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Groundwater and Water Accounting in Southern Africa within the Perspective of Global Climate Change

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Abbreviations

BOD	Biological Oxygen Demand
BPUW	Best Possible Use of Water
CSO	Central Statistics Office (Botswana)
DC	District Councils (Botswana and Namibia)
DWA	Department of Water Affairs (Botswana and Namibia)
DWAF	Department of Water Affairs and Forestry, South Africa
EU	European Union
GCC	Global Climatic Change
GCM	General Circulation Model
GEC	Global Environmental Change
GWP	Global Water Partnership
GS	Department of Geological Surveys (Botswana)
HP	Harvest potential
IFR	In-stream Flow Requirements
IWRM	Integrated Water Resources Management
MAWRD	Ministry of Agriculture, Water and Rural Development
Namwater	Namibian Water Supply Company
NCSA	National Conservation Strategy Agency (Botswana)
NRA	Natural Resource Accounting
NRASA	Natural Resource Accounting in Southern Africa project
NSWC	North-South Water Carrier
PET	Potential Evapo-Transpiration
RWS	Department of Rural Water Supply
SADC	Southern African Development Community
SEEA	System of Environmental and Economic Accounting
StatSA	Statistics South Africa
UN	United Nations
UNCED	UN Conference on Environment and Development
WB	Water Boards
WDM	Water Demand Management
WELLMON	Well field Monitoring Data base (Botswana)
WSSD	World Summit on Sustainable Development
WUC	Water Utilities Corporation (Botswana)

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CHAPTER ONE
INTRODUCTION

1.1 Background

Concerns about water scarcity in southern Africa have been frequently raised during the last two decades. This has led the Southern African Development Community to develop a strong water programme that covers water policies and planning, water development and water demand management. It has also led several countries to select water resources for the development of the first resource accounts. These countries are Namibia, Botswana and South Africa.

Global environmental change, including global climate change will have profound impacts on the hydrological cycles and available water resources. Water resources were therefore given prominence within the global change research agenda, initially through IGBP-BAHC and later through the integrated Water programme. IGBP-BAHC initiated the African Groundwater Initiative, which focused on semi-arid and arid countries in Southern Africa. An international workshop, organised by BAHC, START and the Centre for Applied Research, was held in June 2002 in Botswana to identify and prioritise themes and activities for the initiative. Participants identified four critical themes for groundwater in southern Africa:

- Groundwater recharge, including artificial recharge;
- Value and economics of groundwater;
- Groundwater vulnerability mapping; and
- Catchment area studies

During the workshop, it was decided to develop a 'kick-off' proposal that covers the themes 'value and economics of groundwater' and 'groundwater recharge'. The study on value and economics of water focused on bringing out the role of groundwater in water accounts in southern Africa. This is a prerequisite for integrated water resources management, where the use of ground and surface water need to be compared and evaluated. The study focuses on the three countries with water accounts, i.e. Namibia, Botswana and South Africa. The study's findings are however, relevant to all SADC countries as they demonstrate the merits of water resource accounts for IWRM, and identify methods as to how groundwater can be better incorporated in the design of water accounts right from the start. NRA offers a good framework for the integration of physical and economic data and for unlocking data that exist, but are not routinely used in water resource management. NRA has been used as a tool to:

- monitor water stocks and uses;
- determine the economic benefits of water consumption by economic activity;
- assess cost-recovery through water charges;
- identify emerging water management issues; and
- better understand the sustainability of welfare gains.

Both the workshops and the study have been funded by START, Washington DC, and the financial support is highly appreciated.

1.2 Study objectives

The objective is to improve the integration of groundwater resources in NRAs in Southern Africa by incorporating stock and recharge data as well as value and cost data. It is particularly important to incorporate the possible effects and impacts of global environmental change properly.

It is hoped that a follow-up of the project could link the water accounts to scenario analysis, based on different IWRM options and different possible impacts of global environmental change. Subsequently, a decision-support model could be developed to improve water management, and that optimises the role of groundwater. Organisations such as UNEP have recognised the need to develop simulation models as decision-support tools for water resources management.

