criterion for their selection. Any typical socio-economic variables would have sufficed for this test; hence, those for which data were readily available were used. The variables and indicators analysed are shown and described in **Table 6.2**. They were taken directly, or were derived, from the 1996 South African National Population Census data and they can be categorised into measures of levels of service provision, human capacity and economic wellbeing. The economic dependency ratio (EDR) is the ratio of people out of work (whether inactive or unemployed) to people in work. The EDR gives an idea of the economic burden which the non-working population bring to bear on those in work. The 2001 Census data were not used because they were not available at the time of this particular analysis in the first quarter of 2004.

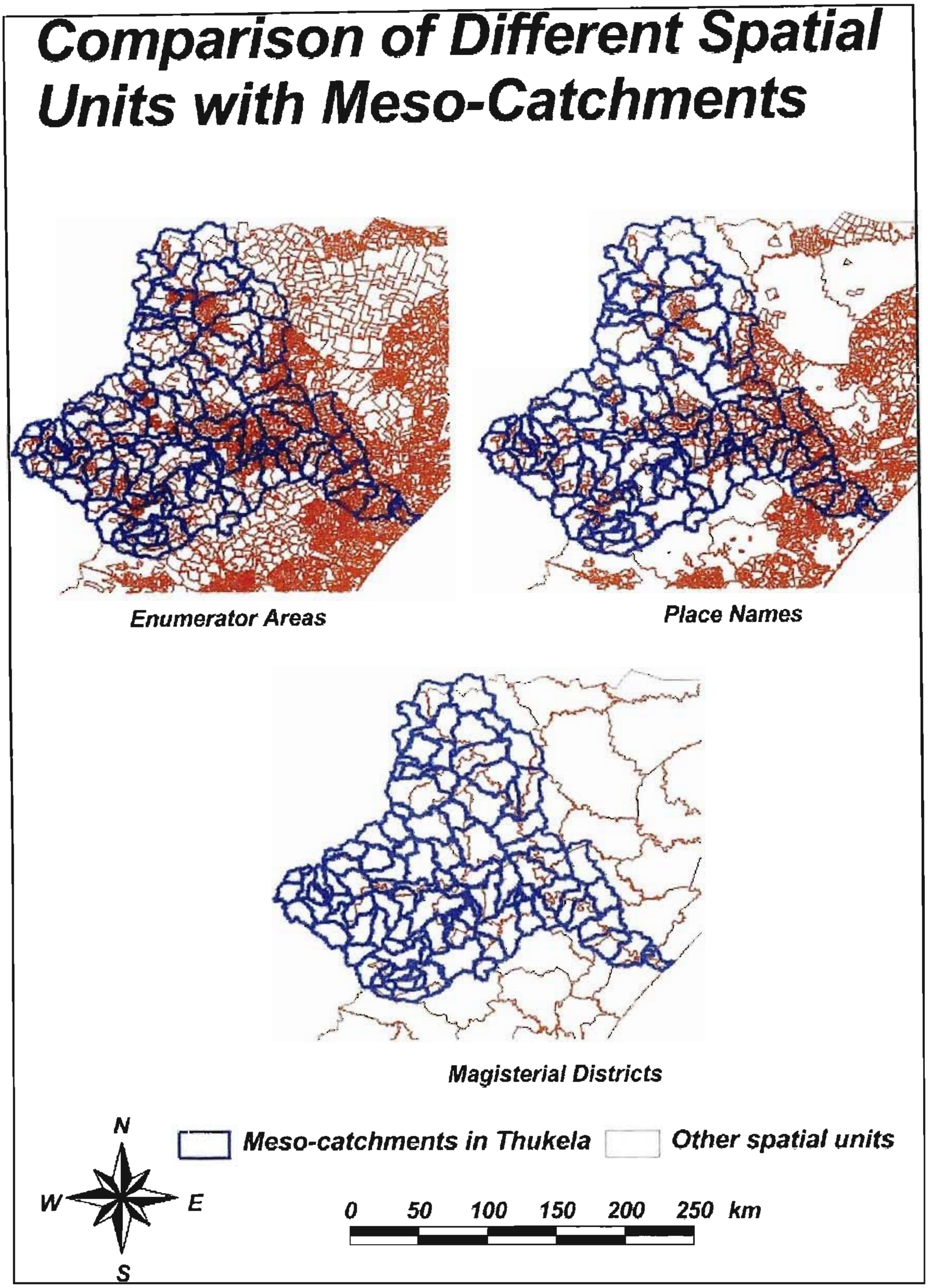


Figure 6.1 A comparison of other spatial units in the Thukela catchment with meso-catchments

Table 6.2 Variables selected for the construction of the correlation matrix

Variable	Description
% No Elect	Percentage of households with no electricity
% Poor	Percentage of poor households, i.e. annual income <ZAR2400 (approx. US$370 during the 1st quarter of 2004)
% Trad	Percentage of households with traditional dwellings
EDR	Economic dependency ratio (Wilson, 2000)
% UWat	Percentage of households using unprotected water sources
% No Sch	Percentage of adult population that never attended school

6.4.1 The Correlation Matrix

The correlation coefficients between the selected variables in each spatial unit are shown in **Table 6.3** and all these coefficients represent relationships which are statistically significant at the 95% level of confidence ($p < 0.05$). High correlation coefficients (> 0.60) indicate strong relationships between the pairs of variables at the MD level in the KwaZulu-Natal province.

Table 6.3 shows that the correlations are consistently high at MD level (15 out of 15 with $r \geq 0.6$) and the coefficients are the highest compared to the other spatial units. The correlations are relatively weak in the EA (7 out of 15 with $r \geq 0.6$), and are by far the weakest in PN (4 out of 15 with $r \geq 0.6$). The SQ (7 out of 15 with $r \geq 0.6$) ranks second to MD, followed closely by the QC (5 out of 15 with $r \geq 0.6$). In fact, in nine out of 15 cases, QC ranked higher than SQ, compared to six out of 15 for SQ. Statistically, the differences between the correlations in SQ and QC are not significant. This begs the question whether it is worthwhile to sub-delineate QCs further into smaller homogeneous hydrological response zones. The answer to the above question is found in the reason for subdividing the QC in the first place. While the SQ is a suitable spatial unit for this particular study on water poverty, its delineation was not done specifically for socio-economic evaluations, but for hydrological investigations, e.g. Jewitt *et al.* (1999), for which no doubt exists regarding its necessity. Moreover, this exercise aims at establishing the suitability of the QC and SQ in socio-economic analyses rather than the necessity for subdividing the QC into smaller units *per se*.

Table 6.3 A correlation matrix of selected socio-economic variables for different levels of spatial aggregation within the province of KwaZulu-Natal

	% No Elect	% Poor	% Trad	EDR	% UWat	% No Sch
% Poor	0.60	EA -Enumerator areas in KwaZulu-Natal				
	0.32	PN - Place names in KwaZulu-Natal				
	0.72	SQ – Sub-Quaternary catchments in the Thukela catchment				
	0.73	QC – Quaternary catchments in KwaZulu-Natal				
	0.84	MD - Magisterial districts in KwaZulu-Natal				
% Trad	0.75	0.54	EA			
	0.61	0.63	PN			
	0.80	0.73	SQ			
	0.85	0.76	QC			
	0.93	0.86	MD			
EDR	0.33	0.24	0.38	EA		
	0.24	0.21	0.29	PN		
	0.50	0.54	0.51	SQ		
	0.51	0.53	0.54	QC		
	0.71	0.68	0.71	MD		
% UWat	0.67	0.47	0.76	0.36	EA	
	0.54	0.50	0.70	0.28	PN	
	0.71	0.53	0.71	0.42	SQ	
	0.67	0.58	0.72	0.51	QC	
	0.81	0.72	0.85	0.63	MD	
% No Sch	0.66	0.52	0.66	0.39	0.62	EA
	0.45	0.49	0.60	0.37	0.56	PN
	0.63	0.51	0.60	0.48	0.71	SQ
	0.56	0.42	0.53	0.49	0.59	QC
	0.78	0.72	0.78	0.65	0.78	MD

Although the relationships between the pairs of socio-economic variables are not as strong as those in the MDs, they are retained in all the other spatial units, including the meso-catchments (Quaternary and sub-Quaternary catchments). Within the meso-catchments, the correlation coefficients are higher than 0.5 between all the pairs of variables, except for those that involve the economic dependency ratio. Using relationships at MDs as benchmarks it may, therefore, be deduced that expected relationships and trends between pairs of socio-economic variables are preserved in hydrological spatial units such as meso-catchments. Although not conclusive on its own, the preservation of these associations at meso-catchment level presents evidence that lends credibility to the suitability of this hydrological scale as a spatial unit for assessing social dynamics, both in the Thukela catchment and KwaZulu-Natal province. The weak relationships between the variables represented by low correlation coefficients at enumerator area (EA) level result from the fact that the EA boundaries have neither a physical nor a strictly socio-economic basis. They are drawn by StatsSA with the sole objective of producing units with similar numbers of households in order to distribute work to the census enumerators fairly. Logical grouping of households on the basis of social welfare and service provision was not a major concern to StatsSA because the EAs are not used for any analysis. Instead, the values are aggregated to large-scale units such as MDs for analysis.

As discussed above, the objective of this chapter, and in particular that of the correlation matrix, was to determine whether known, or expected, socio-economic trends and relationships were preserved at the hydrological meso-catchment scale without, at this stage, necessarily delving on what causes the trends. It is acknowledged that the data used (1996 Census) may by now (2005) be dated and that relationships and trends may possibly have changed to a lesser or greater extent as a result of effects of HIV/AIDS, government initiatives such as water provision and land redistribution, as well as other positive and negative triggers that could result in demographic changes, e.g. rural to urban migration. It is, therefore, assumed that although the noted trends and relationships are likely to change over time at meso-catchment scale, as much as they will at other scales, their change will not invalidate the use of meso-catchments to study them.

6.4.2 Consideration of Human Issues in Subcatchment Delimitation

Although the classical definition of a catchment emphasises hydrology-based criteria for the delimitation of its boundaries, non-hydrological factors have been used in the past. The original 86 individual Quaternary catchments in the Thukela have been further subdivided into 235 smaller subcatchments on the basis of hydrological points of interest such as dam sites, streamflow gauging stations and water quality monitoring sites, relatively homogenous physiography, soils, land use, natural vegetation and historical human settlement, in order to isolate and study their impacts on hydrological and sediment responses (Schulze *et al.*, 2005). Although hydrologically "artificial" up to a point, this method of delineation presents a flexibility that allows investigators to draw the boundaries to suit the objectives of their studies. This is acceptable in hydrological studies as long as the smaller units are nested within acceptable and/or logical hydrological units such as the Quaternary Catchments. In the Thukela catchment, areas located in what used to be 'homelands' were delineated into separate subcatchments within QCs which, to an extent, indirectly incorporates social and former political dynamics in the catchment delimitation process.

Many multi-disciplinary indices, such as the WPI, have strong socio-economic components which may not be amenable to characterisation at meso-catchment levels. The human dimension which is meant to be incorporated in the WPI, *viz.* the capacity to cope with water shortage and inherently take into account activities such as water utilisation and improvement of access, may impact positively or negatively on the status of the water resources. The impacts themselves need to be assessed and incorporated in the WPI in order to obtain a fair representation of water supply vs demand, and hence water surplus or shortage. With these impacts affecting the hydrological system, which itself is better assessed at catchment level, the justification of the catchment as a suitable spatial unit for the WPI is further consolidated. The contemporary hydrological practice of delineating "pseudo-socio-economic" catchments and subcatchments finds some validation from the Modifiable Areal Unit Problem (Openshaw, 1977), a concept which is recognised and accepted in the social science research (Marceau, 1999).

6.4.3 The Modifiable Areal Unit Problem (MAUP)

A significant contribution towards a better understanding of scale and moving towards a solution for scale-related problems in the social sciences was made by Openshaw (1977; 1978; 1981; 1984a, b) and Openshaw and Taylor (1979; 1981), who fully described what they called the "modifiable areal unit problem", or MAUP (Marceau, 1999). The MAUP emanates from the fact that, theoretically, an infinite number of different ways exist by which a geographical study area may be divided into non-overlapping areal units, each at a similar scale, for the purpose of spatial analysis. These units are often defined primarily on the basis of the operational requirements of the study and, according to Wiens (1989), are often chosen "based on our own perception of nature". Hence, none of these spatial units have any intrinsic geographical meaning. Since the areal units are arbitrary and modifiable, the relevance and validity of any work based upon them is limited to the units which are being studied. The MAUP consists of two component "problems", *viz.*

- the scale problem and
- the aggregation problem.

The scale problem refers to the variation in results which may be obtained when data acquired from areal units are progressively aggregated into fewer, larger units for analysis. On the other hand, the aggregation problem represents the variation in results produced by the use of alternative combinations of areal units at similar scales.

The MAUP, and in particular in regard to the aggregation problem, has implications on the spatial units for evaluating multi-disciplinary indices. Some administrative or historical spatial units may be equally as arbitrary, if not more so, than natural or physical units such as catchments because their boundaries may not necessarily represent any natural discontinuities of socio-economic characteristics. Despite this, investigations about socio-economic phenomena are still undertaken in them. The conclusions from such studies are valid as long as they are not assumed to be general, but rather specific to the catchment and at the scale under consideration. By extension, the same argument may be used to justify the study of socio-economic issues within natural or physical spatial units such as catchments.

6.4.4 Comments on the Use of Weighting When Computing Indices

The arguments in the previous section show that whichever spatial unit is chosen to evaluate multi-disciplinary indices, there is bound to be a measure of compromise on accuracy and effectiveness of the index. Choosing historical, or administrative, boundaries (e.g. municipal districts, magisterial districts or even provinces) could lead to better representation of social components of an index, but make it extremely difficult to obtain reliable quantifications of the physical aspects such as water, which after all is a commodity of interest in a water poverty index. Similarly, sacrificing some accuracy in socio-economic indicators at the expense of better indicators of water resources by using the catchment as a spatial unit, may yield misleading values of the index because of possible misrepresentations of the socio-economic dimension. The absence of a perfectly suitable and universal scale implies that the choice of the spatial unit to use will rely on the objectives of the study to be undertaken. This viewpoint is in line with the use of weightings which can be applied to the components of the WPI to emphasise a particular need or sector (Sullivan *et al.*, 2002). For example, if water resources development and environmental issues are a high priority, giving the resource and environment components of a water poverty index heavier weights and using the catchment as a spatial unit for evaluation of the index would be more appropriate than using historical or administrative districts. Since the focus of this chapter is on water poverty indices and, more specifically, on their application in water resources planning and management, the adoption of the meso-catchment as the suitable spatial unit is thus viewed as both justified and credible.

6.4.5 An Illustration of the Application of Socio-Economic Indices at Meso-Catchment Level with the General Poverty Index

Having demonstrated the preservation of the relationships at meso-catchments level by studying correlations between selected socio-economic variables at a range of scales, a further illustration is presented by a comparison of values of a compound poverty index calculated at both the meso-catchment and magisterial districts for the entire province of KwaZulu-Natal. The provincial scale was preferred to that of the Thukela catchment because the small number of magisterial districts whose entire area (and not only a fraction of) was within the Thukela provided too few data points and limited representation of spatial diversity to undertake this assessment and draw meaningful conclusions.