1.3 Project tasks and activities

Task 1: Analyse the groundwater coverage in existing NRA in Namibia, Botswana and South Africa

- Assessment as to how groundwater is currently incorporated into water accounts;
- Assessment as to how groundwater should be properly reflected, and what the impacts of global environmental change on groundwater may be; and
- Determine how groundwater coverage in water accounts can be improved, what the data requirements are.

Task 2: Explore the costs and benefit of groundwater use

- What are the costs of groundwater utilisation as compared to the benefits? How do these costs compare to the net costs of surface water? Is it possible to indicate how global environmental change may affect the relative costs of ground water?
- To what extent are the costs of groundwater recovered?

Task 3: Explore possible scenarios of IWRM and water accounts to meet water demands and to estimate their economic implications.

- Identification of key determinants of water supply (groundwater, surface water and treated effluent) and consumption (nationally and possibly regionally).
- Based on the key identified key determinants, design of different scenarios
- Assessment of the macro-economic impacts of the different scenarios

The following outputs were envisaged:

- Review of the changing role of groundwater in Integrated Water Resources Management.
- Review of the current and appropriate coverage of groundwater in Natural Resource Accounts in Southern Africa.

In addition, the study would contribute towards the building of research and water management capacity in the region through workshops (in the case study countries), utilisation of research assistant/ junior researchers, and sharing of expertise.

1.4 Project structure and operation

The project was co-ordinated by the Centre for Applied Research (CAR) in Botswana. Institutional cooperation was established with the University of Pretoria (CEEPA) and the New York University (with NRA and SAM-projects in Namibia). The core team for the study comprised Prof. R. Hassan (CEEPA, Pretoria, responsible for South Africa case study), Dr.G.M. Lange (New York University, responsible for the Namibia case study) and Dr. J. W. Arntzen (CAR, project leader and responsible for the Botswana case study).

The study lasted nine months during which period the core team met twice to discuss a common approach and compare the findings. The set up of the country case studies varied. In Namibia, it was linked to the restructuring of the water accounts; and Glenn Marie Lange did most of the case study work. The South African case study was carried out jointly by CEEPA and CSIR under the direction of Rashid Hassan. In Botswana, CAR carried out the case study using its staff and an M.Phil student from the University of Botswana. Close relationships were maintained with most water supply and water planning institutions in the country. Draft findings were discussed in a workshop in May.

Due to restructuring of the global change research arena, IGBP-BAHC has disappeared and the Southern African groundwater initiative has gone with it. This made it more difficult to keep links with the global as well as regional research community. Prospects for any immediate follow-up studies became more uncertain. It appeared therefore less important to develop an immediate follow-up proposal that would deal with scenarios and decision-support model. Plans for this follow-up proposal will be developed late this year, hopefully with the benefit of feedback from policy makers and researchers on this report.

1.5 Structure of the report

The report has the following structure. In chapter two, the concept of integrated water resource management and its linkages with water accounts are discussed. Chapter three outlines the 'internationally accepted (SEEA) structure of water accounts, and reviews experiences with water accounts from countries outside southern Africa (developed and developing countries). Chapter four explores the impacts of global climate change on water resources. While a lot of information is still missing, it appears that most of southern Africa's water resources will be adversely affected, particularly surface water sources.

Chapters five to seven contain the findings of the three country studies (Botswana, Namibia and South Africa). The studies identified ways of incorporating groundwater resources better into existing water accounts and also identified data needs, particularly on economic aspects (cost and benefits). Chapter eight compares and contrasts the country studies, and draw lessons for other countries. It also identifies key variables for and components of future IWRM scenarios. This work is exploratory, and by no means complete. Details of water accounts are provided in separate appendices.

Chapter 2
Integrated water resources management and natural resource accounting

2.1 Introduction

Water management has traditionally focused on surface water sources, even in semi-arid countries such as Australia, Botswana and Namibia that primarily depend on groundwater. This bias is reflected in the adoption of river catchment area management approaches. Where a choice between using surface and groundwater existed, the advantages and disadvantages of each source were rarely systematically assessed because of lack of knowledge about groundwater and lack of coverage of groundwater in water policies and strategies. The importance of ground water is gradually being recognised. In the Regional Strategic Action Plan, groundwater is labelled 'extraordinary important in the region', particularly during the dry season, in arid zones and in rural areas:

> *'More than three quarters of the region's population use groundwater as their main source of water supply, especially in rural settings. The region's groundwater resources, although widely distributed, are limited, accounting for 15% of the total renewable water resources. A better understanding of groundwater occurrence, use and management is vital since their development could be the key to managing rainfall variability and drought in some parts of the region' (SADC-WSCU, 1999, p. 19).*

While groundwater was not fully integrated in water management, groundwater resources were treated largely on an ad-hoc basis. Opportunities for substitution and conjunctive use were not sufficiently analysed. As a result, groundwater resources are being under-used in some areas, while in other areas groundwater mining occurs. The latter is environmentally unsustainable, whereas under-utilisation is inefficient.

It is therefore essential to fully integrate ground water resources in water management and planning by:

- Monitoring the trends in availability and quality of groundwater resources;
- Comparing the compatibility and substitution options between groundwater and surface water sources;
- Comparing the costs and benefits of using ground and surface water as well as options of conjunctive use and artificial recharge; and
- Assessing the impacts of global environmental change on surface and groundwater resources.

The full potential of groundwater can only be realised through an integrated approach towards water management, which will also serve as a framework that addresses the above issues. Integrated water resource management (IWRM) seeks to address these issues, and natural resource accounting offers a framework for their analysis.

In this chapter, the switch in water paradigm towards IWRM is first discussed (2.2), followed by a brief analysis of the nature of the region's water resources, including the

role of groundwater resources (2.3). Section 2.3 deals with water stress and scarcity, and the chapter is concluded with section 2.4.

2.2 From water supply bias towards integrated water resources management

The growth in human population, food production and industrial production has put global water resources under pressure. Initially, the attention of water managers and decision-makers focused on supply of adequate drinking water and sanitation, but during the 1990s it became evident that water resources were becoming increasingly scarce and that pollution poses serious water quality challenges.

In response, the water management paradigm shifted from a technocratic, water supply approach[1] towards a holistic paradigm of integrated water resource management (IWRM). According to the Global Water Partnership's toolbox, IWRM is a process, which promotes the co-ordinated development and management of water, land and related resources in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems. This description has been adopted in regional SADC projects. The overall IWRM goal is to ensure an efficient (low-cost, and increasing welfare), equitable (meeting essential needs and provision of affordable water) and environmentally sustainable (no water mining unless substitutes can be found in time; sufficient water to meet ecosystem requirements) water provision in the short and long term. In 1992, four guiding principles for IWRM were established in Dublin: decentralised water management, participatory water management, water as an economic good[2] and genderisation of water management. As opposed to the earlier paradigm, demand management and expansion of non-traditional supplies, including conjunctive use of ground and surface water, are important components of IWRM. The potential for demand reduction is significant, and ranges from 20 to 50% on the short term (e.g. during droughts) and even 40 to 60% on the long term (Macy, 1999).

The evolution in water management thinking in the global arena is captured in Table 2.1. During the period up to the late 1970s, water management focused on technocratic, water supply measures, i.e. meeting the existing and predicted demands. Supply costs were rarely considered, as water was treated as a basic need and public good. Basic water requirements, excluding water requirements for food production, are usually estimated at around 50L per day per person (Lundqvuist and Gleich, 1997). The 1980s was a decade of transition, in which sustainable development was conceptualised, popularised and gradually widely accepted. The implications for water resource management were only detailed in the 1990s with the Dublin Conference and the UNCED-conference in 1992. Four guiding water management principles for IWRM were adopted, and a fresh water IWRM chapter was part of the Agenda 21. The IWRM paradigm continues to be used in the 2000s. During the 2002 World Summit on Sustainable Development, six specific IWRM recommendations were made, including the development of IWRM and water efficiency plans by the year 2005, and prioritisation of allocative efficiency.

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[1] Under this paradigm, the key questions were how much water do we need and where do we need to develop it (Lundqvist and Sandstrom, 1997).