While any other measure of human wellbeing (e.g. the Human Development Index) could have been used for the illustration (cf. **Section 6.4**), the compound poverty index (PI) was chosen because of its simplicity and the ready availability of data for its computation. The PI was also evaluated in the Thukela catchment, during an important study prior to this one, to measure patterns of advantage and disadvantage at the level of magisterial districts (Wilson, 2000). Therefore, despite its simplicity, the PI is an accepted and trusted measure of general poverty. The PI differs from general water poverty indices, which explore the implications of socio-economic wellbeing (depicted by PI) on access to water, in that it measures general poverty without relating it to water. Three criteria were used to create the compound poverty index and they are the:

- economic dependency ratio ;

- average years of education of adults (i.e. the total number of years of completed schooling and tertiary education divided by the total number of adults); and the
- percentage of households with electricity.

These criteria illustrate three dynamics: first, the level of economic activity within the local population, second, the extent to which the population is literate, and third, the level of service provision to the community. Each criterion was given equal weight, ranked from worst to best and combined into a single index ranging from 1.0 (most disadvantaged) to 0 (most advantaged). Following the above procedure, the PI was also calculated at meso-catchment level. A comparison of the spatial patterns of poverty at magisterial districts (MDs) and meso-catchments (MCs) for the entire province of KwaZulu-Natal is shown in **Figure 6. 2**.

The general spatial pattern of poverty in KwaZulu-Natal appears to be similar for the MD and MC subdivisions, except for the more distinctive spatial detail of disadvantaged versus more affluent areas in MCs than MDs, which is likely to be a result of the finer scale of the MCs. The overall similarity of the patterns is another piece of evidence that socio-economic variables and multi-disciplinary indices such as the WPI can be assessed for physically/hydrologically delineated spatial units such as meso-catchments.

6.5 Conclusions

The reviews and discussions in this chapter have revealed three main reasons that justify, and lend credibility to, the evaluation of the multi-disciplinary indices at meso-catchment level. First, the dilemma of selecting a suitable spatial unit for multi-disciplinary indices is an inevitable consequence of the combination of socio-economic and hydrological (or other biophysical) indicators in the index. There is no single spatial unit that can be categorically stated to be ideal. Therefore, a choice has to be made on the basis of the needs or priorities of individual evaluations. After all, spatial units and scales are, in many cases, arbitrary because they are often determined on the basis of the operational requirements of the specific study to be undertaken.

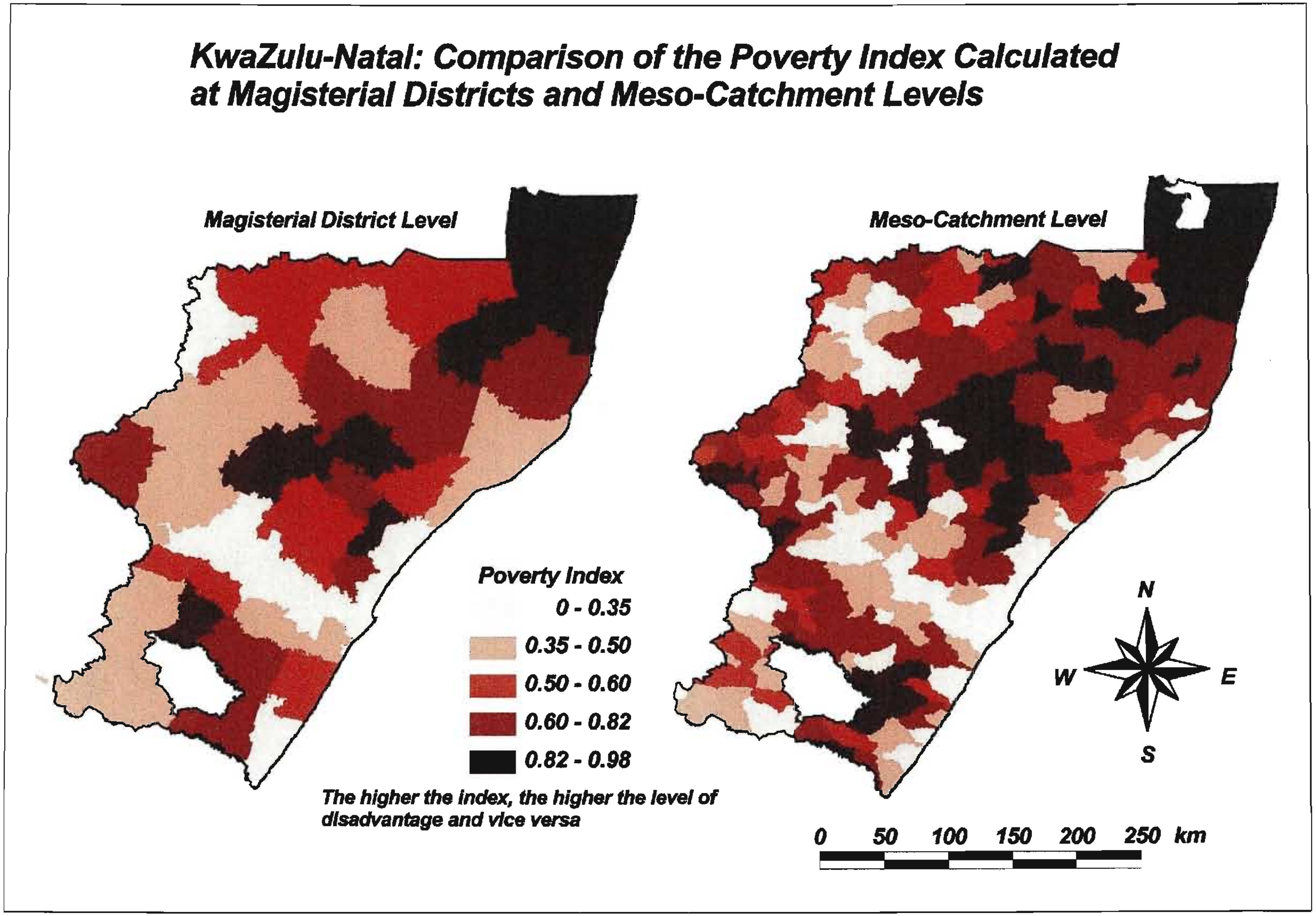


Figure 6.2 Comparison of spatial patterns of the poverty index (Wilson, 2000) at meso-catchment and magisterial district levels in KwaZulu-Natal

Second, the use of socio-economic criteria in conjunction with standard methods of delineating subcatchments presents a sound basis for studying social dynamics at meso-catchment level. Third, and partly as a result of the preceding point, the correlation matrix presented and discussed in this chapter shows that known relationships of certain socio-economic variables are preserved at the meso-catchment scale, probably in most catchments, but certainly in the Thukela catchment. It is concluded, therefore, that the values for the socio-economic components of indices such as the WPI can be calculated for catchment units with high levels of confidence.

It has been shown in **Chapter 6** that although meso-catchments are not the ideal, they are still valid spatial units for assessing socio-economic issues, as long as the results are not assumed to be applicable at other units and scales. This finding validates the evaluation of multi-disciplinary indices, such as the WPI, at meso-catchment scale.

Chapters 3 and **6** have, respectively, established that water poverty can be assessed at meso-catchment scale using multi-disciplinary indicators and indices such as the WPI, and determined that sufficient data and information is, and will be, available to support the computation of these measures, especially, when all the existing and planned water-related monitoring programmes, information systems and databases are fully functional. The following chapter presents a case study of the application of the WPI to assess water wellbeing in the Thukela catchment in the KwaZulu-Natal Province of South Africa.

7 PATTERNS OF WATER POVERTY IN THE THUKELA CATCHMENT

7.1 Introduction

Indicators and indices have become indispensable tools for measuring emerging water-related issues, such as quality of life, which are difficult to measure using more conventional methods. A plethora of indicators and indices is in existence and the majority have been developed over the past two decades. Gleick *et al.* (2003) review a number of the most frequently cited indices in water-related publications. These tools, including the WPI (Sullivan *et al.*, 2002), have been reviewed in **Chapter 2**. The review of the WPI, which is one of the latest additions in the growing list of tools for the comprehensive assessment of water-related wellbeing, is revisited in this chapter, starting with a summary of the link between water and poverty, a topic covered in more detail in **Chapter 2**. The review is followed by an application of the index at meso-scale in the Thukela catchment.

7.2 Poverty and Water Poverty

There are many conceptualisations of poverty in literature. The developers of the WPI (Sullivan *et al.*, 2002) adopted an approach which was postulated by Sen (1983; 1985; 1995) and Desai (1995), namely that poverty is a relative concept and is defined by deprivation of capability, whereby capability consists of basic skills and conditions that define a society. Lack of access to adequate water supplies for domestic and productive use can be linked to lack of this capability (Sullivan *et al.*, 2002). Consequently, the conceptual structure of the WPI incorporates aspects of the livelihood capacities. Allan (2002) states that water poverty is an element of poverty, which is a socially and politically, rather than an environmentally, determined phenomenon. The inability of poor communities to access technology and trade, which can ameliorate poverty, confines these communities to water poverty (Allen, 2002). Water poverty has two dimensions, *viz*, the physical shortage of water in stream and reservoir, also termed by Ohlsson (1998) as first order scarcity, as well as the lack of social-economic adaptive capacity to deal with the shortage, termed by Ohlsson (1998) as second order scarcity, and the WPI attempts to quantify both these aspects.

7.3 The Water Poverty Index

The WPI attempts to quantify the linkage between water poverty and income-related poverty by combining hydrological and socio-economic information to provide a measure of a community's access to sufficient and clean water (Sullivan *et al.*, 2002). It is a tool by which water managers can evaluate the water situation in different locations in a holistic manner (Mlote *et al.*, 2002). Its conceptual framework, which was modelled around the Sustainable Livelihoods Framework (SLF) for evaluating development, encompasses water availability, access to water, capacity for sustaining access, the use of water and the environmental factors which impact on water quality, as well as the ecology which water sustains. The WPI consists of five major components, each with one or more subcomponents. The main components are:

- Resource — measures of surface and groundwater, adjusted for quality and reliability
- Access — indicators of effective access which people have to water
- Capacity — representations of human and financial capacity to manage the water system
- Use — measures of how, and how much, water is used for different purposes
- Environment — attempts to capture ecological integrity related to water

The WPI can be applied at different spatial scales, as shown in **Figure 7.1**. Several national- and community-level evaluations of the water situation have been conducted using the WPI (e.g. Lawrence *et al.*, 2002; Mlote *et al.*, 2002; Sullivan *et al.*, 2002). The following sections describe the sub-indices and their computation for evaluating specifically meso-catchment values of the WPI in the Thukela catchment, South Africa.

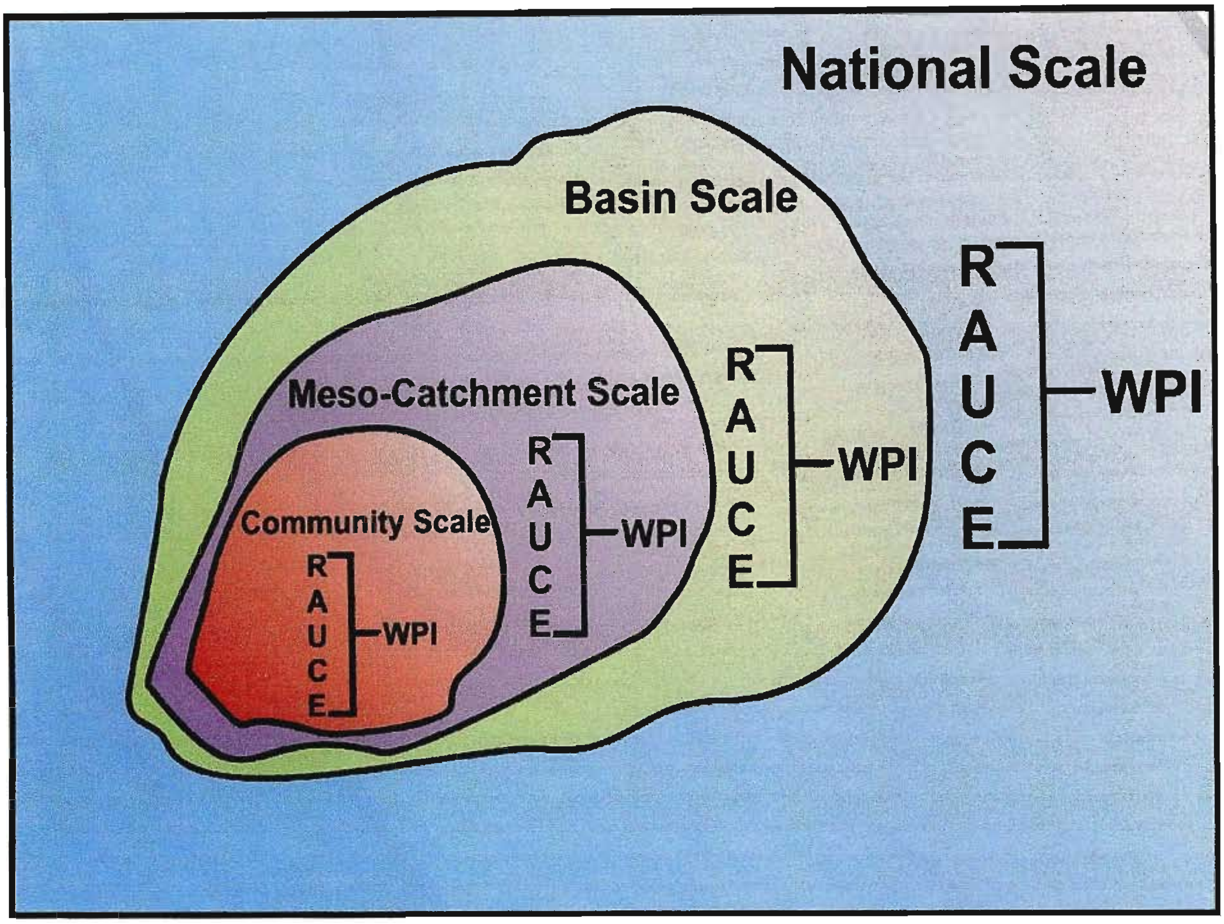


Figure 7.1 Application of the WPI at different scales (after Sullivan *et al.*, 2002), where RAUCE represent, respectively, Resource, Access, Use, Capacity and Environment

7.3.1 Resources

In the WPI the availability, the quality and the reliability of water resources in a catchment are represented by the resources component. These characteristics apply to all aspects of water resources, *viz.* surface water, groundwater and inter-catchment transfers, as they occur in a catchment. This component provides information about the level of stress, as well as levels of the degradation and dependability of the water resources. Therefore, a combination of the three characteristics, each represented by a relevant sub-indicator, should ideally be included in its calculation. These sub-indicators therefore include:

- Availability (i.e. total water resources in the catchment)
- Water quality status and
- Reliability of supply.

These sub-indicators should be calculated individually before being combined into the resources indicator. The manner in which they were evaluated in this study is presented below.

The estimation of available water resources was based solely on simulated daily streamflows, made up of stormflows and baseflows. Groundwater usage (e.g. by borehole abstractions and wells) was not considered because of lack of information, while inter-catchment water transfers were excluded because the indicator was to be calculated based on the meso-catchments' primary water endowments. The primary water endowment gives an indication of the natural susceptibility of meso-catchments to water stress. The reliability of the natural water resource base was estimated from coefficients of variation of streamflows. The natural water availability was estimated from daily streamflow simulations under baseline land cover conditions. A detailed description of the methods of simulating baseline streamflows is presented in **Chapter 5**. For each subcatchment (i.e. meso-catchment), accumulated streamflows including upstream contributions were divided by the corresponding accumulated population in order to approximate the potential demand placed on the water resources. Inter-annual coefficients of variation of streamflows (CV) were used to provide an indication of the reliability of the resource. The water quality sub-indicator was not calculated because of the unavailability of data at the time of computing the index.

7.3.2 Access

This component attempts to capture the degree of access to water or related resources and services. Encompassed by this indicator are issues of eligibility to utilise the resources and services, as well as the actual physical difficulty of accessing them, such as reaching sources and hauling water to households or other points of utilisation. Eligibility may depend on a wide range of factors such as location and ownership of the water source, power relations and rights of usage of water source, as well as operational rules of service providers, while the physical difficulty may be a function of local terrain, distance from water sources and the method of transporting the water. Four indicators were selected to represent access in the Thukela catchment, and they are:

- average time taken to collect water for domestic use,
- proportion of households (HHs) that collect water for domestic uses from unprotected sources,
- proportion of HHs that have appropriate sanitation facilities, and
- access to water for the so-called "productive" uses such as farming.

These indicators were then combined to obtain an overall indicator of access. The methods of calculating the individual indicators are described below.

7.3.2.1 Average Time Taken to Collect Water for Domestic use

The average time taken to collect water was estimated using data collected during a water use survey of four communities (KwaLatha and Ethembeni at Keates Drift, as well as Depot and Section C in Wembezi) in the Thukela catchment in 2001(Sullivan *et al.*, 2002b). Detailed descriptions of these communities are given in **Chapter 5**. The water situations (**Table 7.1**) in these communities were assumed to be representative of those of similar communities in the Thukela catchment. A majority of the households at KwaLatha collect water from unprotected and undeveloped water sources. However, only those that collect water from these sources were included in the estimation of the average time. The same was done for Ethembeni, which has a water supply scheme with the average distance to communal standpipes about 200 m. It was estimated that the trip to collect water from a yard tap would take about 5 minutes, while for households with piped water inside the dwellings this would take zero minutes. The average time taken in each catchment is a weighted sum of the average times taken to collect water from a type of source. The weights are the proportions of the number of HHs using a particular source to the total number of HHs in a catchment. The types of water sources and the corresponding numbers of households using them were obtained from the National Population Census Database (StatsSA, 1996). The calculation is summarised by the following mathematical equation:

$$T_k = \frac{\sum_{i=1}^{n} X_i t_i}{m}$$

where T is the average time taken by HHs to collect water for domestic use in catchment k, X and t are the total number HHs and average the time it takes to collect water from source i, while m is the total number of HHs in the catchment.

Table 7.1 Average domestic water use and time taken to collect water in selected communities in the Thukela catchment

Availability Situation of Water for Domestic Uses	KwaLatha D>200 m	eThembeni D≤200 m	Section C D≤200 m	Depot Urban
Average per capita water use per day (litre)	21.0	18.5	19.0	n/a
Average size of container (litre)	23.9	25.8	22.5	n/a
Average total time per day (minutes)	303.0	145.8	163.1	negligible
Average number of one-person trips per day	6.0	5.0	5.0	n/a
Average time per trip (minutes)	50.6	27.4	35.1	n/a
Average total water use per HH per day (litre)	123.3	135.5	102.3	n/a
Average HH size (persons)	7	10	6	n/a

D = distance to water source

7.3.2.2 Access to Protected Water Sources and Appropriate Sanitation Facilities

Two separate indicators, *viz.* the percentage of the total number of HHs collecting water from unprotected water sources and the total number of HHs without pit latrines, were selected to represent the level of access to safe water and acceptable sanitation facilities, respectively. Unprotected sources include springs, small dams (ponds), stagnant pools, streams and other sources that are exposed to elements that may render the water unsafe for domestic use without some form of purification. Pit latrines, which are considered safer than most rudimentary low cost constructed toilet facilities (Navarro, 1994), were taken as the minimum acceptable sanitation systems. Otherwise, HHs using the other rudimentary systems such as bucket latrines or having no toilet at all were classified as not having appropriate sanitation facilities. The data on the sanitation and water supply systems were obtained from the National Population Census Databases (StatsSA, 1996)

7.3.2.3 Access to Water for Productive Use

Besides domestic use, water is also needed for food production and income generating activities. Owing to the lack of data on small-scale income generating activities, the indicator of access to water for productive use was estimated only for agricultural water use. This was achieved by calculating the proportion of potentially irrigable land that is under actual irrigated commercial agriculture in a catchment. GIS techniques were used to estimate the size of irrigable land in a catchment. Only land with a slope < 2% and not more than 2 km from major water sources such as rivers and reservoirs was classified as irrigable. The size of land under irrigated commercial agriculture was determined from the National Land Cover Database (CSIR, 1996). This approach assumes that access to water is the main limiting factor to irrigated commercial agriculture.

7.3.3 Capacity

The capacity component represents the ability to manage a water system. Managing the systems entails the planning and implementation of actions designed to maintain or restore it to a particular agreed status of water quantity and quality, as well as the distribution of water within an acceptable range of variability (DWAF, 1996). These actions are meant to constrain the impacts of land-based activities on water resources to ensure adequate storage, distribution and allocation of water. Other aspects of managing the water system include rehabilitation of degraded water resources, resolution of conflicts between competing users and the mitigation of impacts of hydrological catastrophes such as floods and droughts.

The management of water resources requires adequate human and financial capacity. Grey (2002) observes that the lack of water resources management capacity is one of the elements of a vicious cycle that must be broken if Africa's people are to escape the poverty trap in which they are locked. From a perspective of water poverty assessment, an evaluation of the availability of this capacity is imperative. In this study, the following factors were selected for the representation of capacity:

- level of poverty,
- level of education, and
- level of human health.

7.3.3.1 Level of Poverty

The level of poverty was determined by evaluating the Head Count Index (*H*), which is the proportion of the population whose economic welfare (*y*) is less than the poverty line (*z*). If *q* people are deemed to be poor in a population of size *n*, then $H=q/n$. A poverty datum of ZAR 2 400 was adopted such that all individuals with annual incomes less than or equal to ZAR 2 400 per annum were classified as poor. The National Population Census Database was used to compute this indicator (StatsSA, 1996).

7.3.3.2 Level of Education

The level of education, which is used as a proxy for skills level, was estimated by computing the percentage of the adult population that had completed secondary schooling up to the "senior certificate" or matriculation (matric) level. The matric (Grade 12) is the minimum skill level required by many employers and training institutions. The data for calculating this indicator was obtained from the South African National Population Census Database (StatsSA, 1996).

7.3.3.3 Level of Human Health

Like the life expectancy and infant mortality rate, the mortality rate for children under 5 years old per 1000 live births is a reflection of the health and wellbeing of a society. This measure was estimated indirectly from the proportion of living children among children ever born, using the Brass method as illustrated by Shryock and Siegel (1976). The main advantage of the under-5 years infant mortality rate over conventional mortality rates is that it may detect trends that the others methods might miss (Shryock and Siegel, 1976). Data from the South African National Population Census Database (StatsSA, 1996) were used to estimate this indicator.

7.3.4 Water Use

The use indicator attempts to quantify water use in a catchment by individuals, or groups of users, for various purposes such as domestic, agricultural or industrial activities. Since sufficient amounts of water of suitable quality levels must be retained within natural channels, lakes, wetlands and dams in order to sustain aquatic ecosystems, the environment is also considered a water user. Water may be utilised *in situ,* i.e. at the source, or it may be diverted or withdrawn from surface- or groundwater sources and conveyed to the place of utilisation. Use is said to be consumptive when, as a result of usage, the water evaporates through plant tissue to produce biomass, or is incorporated into a product and rendered unavailable for further use within the area (Horn, 2000). Methods of estimating water use by the different sectors, which were used to compute the use indicator, are discussed in the following sections.

7.3.4.1 Estimates of Domestic Water Use

Domestic water use is expressed as "per capita per day" for drinking, cooking and hygiene, but it excludes water for the so-called "productive use" such as farming. However, it is difficult to separate the two uses in rural areas, where collected water is often also used for farming (Howard and Bartram, 2003). In this study, the method of estimating domestic water use is based on the fact that the amount of water used by a person in a day depends, *inter alia*, on its accessibility, which is a function of distance, time, reliability and cost of water supply (Howard and Bartram, 2003). Therefore, the proportion of the total number of HHs that collect water from a specific source of water was multiplied by the per capita use per day associated with that source, as shown in **Table 7.2**. Boundary conditions were set according to accepted domestic water use standards of, or targets for, basic water supply, such that all uses outside these limits were adjusted accordingly to reflect either failure to meet the standards or wastage. A lower limit of 25 l/c/d is based on The Guidelines for Compulsory National Standards (DWAF, 2002b), while 100 l/c/d, which is recommended by the WHO as an optimal use level at which all consumption and hygiene requirements can be met (Howard and Bartram, 2003), is used in this study as the upper limit beyond which use is considered wasteful. Therefore, the following equation was used to emphasise the heightened water poverty reflected by using too little an amount of water and to induce a penalty for overuse of water, respectively:

$$WU_{adj} = WU_o - \log(25) \qquad \text{for all } WU_o<25 \text{ l/c/d, and}$$

$$WU_{adj} = 100 - \log(WU_o) \qquad \text{for all } WU_o>100 \text{ l/c/d}$$

where WU_{adj} is the adjusted value of the initial domestic water use, WU_o.

Table 7.2 Estimated domestic water use relative to the distance to source of water

Water Source	Water Use (l/c/d)	Information Source
Piped: inside dwellings	200	Eberhardt and Pegram (2000); Howard and Bartram (2003)
Piped: yard tap	50	Howard and Bartram (2003)
Communal standpipe (≤ 200 m distance)	25	National Standards (DWAF, 2002b)
Other (≥ 200 m)	18	2001 Thukela Survey (Fediw, 2001)

7.3.4.2 Agricultural Water Use

Agricultural water use was estimated using output from the Water Situation Assessment Model (WSAM). The model estimates irrigation water and this quantity was divided by the number of people who are employed in the agriculture sector. Data on employment by sector are available in the National Census Database (StatsSA, 1996).

7.3.4.3 Industrial Water Use

As with agricultural water use, the industrial water use indicator was presented as water productivity in relation to employment. Estimates of total industrial water use were also obtained from the WSAM model, while the data on people employed in the sector were taken from the Census (StatsSA, 1996).

7.3.5 Environment

The term "environment" represents the state, or condition, of the natural environment, especially the aquatic ecosystem, and its link to human wellbeing. Water systems provide goods and services that are necessary for life. The goods include resources such as food for direct human consumption, fodder for livestock, raw materials for construction and handcrafts, while the services include waste assimilation, as well as provision of habitat for aquatic fauna and aesthetic enjoyment.

Several methods were considered for the computation of the environment sub-index. An attempt was made to compute the index from a combination of water quality data and the level of compliance to instream flow requirements. However, water quality data for the Thukela catchment are patchy, both spatially and temporally (DWAF, 2004c). Water quality sampling points are located mainly only along the main tributaries and they are too few to provide a representative spatial pattern (DWAF, 2004c). While environmental reserve determination studies for the Thukela catchment produced quantifications of water resources of the required quality to meet ecological objectives of the river, monitoring protocols and ecological specifications were still under development by DWAF at the time computations were made in 2004. Therefore, there were no actual data on compliance with the regulations, which would have been useful in computing the environment component.

The focus was, therefore, shifted towards the use of proxy indicators for the environment. The land degradation index, LDI (Hoffman *et al.*, 2001), which is a combination of soil and vegetation degradation indices, was considered. The advantage of using this index is its availability as GIS files for the entire South Africa. However, this advantage is overridden by the coarseness of its spatial presentation. The smallest unit is the magisterial district, of which there are only 9 in the Thukela catchment. This scale is far too coarse for this study, which is based on sub-catchments, for there may be more than ten sub-catchments in one magisterial district (cf. **Figure 6.1**). Therefore, another proxy was developed using the National Land Cover Database. A land cover map covering South Africa at a pixel resolution of 1 km developed from the National Landsat TM Image of 1994 (CSIR, 1996) using Thompson's (1996) 31-category land cover classification formed the basis for the estimation of the percentage of degraded land in each sub-catchment using GIS techniques.

All the variables from which the individual indicators were derived are summarised in **Table 7.3**. The indicators are grouped according to the major components of the WPI into which they were combined. The table also shows the sources from which the data were obtained.

7.4 Combining the Indicators

One of the major difficulties associated with multi-variate indicators and indices is combining data that are presented at different spatio-temporal scales and in varying units. Van Loon *et al.* (2005) discusses different techniques of addressing this problem. Normalisation, or standardisation, is one method by which original, or raw, data values are converted into a new set of numbers with common and usually dimensionless scales. While the choice of scale is not of critical importance, scales such as 0 – 100 (%) or 0 – 10 are widely understood and acceptable in many situations (Van Loon *et al.*, 2005). However, Van Loon *et al.* (2005) warns that it is good practice not to adopt a scale with too broad a range of values, particularly when dealing with data characterised by considerable uncertainty, in order to avoid an implication of unjustified high levels of accuracy. Standardisation is particularly appropriate in situations where goalposts, or upper and lower limits, of the scale can be defined. The following general mathematical formula was used to standardise the indicators before they were combined into indices.

$$I_s = \frac{X_i - Min(X_i)}{Max(X_i) - Min(X_i)}$$

where I_s is the normalised indicator value and X_i are the individual values in an array. The minimum and maximum values can be replaced by specific lower and upper limits deemed suitable for a particular indicator. Each of the subcomponent variables was standardised such that all the values lie between 0 and 1, where 0 and 1 represent the least desired and the most ideal situations, respectively.

Table 7.3 WPI component variables and the data sources

WPI Component	Indicators	Data Source
Resource	Subcatchment streamflows Coefficient of Variation of streamflow	Hydrological modelling Simulated streamflows
Access	Average time to collect water % Using unprotected water sources % With appropriate sanitation % Irrigable land under irrigation	StatsSA, field survey StatsSA StatsSA LandSat TM Image
Capacity	Level of poverty % Adults with at least matric education Under five mortality rate	StatsSA StatsSA StatsSA
Use	Per capita domestic use Agricultural use Industrial use	StatsSA, literature, field survey WSAM model WSAM model
Environment	% Degraded land	LandSat TM Image

Straightforward arithmetic averaging was then used to combine the indicators into the major components, each of which was scaled such that all the values could range from 0 to 100. The components which were then combined into the overall index using the WPI equation presented in **Chapter 2**. Weights which may be applied to emphasise either a sector or a specific need were not used in this study. Hence, the equation simplified to:

$$WPI = \frac{R + A + C + U + E}{5}$$

where *R*, *A*, *C*, *U* and *E* represent the major components of *R*esource, *A*ccess, *C*apacity, *U*se and *E*nvironment, respectively.