[2] This implies, among others, that water has a cost and value, and productive water is needed for economic growth/ production.

Table 2.1: Evolution in global water management thinking

Conference	Management conclusions
1977 World Conference on Water	Decade of Drinking Water Supply and Sanitation. Fresh water management remained supply-oriented.
1991 Informal Conference on IWRM Copenhagen	Decentralization of water management; Land and water resources should be managed at the lowest appropriate levels Water is an economic good, and the price should reflect the potential use.
1992 Dublin Conference	Formulation of four guiding principles of IWRM: 1. Decentralised water management; 2. Participatory water management; 3. Water as an economic good; 4. Genderisation of water management.
1992 UNCED Conference in Rio	Chapter 18 of Agenda 21 on fresh water supports IWRM
2002 World Summit on Sustainable Development-Johannesburg	1. Develop IWRM-and water-efficiency plans by 2005; 2. Improve efficiency of water use and promote efficient water allocation among competing uses 3. Support technology diffusion and capacity building for non-conventional water resources; 4. Support developing countries in their efforts to monitor and assess the quantity of water resources, including through networks, data bases and indicators; 5. Develop regional/national strategies with regards to river basins, watershed and groundwater management 6. Reduce water losses and increase water recycling

Sources: up-dated from Lundqvist and Jonch-Clausen, 1994.

IWRM has at least five crosscutting, multidisciplinary features:

1. A holistic, multi-disciplinary and comprehensive approach towards water management. Management needs to balance social, environmental and economic sustainability concerns;
2. Recognition of the essential ecological functions of water and the associated ecological water requirements. Ecological water requirements may be around 15% of annual run-off (Hassan and Breen, 1999);
3. Recognition of water competition among economic sectors, and consideration of allocative efficiency;
4. Greater attention for the optimal spatial level of water management (local, national and transboundary);
5. Decentralisation of water management to river basins, watersheds and aquifers.

In addition, IWRM has five predominantly economic features:

1. Recognition that water is finite and that not all demands can be met. This calls for demand prioritisation and demand management;
2. Comparing the net benefits of supply and demand oriented measures
3. Recognition of present and future water needs;
4. Recognition of the close linkages between land and water management; and
5. Water is considered as an economic good with a value.

Serageldin (2000) argues that effective IWRM requires radical technological changes, strong political commitment and enormous funding from both the public and private sectors. The latter is particularly difficult in developing countries, which experience low economic growth, high indebtedness and which try to reduce the role of government.

The adoption of IWRM opens a broader range of solutions to water problems than hitherto considered. The full range of management options is presented in Table 2.2. Some options refer to water resources in general; others are specific for either ground or surface water (expansion). Societies normally adopt the easiest and cheapest solution first. Usually this is expansion of water supplies in the form of drilling well fields or dam construction. However, continued expansion is technically complex and expensive. For example, water transfer schemes transfer water from dams to consumption centres, but the schemes are expensive, technically complex and their environmental impacts may be far reaching. With respect to ground water, additional well fields may require desalination plants in order to provide potable water. Desalination is still technically complex and costly, even though technology is improving and the costs are decreasing.

Because of the technical complexity and escalating costs of new water expansion works, other types of options receive more attention to date. These include use efficiency improvements, economic diversification and demand control. A package of measures needs to be selected that represents the best use of available water, and is based on efficiency, equity and environmental sustainability.

Table 2.2: Major IWRM coping strategies for water scarcity

Strategy	**Possible interventions**
Expansion of supplies	Increase storage capacity (dams), well field development desalination, artificial recharge, transfer schemes and conjunctive use
Resource intensification	Greater user efficiency, technology development, water pricing, covenants
Economic diversification	Improve allocative efficiency, water pricing, water markets/ competition, food security instead of self reliance
Curb demand	Prioritisation of needs, drought regulations, user restrictions, relocation of people and human activities

Sources: adapted from Lundqvist and Gleick, 1997 and Arntzen, 2001.

This NRA project addresses one of these directly, i.e. monitor and assess the quantity of water resources. It also creates a better platform for the development of IWRM and water efficiency plans (to be ready by 2005) and improving allocative and user efficiency. Allocative efficiency increases when a shift in water allocation from one sector (e.g. agriculture) to another sector (e.g. industry) leads to an increase in overall production. User efficiency increases when water is used more productively within a sector due to improved production methods. For example, a switch from flood to drip irrigation improves water use efficiency considerably. An example of the importance of allocative efficiency is given below. According to Allan (1995, quoted by Lundqvist 1997):

> "*If allocative efficiency is not achieved, it is possible, and even common, to be doing the wrong thing extremely efficiently. It would be much more useful to be doing the right thing, that is with efficiently allocated water, a little bad"*

They use the example of Israel's agriculture, which is extremely water efficient, but the sector accounts for 70% of the country's water consumption and only contributes three to five percent of GDP.

The old water supply paradigm focused on increasing water supply to meet the demands of households and productive consumers. The demands were treated as given, and the management task was to meet these demands in time. In contrast, IWRM recognises that water supply is limited, and therefore it does not treat demand as a given. Demand manipulation is an essential component of the management strategy. In addition, IWRM focuses on the best possible use of water (BPUW) and balancing of water use efficiency (use and allocative efficiency), social equity and environmental sustainability. Consequently, water is considered as an economic good, whose use has social and environmental implications that need to be considered. User and allocative efficiency ('using water for the right purpose') are central components of IWRM. User efficiency refers to increasing the output per unit of water for individual users. Allocative efficiency refers to increasing the output from a certain amount of water by manipulating its allocation. Allocative and user efficiency are achieved when the net marginal returns of each water- using sector and each water user are the same. At that point, changes in water allocations or water technologies will not lead to an increase in welfare.

2.3 The nature of water resources

Water is a vital natural resource that is indispensable for human activities and survival. Water is globally abundant, but only a small portion is usable, hence making it a de-facto scarce resource. Fresh water only constitutes 2.5% of total water resources, and less than 1% of the fresh water resources can be used. Two-thirds of the fresh water resources are locked in icecaps and glaciers. Another substantial part of fresh water is either too remote or the rain falls at the wrong time and place (Serageldin, 2000). The limited access to water makes both water availability and quality very important. Water pollution is a growing problem in developing countries, and therefore pollution control is required.

Water resources are used for consumptive and non-consumptive purposes. Drinking is an example of consumptive use; transport and hydroelectric power are examples of non-consumptive use. Water resources perform a variety of important environmental functions, including:

- life support and human and environmental health;
- carrier function of goods and pollution; production function (biomass and resource inputs);
- habitat function for water flora and fauna; and
- psychological, cultural and aesthetic functions.

Water management may affect any of these functions, leading to a reduced use value of water resources as well as to damage to ecosystems.

Multiple water uses could increase the efficiency of water use. For example, non-consumptive uses such as transport and hydroelectric power could be combined with consumptive uses. Re-use and re-cycling of water could release fresh water for the purpose of increased production or to supply more people with safe drinking water.

Water used to sustain economic production is sub-divided into two types (Falkenmark, 1994 and 2001). *Green water* is water that provides soil moisture and is used for plant growth. Thus, green water covers the ecological needs and the agricultural production function. *Blue water* is the extra water that is available for domestic and industrial use. Reducing the amount of green water use implies that more 'blue water' is available to support non-agricultural development and welfare creation. The amount of 'green water' can be reduced by cutting alien species and by adopting more water efficient irrigation. Increased food production needs puts, however, pressure on green water resources. As globally and regionally 70% of the water is consumed in agriculture, water efficiency of the agricultural sector and allocative efficiency are important components of IWRM.

Water resources are partly renewable and partly non-renewable. Fossil groundwater resources are effectively non-renewable. Surface water is renewable, but the amount depends on rainfall patterns and variability. Obviously, it is important for water managers to know the available renewable and non-renewable resources, abstraction and recharge/ run-off rates.

Dependency on ground water appears negatively correlated with rainfall levels. Ground water accounts for over half of the water consumption in countries with low rainfall. In tropical countries this percentage is much lower (e.g. less than 10%). In the latter countries, ground water may be an under-utilised resource.