7.5 Results

After computation, the indices were tabulated and linked to the attributes table of the shapefile of the 113 individual subcatchments of the Thukela. **Figure 7.2** shows the spatial patterns of the Water Poverty Index in the Thukela catchment. In the Thukela catchment, water poverty appears to be associated with socio-economic poverty. The most water poor subcatchments are found in regions or places that were designated "locations" since the 1840s and were, during the apartheid era, under the rule of the so-called "independent homeland" of KwaZulu. A majority of these places coincides with the places of residence of the most socio-economically disadvantaged (cf. **Figure 4.20**). The converse is also true, with most of the least water poor subcatchments found around more affluent regions such as urban centres. Subcatchments which are located in areas that are predominantly occupied by nature reserves and commercial agriculture show medium to moderately low levels of water poverty.

Figure 7.3 illustrates that different factors may have different levels of influence on the water poverty situation in different parts of the Thukela catchment. As was also observed in **Chapter 5**, the Thukela catchment is water-rich in terms of total water resources. Because the resources component is based on the WSI's water stress threshold of 1 700 m^3 per capita per annum (Falkenmark *et al.*, 1989), it can be stated that, besides a few subcatchments, the catchment has more than enough water relative to its population. However, this picture changes markedly when the levels of actual access, use and capacity to manage the water are taken into consideration. All the subcatchments that have low scores in terms of the overall WPI also score lowly for the three components which relate to the socio-economic situation in an area.

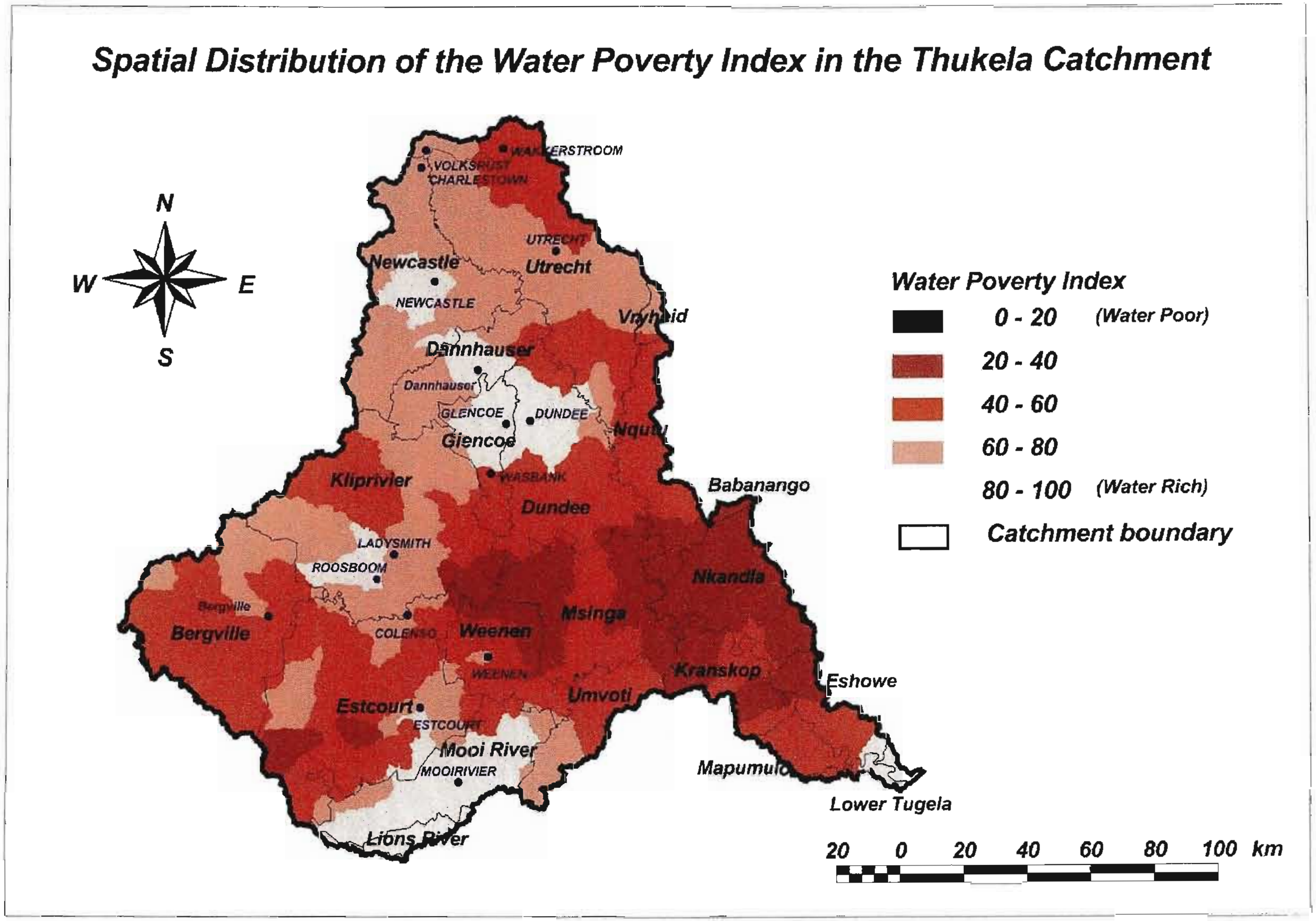


Figure 7.2 Spatial patterns of the Water Poverty Index in the Thukela catchment

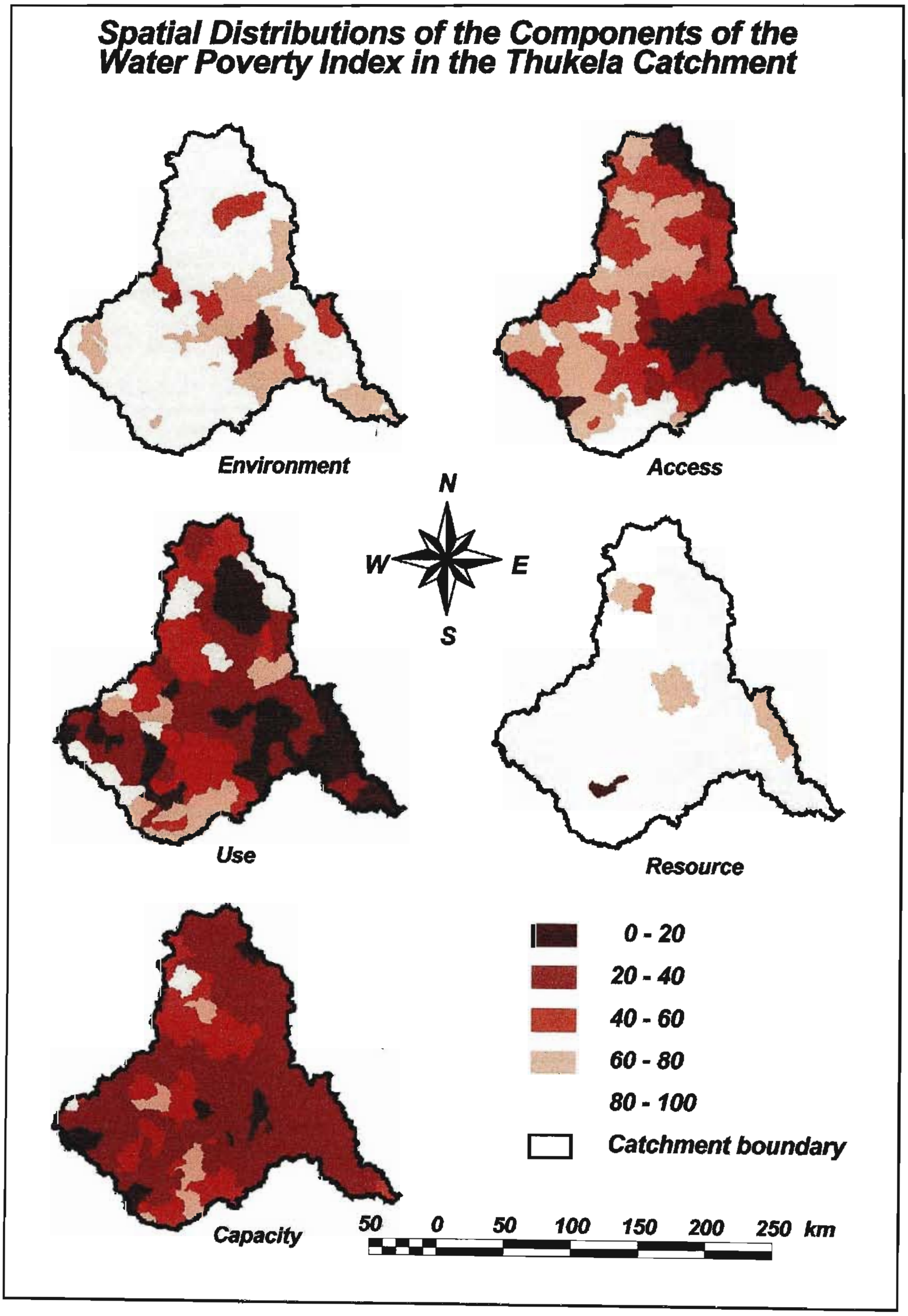


Figure 7.3 Spatial patterns, in the Thukela catchment, of the five components of the WPI

This association indicates that socio-economic issues are likely to be more critical than primary water endowment concerning water poverty in the Thukela catchment. A similar observation exists in terms of the environment component, which is a consequence a human impact on land cover, in this case degradation. The subcatchments which have large percentages of degraded land coincide with economically disadvantaged areas (cf. **Figures 4.10** and **4.18**)

7.6 Appraisal of the Water Poverty Index

Associations between the components of multi-dimensional "quality of life" type indices such as the WPI are often inevitable. This is so because of the interrelatedness of the variables that constitute the components, such as income and life expectancy in the HDI. The existence of cause-effect relationships between the elements of an index can lead to both redundancy as well as confusion in its interpretation (Hilderink, 2004). Despite these limitations, it is sometimes necessary to include the related components in order to capture as much individual component uniqueness and variability of the quality of life as possible. The major criticism of indices in this regard is the arbitrariness of the process of selecting the variables, without subjecting the data to empirical testing (Rahman *et al.*, 2003). The criticism is not on the individual indicators *pe se*, because individually they are well known and trusted (cf. **Sections 2.66** and **2.9**), but on the criteria for organisation or grouping them into the main themes or components of the WPI. An analysis of associations of the constituents of the WPI is summarised in **Table 7.4** and **7.5**, which show correlation coefficients (r) between the major components and between the variables.

Table 7.4 Correlation coefficients in the Thukela catchment between sub-indices of the WPI

	Capacity	Access	Environment	Use	Resource
Capacity	*				
Access	**0.65**	*			
Environment	0.28	0.25	*		
Use	0.25	0.17	0.41	*	
Resource	-0.18	-0.18	0.01	0.00	*

The access and capacity components appear to be strongly and positively correlated with r = 0.65. This was not unexpected, because capacity reflects skills level and economic wellbeing, which in turn may influence (or be influenced by) the level of access to water. A similar observation about the WPI was made by Lawrence *et al.* (2002), who also noted that these components were strongly correlated to the HDI and concluded that the WPI could be said to be an extension of the HDI. The correlations between the other components are weak. Disaggregating the major components to their constituent indicators reveals that correlations also occur within the components (**Table 7.5**).

Table 7.5 Correlation coefficients in the Thukela catchment between variables making up the components of the WPI

	Irrig	Time	Unprot	Matr	Mort	Pov	Env	Res	Agri
Time	0.01	*							
Unprot	-0.15	**0.80**	*						
Matr	-0.03	**-0.88**	**-0.76**	*					
Mort	0.14	0.26	0.17	-0.32	*				
Pov	0.08	**0.78**	0.50	**-0.69**	0.18	*			
Env	-0.15	0.06	-0.13	-0.05	0.07	0.18	*		
Res	-0.14	-0.05	0.08	0.05	0.25	-0.15	-0.24	*	
Agri	-0.04	-0.08	-0.18	0.04	-0.11	0.08	0.05	-0.04	*
Dom	-0.13	-0.13	-0.04	0.05	-0.19	-0.14	-0.36	0.22	0.25

[Time = time taken to collect water; Unprot = % collecting water from unprotected sources; Matr = % matriculated; Mort = under 5 Mortality rate; Pov = % poor; Env = % degraded land; Res = water availability; Agri = agricultural water use; Dom = domestic water use]

7.7 Temporal Trends of the Water Poverty Index in the Thukela Catchment

While its limitations are acknowledged, the WPI appears to provide intuitively correct results in the Thukela catchment which can be useful when they are used prudently as first pointers for places likely to be affected by water poverty. The application of this technique was extended to evaluate temporal trends of water poverty in the Thukela catchment by computing the index for 1996 and 2001, which are the two most recent South Africa National Population Census years. The National Census data were adopted as the core database for calculating the WPI. It was assumed that these data would enable a valid comparison of results to be made over time because the variables that were measured during censuses were expected to remain the same. These data also allow the evaluation of the index at regular intervals, coincident with the census years.

The indicators that were used when computing the indices and the respective sources of data are shown in **Table 7.6**, where they are grouped according to the major components of the WPI. It can immediately be seen that this set of indicators is different from the one that was used when evaluating the spatial pattern of water poverty in **Section 7.3** (cf. **Table 7.3**). The under five mortality rate was not incorporated in the calculations because death statistics which were used for its estimation are not included in the 2001 Census. The water use sub-index was re-estimated from estimates of domestic use only.

Updated estimates of the agricultural and industrial uses were also not available at the time of writing this section (beginning of 2005). The percentage of degraded land estimate from the 1996 Landsat TM Image was again used to proximate the environment component because the latest national land cover maps (2005, based on 2001 satellite imagery) are still under development.

Table 7.6 WPI component variables and data sources used when analysing temporal trends of the WPI

WPI Component	Indicators	Data Source
Resource	Subcatchment streamflows Coefficient of Variation of stramflow	Hydrological modelling Simulated streamflows
Access	Average time to collect water % Using unprotected water sources % With appropriate sanitation % Irrigable land under irrigation	Census '96, '01, StatsSA, Field Survey Census '96, '01, StatsSA Census '96, '01, StatsSA LandSat TM Image
Capacity	Level of poverty % Adults with at least matric education	Census '96, '01, StatsSA Census '96, '01, StatsSA
Use	Per capita domestic use	Census '96, '01, StatsSA, Literature, Survey
Environment	% Degraded land	LandSat TM Image

The results are first presented as a comparison of the spatial patterns of water poverty for 1996 and 2001, as shown in **Figure 7.4**. There is a general improvement of the water poverty situation between these two census years in the Thukela catchment. Many more subcatchments moved to a higher category of index, i.e. they are depicted in a brighter colour in the 2001 poverty map than that of 1996. For other subcatchments, the improvement is not reflected in the maps because the change is not large enough to put them in a different mapping category. A total of 86 out of 113 (76%) of the subcatchments showed an improvement, while the water poverty situation appear to have worsened in the remaining 24 % of subcatchments.