The comparative (dis-) advantages of ground water are summarised in Table 2.3. Global environmental change (GEC) is expected to make ground water more attractive because of the increased evaporation of surface water, but it is expected to reduce recharge in areas where rainfall is expected to decrease and become more variable. Section 2.5 explores the impacts of GEC on groundwater resource in more detail.

Table 2.3: Advantages and disadvantages of ground water over surface water

	Groundwater	**Impact of global climate change**
Advantages	No evaporation	More important
	Widespread, flexible resource with low transportation costs	No change
	Pollution risks often limited and take a long time	No change
	Possibilities for resting and artificial recharge	More important
	Resource is under-utilised in some areas	Under-utilisation will become less common with growing water scarcity
Disadvantages	Very limited cost-effective remedies for polluted ground water	No change
	Sustainable yields are difficult to predict. Monitoring required.	Possible change through change in recharge patterns
	Acquifer may leak water	No change
	Water salinity	No change
	Low recharge in low rainfall areas	Recharge expected to decrease in areas with an expected drop in rainfall.
	Part of resource is fossile	No change other than above

	High costs of abstraction	No change
	Substantial exploration costs and ground water may not be available where it is needed.	No change
	Ground water data are poorer than surface water data.	Improving, but not directly related to global environmental change.

2.4 (Ground) Water resources in southern Africa

Southern Africa has a land area of around 6.8 M km^2 and estimated renewable fresh water resources of on average 650 billion m^3 per annum. The region has fifteen major river basins, mostly shared among several countries. Climatic factors such as temperature and rainfall exert a strong influence on water availability and distribution.

The information about the region's surface water sources is much better than that for groundwater resources. Some key variables for surface water availability are summarised in Table 2.4. Clearly, Botswana and Namibia have the most limited surface water sources in southern Africa; South Africa is considerably better off.

Table 2.4: Rainfall and surface water source by country

Country	**Average rainfall (in mm.)**	**Potential evapotranspiration in mm.**	**Total surface run-off (mm)**	**Total surface run-off (Km^3)**
Angola	800	1300-2600	104	130
Botswana	400	2600-3700	0.6	0.35
Lesotho	700	1800-2100	136	4.13
Malawi	1000	1800-2000	60	7.06
Mozambique	1100	1100-2000	275	220
Namibia	250	2600-3700	1.5	1.24
South Africa	500	1100-3000	39	47.45
Swaziland	800	2000-2200	111	1.94
Tanzania	750	1100-2000	78	74
Zambia	800	2000-2500	133	100
Zimbabwe	700	2000-2600	34	13.1

Note: no data available for Mauritius.
Source: SADC-WSCU, 1998.

The Regional Strategy and Action Plan (SADC-WSCU, 1998) acknowledges the importance of ground water, particularly for the rural population and for managing rainfall variability and droughts in parts of southern Africa. The groundwater resources are considered to be limited, accounting for 15% of total renewable water resources or about 97.5 billion m^3. It is not clear whether this estimate refers to groundwater stocks or sustainable abstraction flows. Concerns exist about groundwater mining as well as under-utilisation of groundwater resources.

Water resources are unevenly distributed within southern Africa. Water resources are abundant in northern and western parts of southern Africa, while water is extremely scarce in southwestern parts of the region. In these parts temperatures are very high, and surface water is extremely limited. Therefore, dry regions tend to rely on groundwater. For example, groundwater accounts for more than half of the water

consumption in Namibia and Botswana, compared to less than 10% in wetter countries such as Zambia and Zimbabwe.

Droughts are endemic in southern Africa, and seasonality is important. During the wet season, water flows are abundant, while there may be no water during the dry season.

Most surface water sources are shared between countries. Their use is subject to the SADC Protocol on Shared Water Courses, and countries are only entitled to a fair and equitable share of water after consideration of the environmental needs. Surface water sources are particularly vulnerable to GEC because of the high levels of evapo-transpiration.