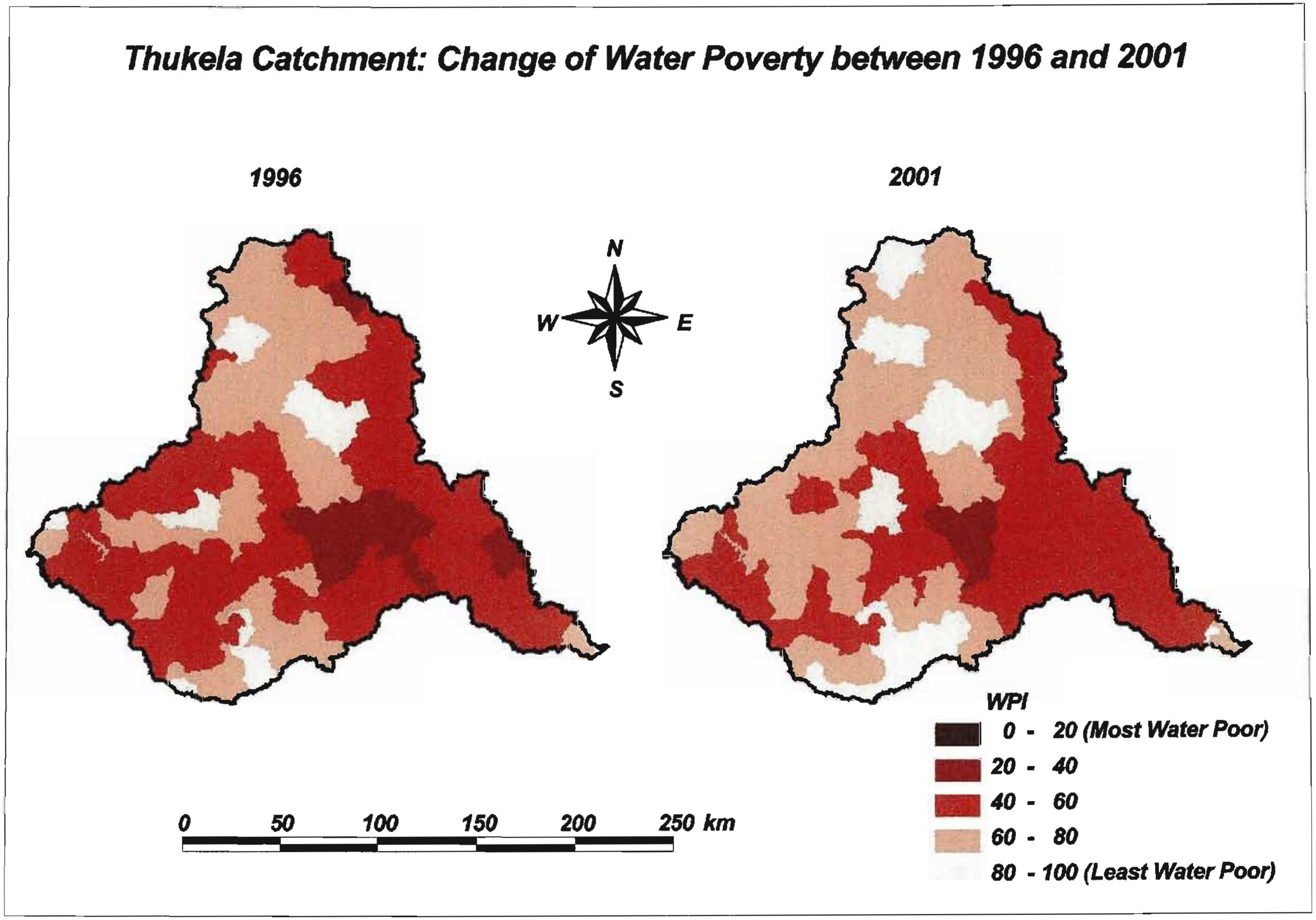


Figure 7.4 Changes in the Thukela catchment between 1996 and 2001 in spatial patterns of the WPI

The absolute and relative differences between the 1996 and 2001 WPIs are shown in **Figure 7.5**, in which the subcatchments in which improvements occurred from those that became worse off are also separated. The improvements appear to have occurred in a majority of those subcatchments that are located in areas that were most economically disadvantaged according to household wealth, estimated by using average incomes that were obtained from the 1996 Census data. The deteriorations seem to have occurred in a diversity of subcatchments, including those that are in and around urban areas, farmlands and some poor rural areas.

There are no discernible trends in relation to the magnitudes of change, in both absolute and relative terms, and perusals of **Figures 7.4** and **7.5** do not provide immediate reasons or explanations for this state of affairs.

A standard caution regarding the use of indicators and indices is the need to avoid over-interpretation, which may lead to misleading conclusions and incorrect policy decisions. Over-interpretation often occurs when the user attempts to explain causation when cause-effect relationships between the index and other variables have not been established, either empirically or otherwise. In this study, the WPI was disaggregated into its major components in order to obtain pointers towards the dimension(s) of the physical-socio-economic system that may be possible, rather than definitive, causes of the water poverty situation. This analysis involved evaluations on how the individual components of the WPI changed between 1996 and 2001, and was undertaken in two stages. First, the focus was on those subcatchments which showed overall deterioration of the index (**Figure 7.6**). According to this analysis, resources, levels of water use and levels of access to the resources contributed towards the negative change in the index in these catchments, despite the positive changes in levels of capacity. In those subcatchments that showed overall improvement of the WPI (**Figure 7.7**), the level of capacity changed positively in all of them. Resources availability did not change significantly in the majority of subcatchments, while a few displayed negative changes. There were mixed changes characterised by a near-even split between the subcatchments as they showed both improvements and declines in terms of the levels of access and that of water use, as well as of environmental integrity. Again there is no distinct pattern in relation to the spatiality of the changes.

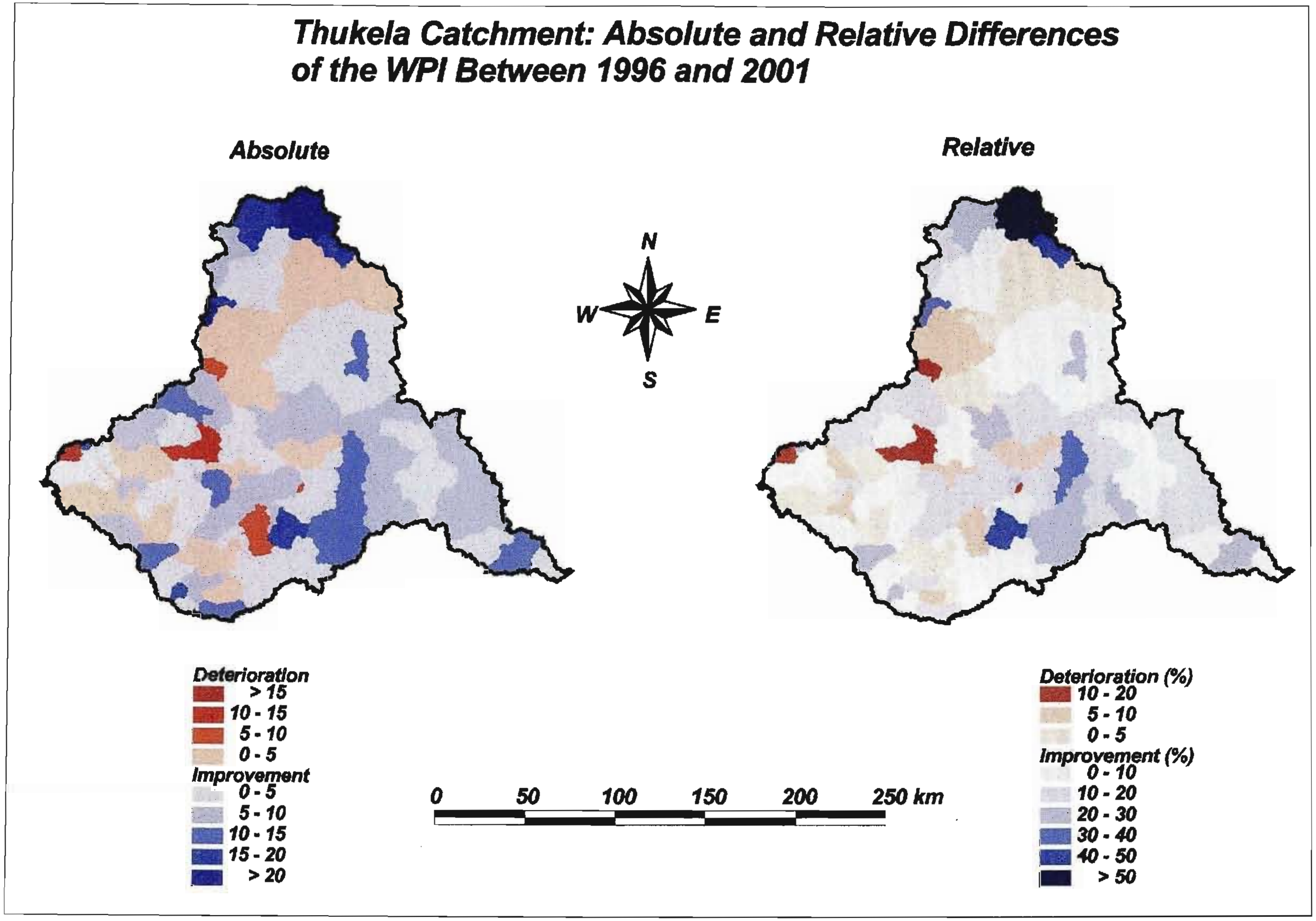


Figure 7.5 Absolute and relative changes in subcatchment water poverty in the Thukela catchment between 1996 and 2001

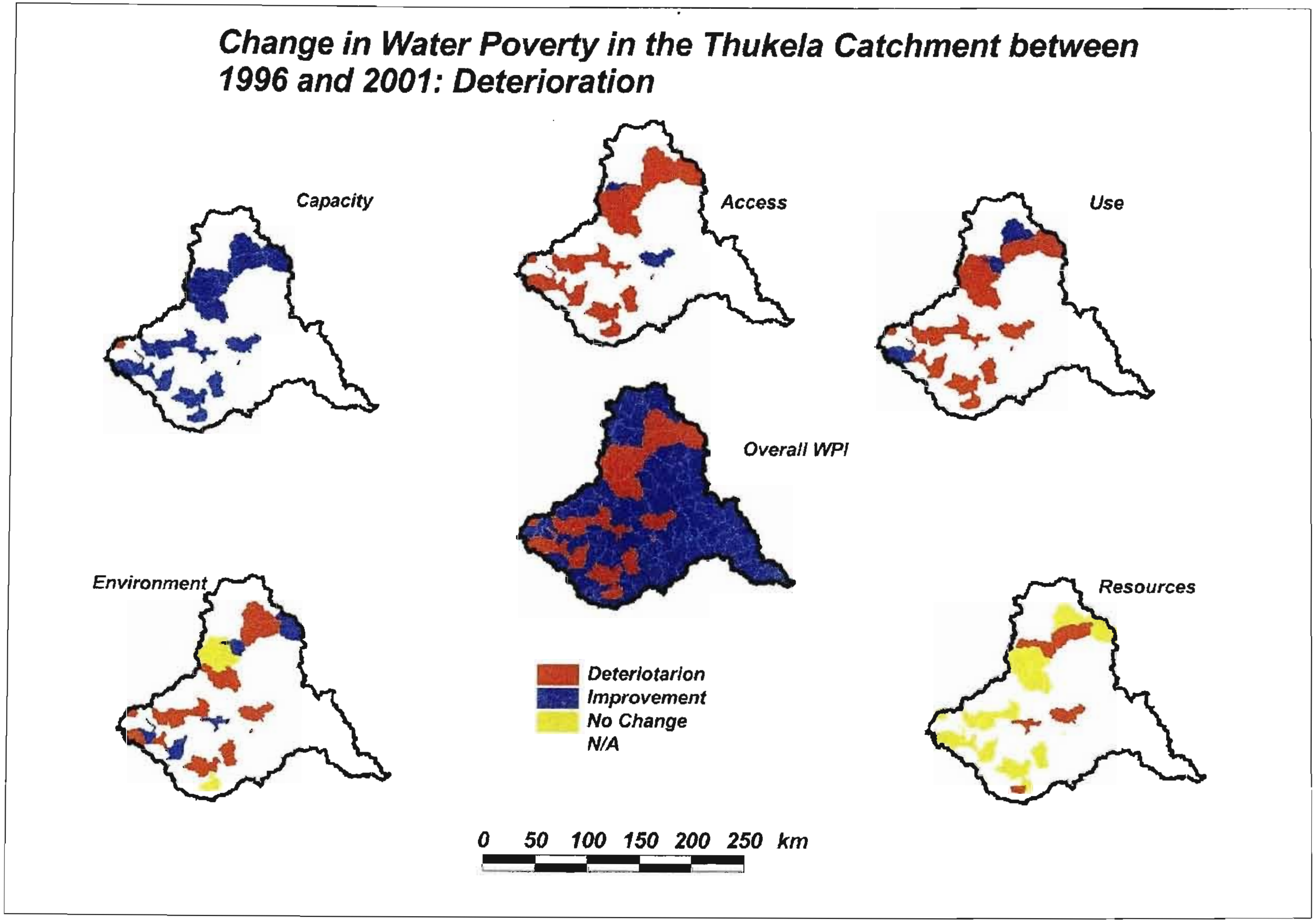


Figure 7.6 Changes in the major components of the WPI in those subcatchments Thukela catchment that display an overall deterioration in the index in the between 1996 and 2001

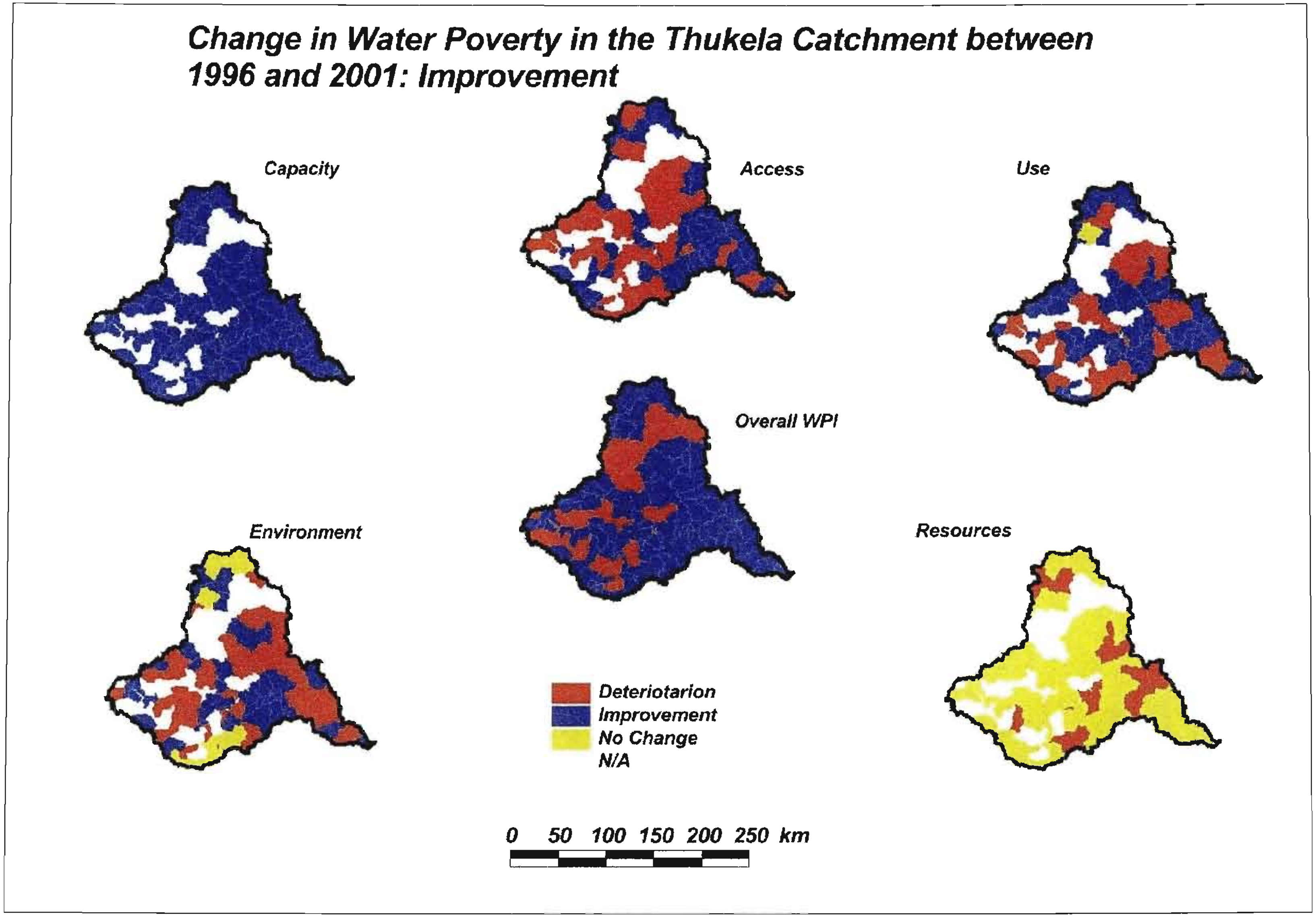


Figure 7.7 Changes in the major components of the WPI in those subcatchments in the Thukela catchment which display an overall improvement in the index between 1996 and 2001

7.8 Water Poverty in the Context of Possible Climate Change in the Thukela Catchment

The WPI is an integrated tool for water stress and water scarcity assessment, which can be used to determine water stressed areas at different spatial and temporal scales. When computed before and after the implementation of water-related development initiatives, the index can also be used to monitor progress and assess impacts of the initiatives. The index can, therefore, also be adapted to incorporate climate change projections in order to assess the potential increases or decreases of the water stress in the future (Prudhomme, 2002). The following sections investigate patterns of water poverty under hypothetical, but plausible, scenarios of climate change in the Thukela Catchment.

7.8.1 Climate Change Scenarios

Climate processes are simulated using Global Climate Models (GCMs). Generally, GCMs operate at large spatial scales. For investigations of local impacts of climate change, especially on water resources, the output of climate variables from GCMs is "downscaled" to regional scales using suitable statistical or dynamic modelling procedures (Prodhomme, 2002; Engelbrecht, 2005; Hewitson *et al.*, 2005) before the regional values are input for application with hydrological models.

A commonly used future climate scenario is that of an assumed doubling of the pre-industrial atmosphere concentrations of CO_2 from 280 ppmv to ~ 560 ppmv. The predicted climate depends on the specific GCM used to model the climate, but it is now generally accepted that temperature increases would range from 1.5 to 4.5 °C (IPCC, 2001a). Previous southern African studies in the South African Country Studies Project on Climate Change, using output from three GCMs (HadCM2-S, HadCM2+S and CSM), have shown that a 2 °C increase in temperature could coincide with an overall decrease of rainfall of ~ 10 % and a 5 to 10 % increase in reference evaporation for a doubled CO_2 future climate (Perks *et al.*, 2000). These orders of magnitude have recently been corroborated for South Africa by Engelbrecht (2005). For this study, these plausible climate change scenarios were represented by making appropriate adjustments to input to the *ACRU* agrohydrological model before the streamflow responses in the Thukela catchment were simulated (cf. **Chapter 5** for detailed descriptions of the configuration and set-up procedures of the *ACRU* model). The simulated streamflows were then used in a revised computation of the resources component of the WPI to represent a hypothetical, but plausible, future climate scenario.

While it is recognised that the implemented climate represents no more than a sensitivity analysis within the plausible bounds, and that changes in the socio-economic situation which will affect the access and utilisation of water resources in the Thukela catchment are likely to occur, no modifications were effected to represent future conditions on the other components of the WPI owing to the unavailability of simple techniques for making reliable projections of the associated variables. Therefore, the results of this investigation reflect the patterns of water poverty in the Thukela catchment if the possible future climate scenario was to be superimposed upon the prevailing socio-economic situation.

7.8.2 Potential Impacts of Climate Change on Accumulated Mean Annual Streamflows

The hypothetical, but plausible, perturbation of climate of the order applied in this study, *viz*, +2 °C, -10 % rainfall and +10 % potential evaporation, is likely to have marked impacts on mean annual streamflows (MAR) in the Thukela catchment. Simulations show that minimum accumulated subcatchment MAR could decrease from 110.9 mm under the baseline climate, to 77.8 mm under climate changed conditions (**Figure 7.8**). The reductions are not limited to the minimum values of MAR, but could occur throughout the catchment (i.e. including "dry", "moderate" and "wet" subcatchments, and irrespective of whether they are internal or external). The magnitudes of reduction range from about 32 to more than 80 mm, which is approximately 15 to more than 40 %, and the overall decrease at the estuary of the catchment is simulated to be ~ 50 mm, which is about 27 % of the baseline value. In absolute terms, the reduction is highest in the wet highlands and lowest in the drier valley regions (**Figures 7.9**). However, this trend is somewhat reversed in relative terms. For the climate change scenario chosen, the majority of the subcatchments, including those in both the wet and dry regions are within the 20 to 30 % range of reduction (**Figures 7.9**).

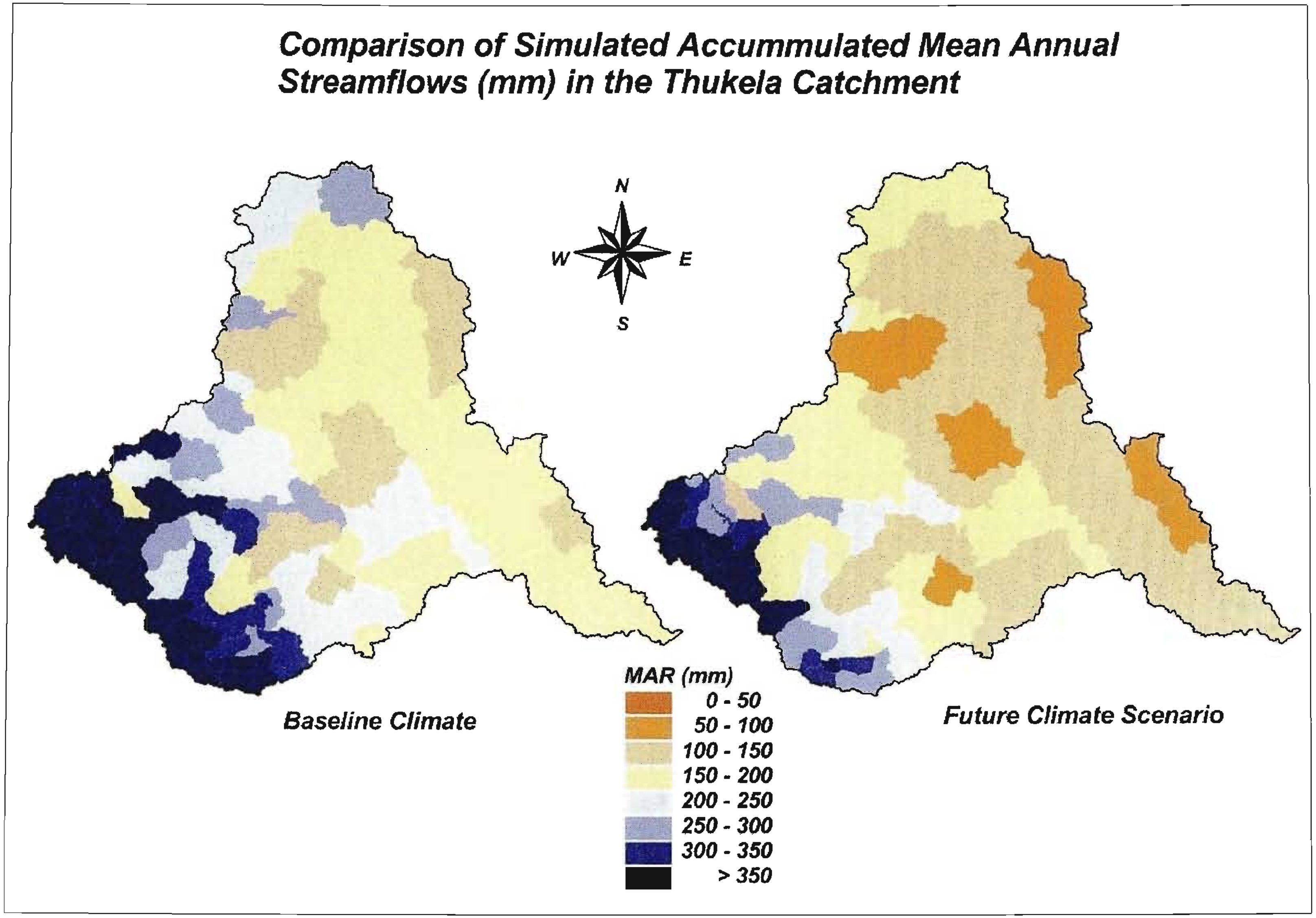


Figure 7.8 Comparison of spatial patterns of accumulated MAR in the Thukela catchment simulated under baseline climate and a plausible future climate scenario

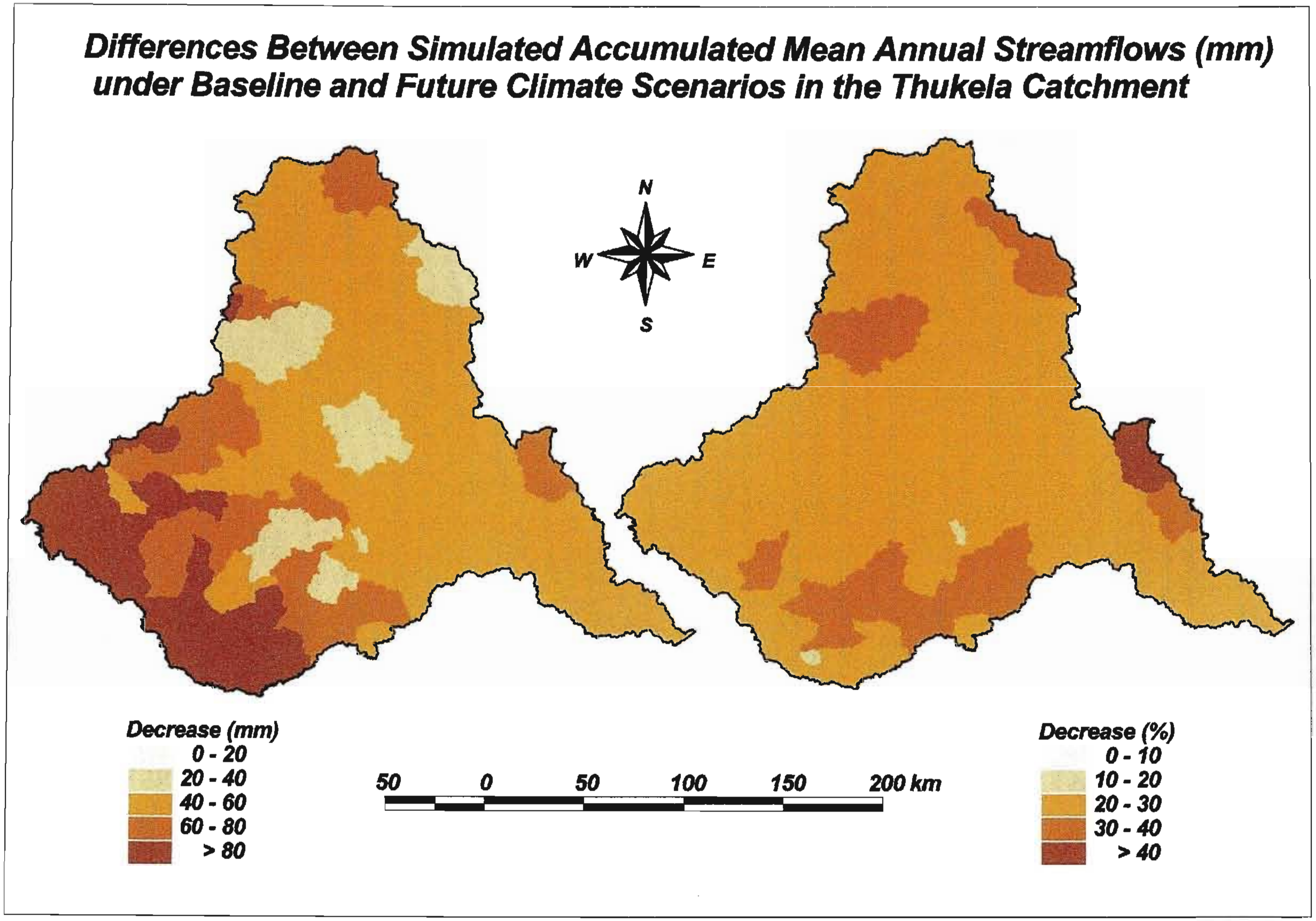


Figure 7.9 Absolute and relative differences of accumulated MAR in the Thukela catchment simulated under baseline climate and a plausible future climate scenario

The decreases of MAR in 111 out of 113 subcatchments are more than double those of rainfall, which were set at -10 % throughout the catchment. This observation highlights the phenomenon of hydrological amplification, through which perturbations in rainfall result in non-linear or exaggerated responses in runoff.

The reductions in subcatchment MAR could be accompanied by increases in inter-annual variability of streamflows throughout the catchment (**Figure 7.10**). The largest changes in CV of up 16 % could occur around the wet highland region, especially along the catchment divide, while the valley regions along main tributaries, where the accumulated annual streamflows are more consistent from year to year, could experience the smallest changes in CV of less than 1 % (**Figure 7.11**).

7.8.3 Potential Impacts of Climate Change on Water Poverty

The changes in the quantity and variability of MAR resulting from the climate change scenario selected are likely to have significant impacts on water wellbeing in the Thukela catchment. As was shown in **Tables 7.3** and **7.6**, annual streamflows and their variabilities are used to compute the resources component of the WPI. Despite the resources component being the only one of the five that was adjusted to reflect the selected conditions of a climate change scenario, **Figure 7.12** reveals a reduction in values of the overall WPI in most parts of the Thukela catchment. In fact, the decrease of the index (i.e. a worsening of water poverty) occurs in all the subcatchments (**Figure 7.12**). However, 15 subcatchments reflect marked decreases of up to 10 %, and all these subcatchments are in the eastern part of the catchment (**Figure 7.13**). It is also noteworthy that the pronounced changes occur in both internal (i.e. along main tributaries) and external (i.e. along low order streams) subcatchments. These changes highlight a possible worsening of the situation in areas which are experiencing severe water poverty already, as well as the transition into serious water poverty for those subcatchments which are currently marginally or moderately water poor.