2.5 Southern African water scarcity and regional water management issues

Water scarcity may be defined in different ways. Hydroclimatological water scarcity is widespread in semi-arid and arid dry lands where rainfall is low and highly variable. The evaporation is high, exceeding the rainfall, and therefore causing water scarcity. Surface water is very limited or absent, and ground water recharge is low. The water scarcity severely restricts the agricultural potential as well as the potential of other human activities. Droughts are common, and they increase the risks of crop failure, and livestock mortality. This situation prevails in much of the southwestern part of region.

Water scarcity also refers to the inadequacy of water resources to meet demands. Due to demand growth, this type of resource scarcity is becoming common in the region. *Water stress* is the mildest form of scarcity and exists when water resources are short of meeting the basic consumptive and productive needs of the population. Water stress is said to occur when there is less than 1700 m^3 of water available per person per annum. *Absolute scarcity* is found when water cannot meet all demands. This occurs when there is less than 1000 m^3 of water per person per year. Finally, acute water shortage exists when there is less than 500 m^3 per person per annum available.

In the literature, water scarcity is measured through a wide range of indicators. Table 2.5 provides the results of several scarcity assessments for the three countries (Botswana, Namibia and South Africa). It must be noted that the studies are difficult to compare, and may not be fully consistent. The results are surprising, as countries with hydro-climatic water scarcity such as Botswana and Namibia are not considered to be most water scarce. Water scarcity is rated to be most serious in Malawi and South Africa. The South-African situation can be attributed to the large population and the size of its economy. For Malawi, disagreement exists about the seriousness of water scarcity. Chavula et al. (2002) argue that 3000 m^3 of renewable fresh water is available per capita per person, much more than the water stress level of 1700 m^3. Shortages exist, however, due to the uneven spatial distribution of water resources. Interestingly, the assessments also show that Lesotho, currently a major water exporter, will face water stress in future. If this is true, the current water exports may not be sustainable.

The findings of the assessments are sometimes contradictory or even inconsistent, and must be interpreted with great caution. Botswana's situation is rated adequate in Ohlsson (1995) while Fruhling (1995) reports that there are quality and dry season problems, even though the assessments seem to use the same source. Similarly, figures for the per capita water availability vary greatly from 6672 to 27373 m^3/capita for

Namibia (the variation in figures is much less for Botswana and South Africa). Which figure is right? Finally, estimates for Malawi vary from 1700 to 3000 m^3/capita/annum.

It seems clear that figures are used too easily and loosely, and that assessments are not rigorous enough. Natural resource accounting could provide a more rigorous and systematic assessment that permits cross- country comparisons. The current assessments have several limitations. Firstly, they do not differentiate between domestic and shared water resources. It is likely that shared water resources are double counted for the countries involved. More importantly, countries do not have full user rights of and access to these resources. Therefore, the current assessments are misleading for countries such as Botswana and Namibia with disproportionately large shared water sources. Secondly, the current assessment are national, and do not cover water scarcity at the sub-national level. In many cases, water scarcity occurs locally or in certain parts of Southern African countries, and this is a major concern for water managers in southern Africa. Thirdly, they do not take into account the impacts of global change on water resources in the region. According to the latest regional assessment (Tyson et al., 2002), southern Africa will experience:

- An increase in average temperature, which leads to a much larger increase in PET. A temperature increase of 1 to 2 degrees will lead to a PET increase of 5 to 20 below 10 degrees south;
- Tropical regions will have increased rain and run-off with doubling of green house gasses; sub-tropical areas in southern Africa will receive less rain and run-off;
- Larger changes in extreme conditions than changes in mean conditions. Droughts, floods and vulnerability to climate variations will increase.

Land-use cover changes are important for water management as they influence run-off and recharge. Human factors drive such changes much more than global environmental changes.

Global environmental changes impact on water resource, and they also expected to alter water demand and consumption. An increase in average temperatures is expected to change consumption patterns and increase total water consumption (e.g. increased consumption of drinks, more swimming pools).