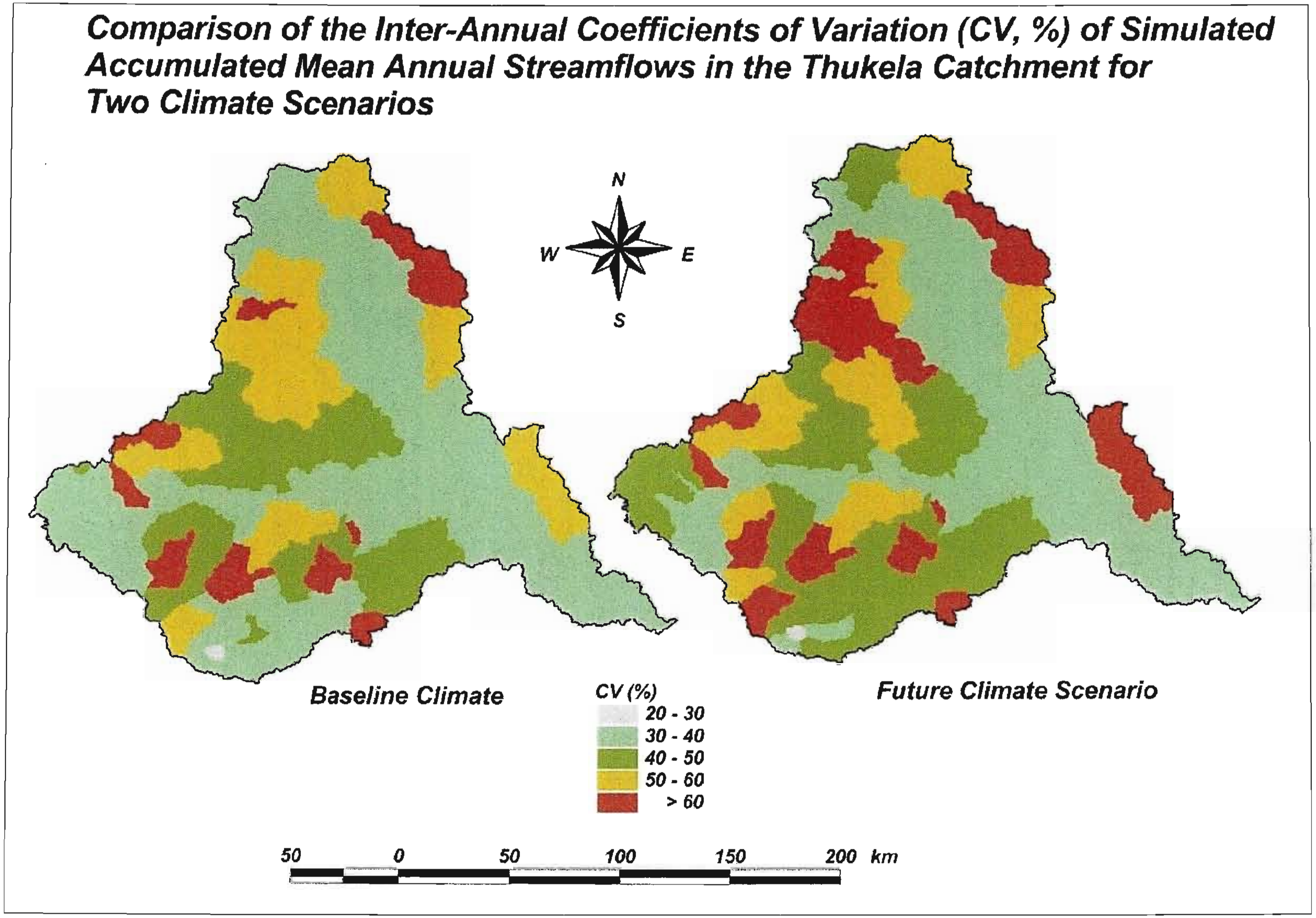


Figure 7.10 Comparison of coefficients of variation of accumulated streamflows in the Thukela catchment simulated with baseline climate and a plausible future climate change scenario

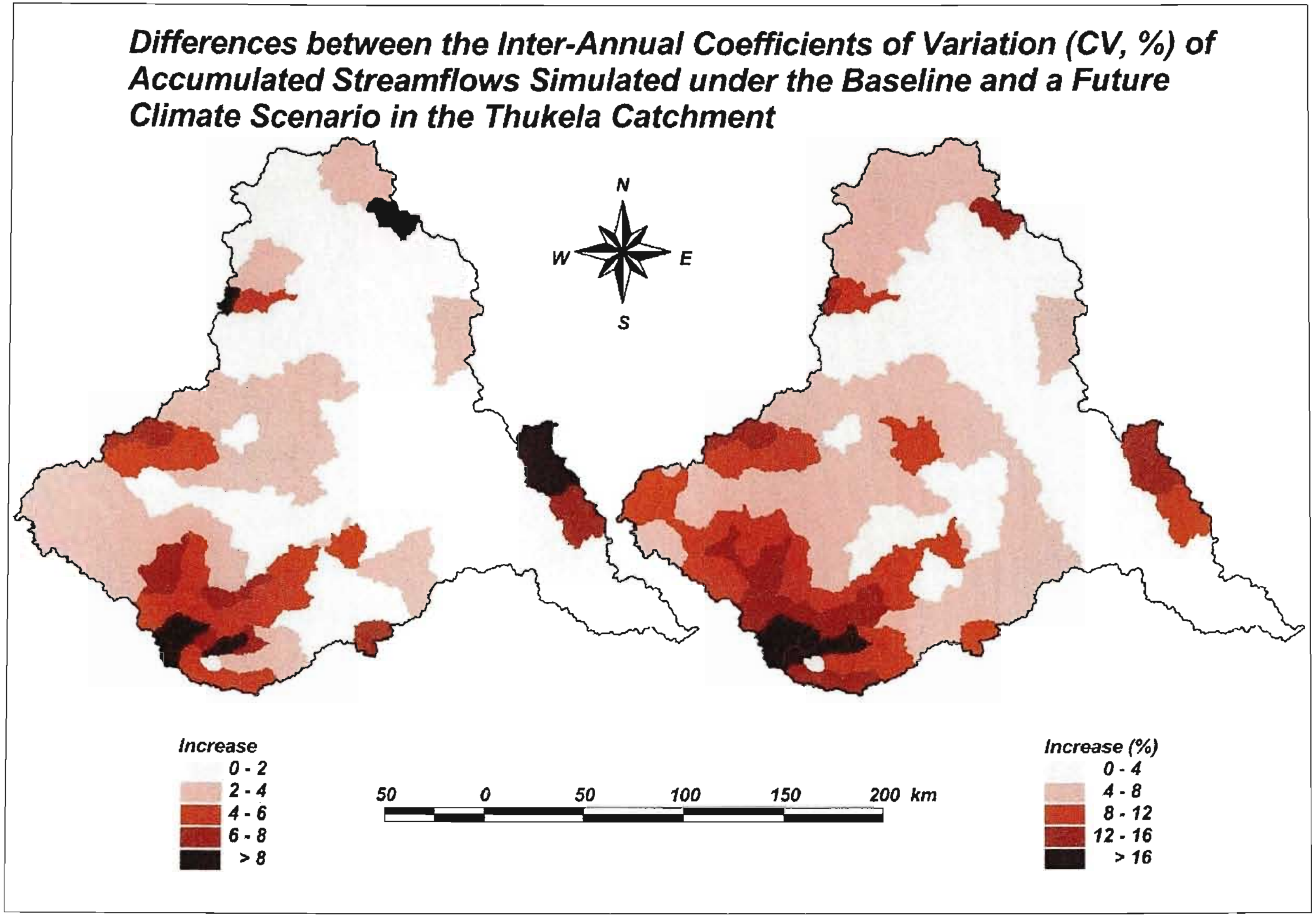


Figure 7.11 Absolute and relative differences of the inter-annual coefficients of variation of accumulated streamflows in the Thukela catchment simulated under baseline and a plausible future climate scenario

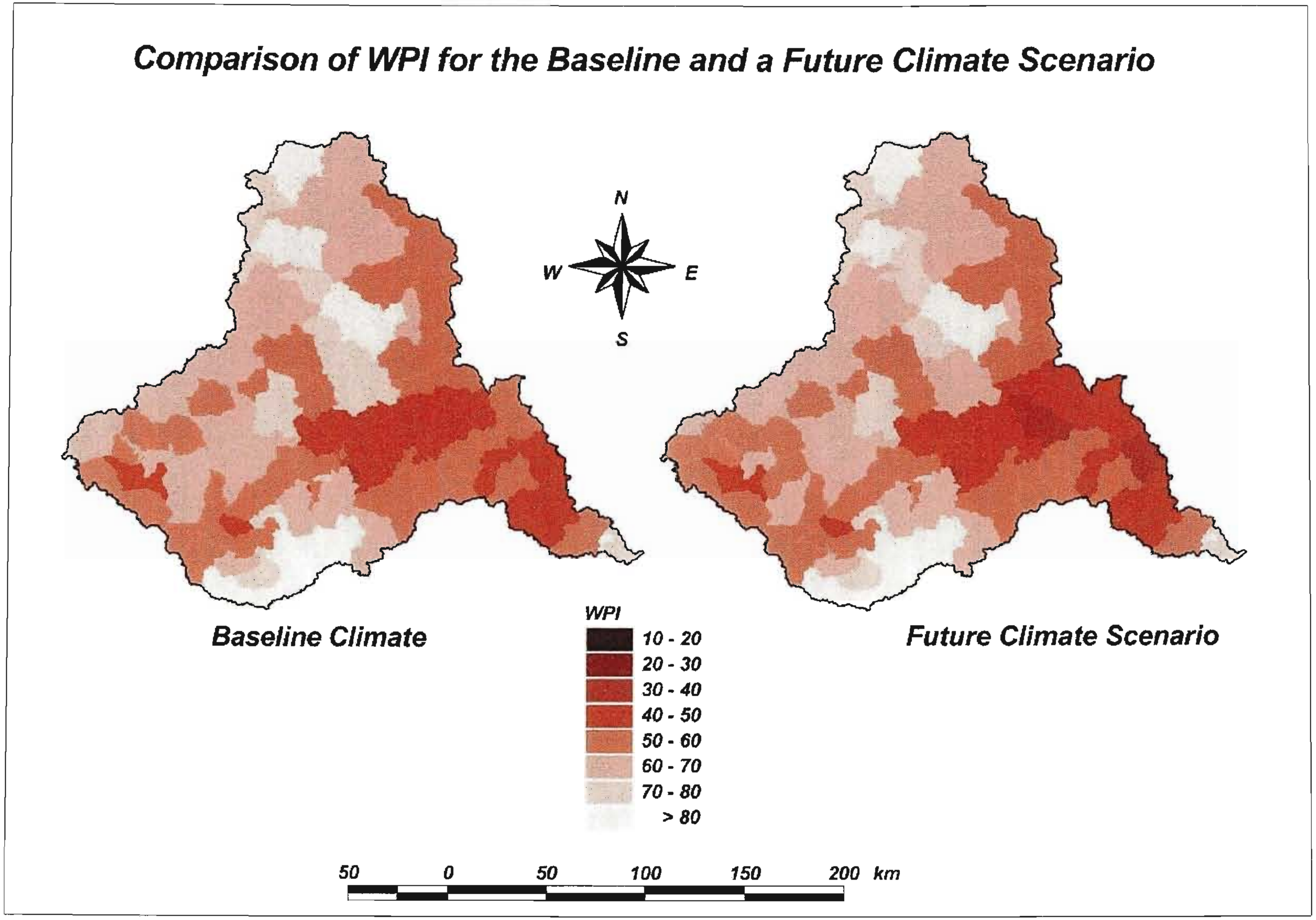


Figure 7.12 Spatial patterns of the WPI in the Thukela catchment under baseline and a plausible future climate scenario

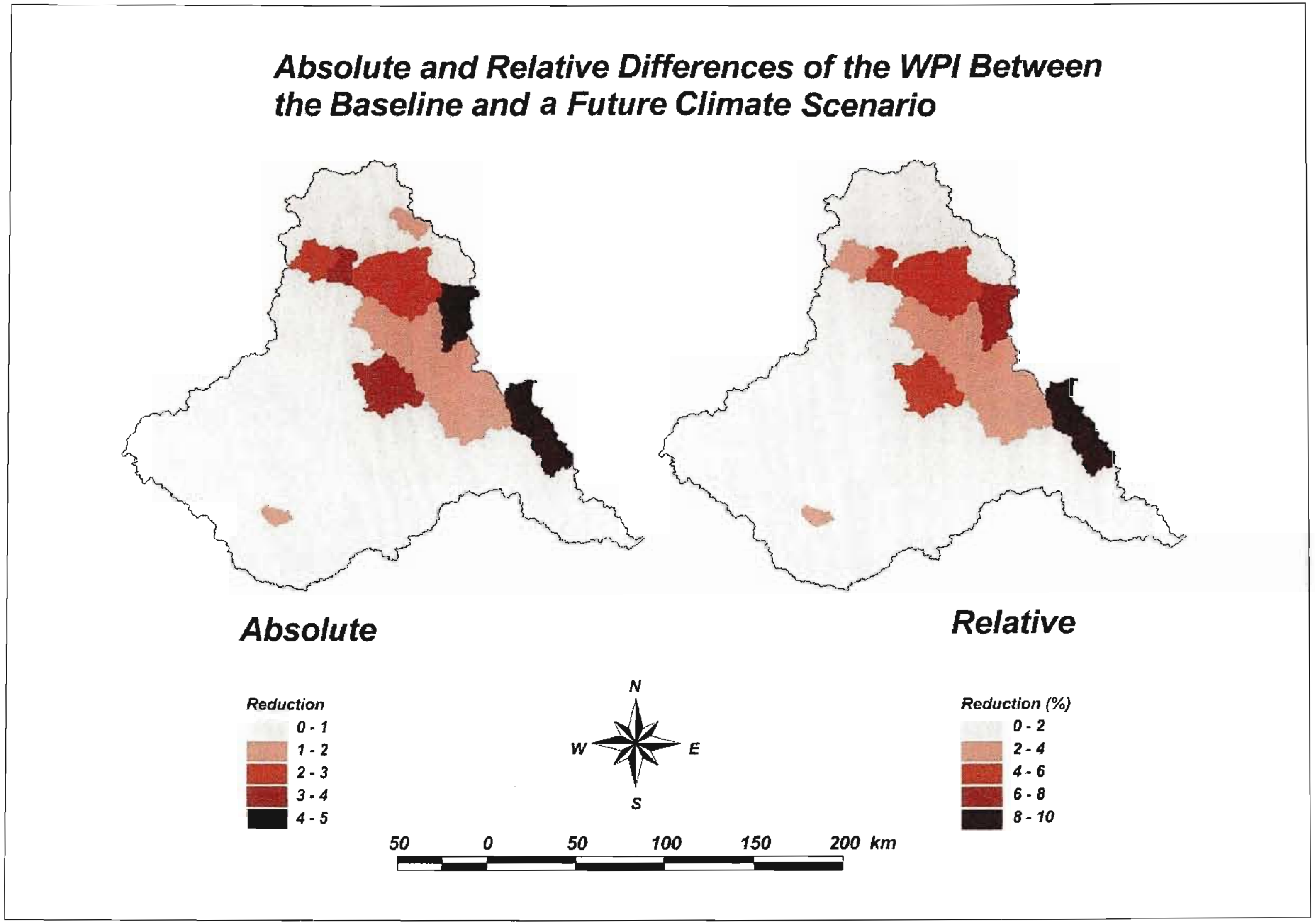


Figure 7.13 Absolute and relative changes between WPIs in the Thukela catchment computed for the baseline and a plausible future climate scenario

7.9 Conclusions

This chapter has established the application of the WPI at meso-catchment level using the Thukela catchment as a test case. Important findings of this study at this stage are as follows:

- The WPI can be utilised in conjunction with GIS to determine spatial patterns of water poverty in catchments at meso-catchment scale.
- The National Population Census data provide a useful core database for computing the socio-economic components of the WPI.
- The temporal regularity of the spacing between census events ensures that the changes of water poverty can be tracked over time.
- The linkage between water and socio-economic wellbeing needs to be re-emphasised.
- Climate change could worsen water poverty and make coping with it more difficult than it currently is, especially in those communities already vulnerable to water scarcity and with low adaptation capacity.
- One of the major limitations of composite indices such as the WPI, is the masking of useful information by averaging or aggregation, and this needs to be reiterated once more.

In this section, the major findings of the chapter have been listed, with little interpretation attempted. Detailed interpretations of these findings and their Thukela-specific as well as general implications are discussed in **Chapter 8**.

8 DISCUSSIONS AND CONCLUSIONS

The use of water-related, multi-disciplinary and aggregated indices in development assessment is complicated by a conceptual dilemma concerning suitable spatial units and scales of application. The catchment, the recommended spatial unit for water resources management, has limitations when used in socio-economic assessments. Similarly, historical boundaries such as magisterial districts, which are better suited than catchments for socio-economic studies, are not appropriate for water resources evaluations. The "modifiable areal unit problem", MAUP (Openshaw, 1977), presents a reconcilliatory, but pragmatic, conceptual resolution of the spatial unit dilemma. The MAUP recognises that, theoretically, a study area may be subdivided into an infinite number of non-overlapping geographical areal units for spatial analysis (Openshaw, 1977; 1978; 1981; 1984a, b; Openshaw and Taylor, 1979; 1981; Marceau, 1999), and that the choice of the unit and scale to use is often determined by what is perceived by an analyst to be the optimal operational requirement of a specific study (Wiens, 1989).

As was illustrated in **Chapter 6** in an assessment of the associations between pairs of socio-economic variables, a particular study can be undertaken at different, but relevant spatial units, with the validity of the results being restricted to the spatial unit and scale at which the study was conducted. Therefore, no single spatial unit can be categorically stated to be ideal for evaluating multi-disciplinary indices. However, in relation to water resources assessments, the catchment and its derivatives possess intrinsic conceptual and operational relevance. The delimitation of "pseudo-socio-economic subcatchments" creates areal units which are perceived by investigators to be socio-economically "aware". In chapter **Chapter 6**, it is highlighted that it is both conceptually and operationally justifiable to evaluate aggregated multi-disciplinary indices such as the WPI in hydrologically derived spatial units such as catchments.

The comprehensive hydrological analysis of simulated streamflows indicates that relative to most other catchments in South Africa, the Thukela catchment is well endowed with water resources. However, the availability of the water within the catchment is highly variable over time and space. In fact, some parts of the Thukela catchment, especially in the Valley and Interior Basin ecological regions (cf. **Figure**

4.3), could sometimes be experiencing physical or absolute water scarcity, which is defined by Molle and Mollinga (2003) as nature- or most often climate-imposed water shortage. This water scarcity is exacerbated by the occurrence of long sequences of low flows, for both annual and low flow months (cf. **Figures 5.14** and **5.15**). The areas where people would be naturally vulnerable coincide with areas inhabited by poor rural communities, which are where they are largely because of the policies of erstwhile governments. These are communities which are without reticulated potable water supplies and, hence, need to collect water from unprotected, frequently ephemeral first order streams, as well as from small dams and springs.

The detailed analysis of streamflows presents a broad, but essential, first pointer of the heavy burden of manually collecting water which is borne by communities and households without reticulated potable water supplies in the scarcity-prone areas. These are the areas that require political, human and engineering interventions such as the construction of water storage facilities, the establishment of water transfer schemes, and the mobilisation of financial and human resources in order to effect urgent relief, especially during periods of prolonged droughts. The implementation of these interventions depends on prior adopted policies at the relevant government levels. In isolation, the hydrological analyses are not sufficient to inform policy development for addressing water scarcity. While they can assist in the identification of areas that are likely to experience water shortages, analyses of streamflows do not provide the information about the socio-economic-political drivers of water scarcity, such as capacity to develop and manage water resources, political issues and power relations in an area and availability of options and resources for productive water use. The Water Poverty Index, in which the hydrological analyses are used in conjunction with socio-economic assessments for its computation, is a useful tool which can inform policy making, monitoring and evaluation in water resources-related developments. Its main functions are discerning spatial and temporal trends of water-related human wellbeing.

As was mentioned earlier, the assessment of the spatial and temporal patterns of water poverty at meso-catchment scale using the Water Poverty Index (cf. **Figures 7.2** to **7.7**) provides a much more holistic investigation of the water availability, accessibility and utilisation in the Thukela catchment than the hydrological analyses by themselves. The spatial pattern of the index confirms the association between water scarcity and the socio-economic wellbeing, but not necessarily a causal relationship. A majority of the socio-economically disadvantaged meso-catchments are also the most water-poor and, conversely, the affluent ones are the least water-poor.

The disaggregation of the WPI into its major components, which is not an attempt at explaining the causes of the spatial patterns, also reveals that except for a few subcatchments the Thukela is, generally, a water-rich catchment in terms of total water resources. However, lack of access to the resources, limited options for water use, especially for the so-called "productive uses", and lack of capacity to mobilise the development, and management, of the water resources appear to be the most influential components of the index in the catchment. Therefore, it is these issues that require attention in terms of the further research in order to obtain definitive answers to the question of what causes the water poverty in the catchment. It is apparent that the policies geared towards addressing water poverty should focus on the socio-economic issues. It is also common knowledge that these aspects of water poverty cannot be addressed through initiatives from the water sector alone. These water-related, but general poverty issues cut across other sectors such as education, economics, finance, agriculture, environment and natural resource utilisation. Cooperation among those departments which are planning, or already have, their own intra-departmental socio-economic development programmes needs to be promoted in order to improve the chances of their success against water poverty.

The apparent improvement in the water poverty situation in the majority of subcatchments in the Thukela catchment between 1996 and 2001 could be a result of the improvement of the quality in certain aspects of life in the catchment. Again, it needs to be reiterated that the discussion on the probable causes of the temporal trends of the index in the catchment is not definitive, but cogitative. Among all the subcatchments which showed overall improvement of the index, capacity appeared to have improved. In fact, capacity improved even in those subcatchments in which the overall index deteriorated. On the basis of its subcomponents such as literacy levels and income, it can be stated that the improvement in capacity could be a reflection of delivery in the education sector, which affords people with the skills to enable them to generate income, be it in the formal or informal sector.

There is no clear explanation of what appears to be a haphazard spatial mixture of improvements and deterioration of the use and access components in some subcatchments, irrespective of whether the overall water poverty situation in those catchments declined or improved. One of the possible reasons could be discrepant rates of delivery in, for example, water and the agriculture sectors which are associated with access to, and use, of water resources. Therefore, in addition to the WPI, it is necessary to determine, the performance in relation to service delivery between, and within, sectors and municipalities in order to identify the hurdles which could be delaying the delivery of services in some sectors.

Climate change, which is considered to be occurring globally already (DFID, 2003) and is certainly manifesting itself in South Africa already (cf. Schulze, 2005), will most likely worsen water poverty throughout the Thukela catchment if it occurs according to the "+2 °C temperature -10 % precipitation" scenario used in the study. Worsened water poverty will dictate the adoption of effective coping measures. However, the adaptation capacity of many communities in the catchment is low because of poverty, low skills levels (cf. **Chapter 4**) and the lack of other resources such as arable land. Therefore, the low coping capacity, which is already strained by prevailing water poverty, could be stretched further by the impacts of climate change, which was simulated to be highest in some of the currently most water poor parts of the catchment.

By their nature indicators and indices are inherently fraught with shortcomings (Gleick *et al.*, 2003; Molle and Mollinga, 2003). The WPI is no exception. While the relatively new concept of water poverty has a sound theoretical background, the lack of an explicit description of empirical relationships between the WPI and its components makes the explanation of the patterns of water poverty, especially what causes it, conjectural as was illustrated in the above paragraphs. Inter-correlations among its major components is another cause of uncertainty over the results (cf. **Table 7.4**), not only those of the WPI, but those of other frequently cited aggregated indices such as the Human Development Index as well (cf. Hilderink, 2004). From this study, it is clear that the strength of the WPI is in "painting the big picture" in relation to the prevailing situation, as well as quantifying the magnitudes and directions of relative changes in water wellbeing over space and time. When used within the confines of its intended application, i.e. devoid of over-interpretation, the WPI presents a useful tool for evaluating the water-poverty nexus holistically (cf. Molle and Mollinga, 2003).

The evaluation of water poverty in the Thukela catchment does not identify the specific communities and households which are therein experiencing water poverty. However, this is neither a limitation of the WPI nor that of this study. First, the WPI has already been applied in the Thukela catchment at community (rather than individual HH) level by Sullivan *et al.* (2002), and second, it was by design that this study focuses on the application of the WPI at meso-catchment scale.

The assessment of the temporal patterns of water poverty in the Thukela catchment does not include inter- and intra-annual variations. While the benefits of time-steps shorter than the five year inter-census interval are recognised, the unavailability of suitably temporally disaggregated data (e.g. monthly) rendered an evaluation of the index at shorter time intervals unfeasible. In fact, data-related difficulties were encountered even when undertaking the inter-census evaluation and these include:

- the discontinuation of some monitoring and data collection programmes, such as the agricultural surveys (Ehlers and Frick, 2000),
- the cessation of the measurement and/or the exclusion of certain variables in the dispensed databases, such as the exclusion of death statistics from the 2001 National Census Database of South Africa, and
- the temporal discord of monitoring and data collection programmes such as the National Census and the National Land Cover Databases.

The unavailability of data, especially water use data, is singled out by Gleick *et al.* (2003) as the greatest limitation to the production of useful water-related indicators and indices. An investigation of the availability of data to support the computation of the WPI (cf. **Chapter 3**) revealed that, if and once they are fully functional, existing and planned monitoring programmes and information systems could provide sufficient information without the need for further data collection initiatives. The information could be enough for meso-catchment and larger scale applications of the WPI. For smaller scales, e.g. at community scale, the information systems in their current or planned formats cannot suffice. For example, the WARMS does not make it compulsory for Schedule 1 water users to register their water use. These are the water users which the community scale WPI would target. Registering all the Schedule 1 users could provide the required in formation on water use (both domestic and productive).

The verification of results is standard practice in evaluation studies, and this is undertaken in order to determine the performance and reliability of tools used in a study. In situations where they exist, observed data are compared against generated output in relation to specific statistical ranges of acceptability. Verification is possible whereby the investigated phenomenon or event can be measured directly using physical scales or "ground-truthing". However, verification is not possible for aggregated indices such as the WPI.

While a quantitative measure of the accuracy of aggregated indices is difficult to establish, the soundness of their conceptual foundations, the transparency of their computation, and correlation of their results with other accepted related measures and studies in specific areas can be used as indicators of their reliability. In addition to concurring with the above criteria, this water poverty study in the Thukela catchment contradicted neither the related studies such as poverty distribution within the catchment (Wilson, 2000), nor the on-site observations made during the Sullivan *et al.* (2002) study nor during numerous field excursions. Therefore, the outcome of the study is believed by this author to be trustworthy.

Overall, the study shows that despite improvement in some areas, water poverty is still widespread in the Thukela catchment. Moreover, water poverty is likely to be worsened by climate change. In line with the universally recognised fact that water scarcity is a limiting factor to socio-economic development, water poverty is one of the main hurdles to poverty eradication in the catchment. Therefore, efforts must be directed towards ensuring access to adequate water supplies, especially in the rural communities. However, the rural communities lack the necessary financial and human capacity required to overcome water poverty on their own, or without external support. Therefore, governmental support is imperative in such places.

Delivery of government initiatives such as the free basic water supply to households is gradually providing relief in many parts of the country, including parts of the Thukela catchment. While the critical importance of access to water for domestic use, which is covered by the free basic water initiative, is not in doubt, access to water for "productive use", which relates directly to livelihoods and hence food security and income or wealth, is also important for socio-economic upliftment. Socio-economic regeneration requires additional interventions such as access to land, access to credit, access to markets and infrastructural development, which are beyond the ambit of the water sector *per se*. The sectors such as agriculture, economic planning, finance, education, labour, legal and environment, which do have a bearing on water wellbeing, are diverse and may have different agendas and schedules regarding their socio-economic development programmes. Despite the diversity, there are opportunities for inter-sectoral cooperation. There are many possible benefits of inter-sectoral collaboration, one of which is the promotion of joint ventures, which can lead to the improvement of overall cost effectiveness of projects as a result of a minimisation of the duplication of tasks.

This study has illustrated the utility, notwithstanding the limitations, of the WPI in assessing water-related human wellbeing at meso-catchment scale. Again, the main purpose of the WPI is in "painting the big picture". Therefore, additional tools or studies are necessary for investigating local details of this indicator of water wellbeing. Future research should focus on addressing the apparent uncertainties surrounding choice of the variables from which the sub-indices of the WPI are evaluated. In order to make the indicator selection process more reliable and consistent than it is currently, objective methodologies need to be developed. Presently, indicators or variables are grouped into the main themes of the WPI intuitively and there is no method for determining the optimum number of indicators representing each component.

Initially, the study was intended to include, in addition to the Thukela catchment, catchments in other southern African countries, especially in Swaziland and Lesotho.

However, data limitations resources and deprived the study of such a wider and more diverse analysis of the WPI. In terms of data limitations, the problems were related to both the lack of data, as well as the formats in which they are presented. Some datasets that would have been used were not geographically referenced; hence, they would not have been amenable to GIS analysis and presentation. In Swaziland, information on many variables, such as water use, is not only patchy (temporally and spatially), but is also aggregated to spatial units of considerably larger scale than the meso-catchment, which is the focus of this study. Therefore, it is recommended that this study should be extended at large-scale administrative units (e.g. Districts in Swaziland) in order to establish the relevance of the WPI in other southern African countries.

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