While the current assessments are inaccurate and may even be misleading, it cannot be disputed that water scarcity is increasing in southern Africa due to population growth, required increases in food production and economic development. This situation poses several important challenges:

- The need for green water, food production and security. Currently, southern Africa is regularly plagued by droughts, and its adverse impacts on food production and security are compounded by HIV/AIDS and in some countries by political problems. Water scarce countries face the strategic decision to aim at food self reliance or food security, and how much water they wish to allocate irrigation. In areas with less than 500 mm, traditional dry land farming has very poor yields, and countries need to decide whether they wish to develop such areas for irrigation, for non-conventional dry land crops or for other purposes (e.g. livestock);

Table 2.5: Measurements of water availability and scarcity.

Scarcity indicator	Botswana	Namibia	South Africa	Other most water scarce SADC countries
Water scarcity Index (Ohlsson, 1995)	1 (adequate)	2 (quality and dry season problems)	3 (water stress)	Malawi: 4 (absolute scarcity)
Water availability per person/ annum (Fruhling, 1995)	No stress; quality and dry season problems only	No stress; quality and dry season problems only	Water stress; absolute scarcity predicted for 2025	Malawi: absolute water scarcity For 2025: Acute water shortage in Malawi Water stress in Lesotho Water stress in Zimbabwe, Mozambique and Tanzania
Water resources per capita (m^3; Allan, 2002)	9413	27373	1208	Zimbabwe: 1711 Malawi: 1775 Lesotho: 2527 Tanzania: 2770
Water availability per capita (m^3; 1990 value; Ohlsson, 1995)	1990: 14107 2025 est: 6040	1990: 6672 2025 est: 2952	1990: 1349 2025 est: 705	Malawi: 961 Lesotho: 2232 Zimbabwe: 2323 Tanzania: 2969
Total annual fresh water resources (M m^3)	18	9	50	Lesotho: 4 Swaziland: 7 Malawi: 9
Annual internal renewable water resources per capita (m^3; UNDP/ WRI)	1558	333	1206	
Water use as % of available resources (Margat, 1995 and Falkenmark and Lundvist, 1997)	Less than 1%; 1%	1 to 10%; 38%	20-50%; 18%	
Annual fresh water withdrawal (M m^3)	0.09 (1980)		9.20 (1970)	Zimbabwe: 1.22 Mozambique: 0.76 Tanzania/ Angola; 0.48
Water withdrawal as % of total renewable fresh water available (Ohlsson, 1995)	1%;	2%;	18%	Zimbabwe: 5% Swaziland: 4% Malawi; 2%
Per capita water withdrawal (m^3/annum; Ohlsson, 1995)	98	77	404	Swaziland: 414 Zimbabwe: 129
H-value (100L/day/person)	2.7	2.1	11.1	Zimbabwe: 3.5 Zambia: 2.4

Sources: Fhruling, 1995; Margat, 1995; Ohlsson, 1995; Falkenmark and Lundvquist, 1997; SADC-WSCU, 1998 and Allan, 2002.

- Allocative efficiency should be given increasing priority. Most countries focus on user efficiency, and have neglected the important area allocative efficiency. The trends towards decentralised catchment area water management (e.g. South Africa and Zimbabwe) offers opportunities to address allocative efficiency systematically;
- Development and use of the optimal combination of ground and surface water sources based on economic, environmental and social arguments;
- Water protection and sustainable use of the available water resources. This implies prevention of water pollution and mining of water sources. It further implies increased use of under-utilised water resources;
- Decentralisation of water management to acquifer and river basin levels; and Decentralisation will bring about water constraints more clearly, facilitate swift responses to droughts and floods, encourage allocative efficiency and reduce the burden on central governments and parastatals.

2.6 Natural Resource Accounting in IWRM

Natural resource accounting offers a systematic framework to analyse the stocks and use of water resources in relation to the economic benefits derived from its use. NRA distinguishes the following water accounts:

- Stock and flow accounts. Stock accounts record the available water resources. Sub accounts may be made for ground water and surface water sources and for domestic and shared water sources. Flow accounts indicate how much is used annually and for what purpose (domestic and productive purposes)
- Physical and monetary accounts. Physical accounts are recorded in resource units (m^3) while monetary accounts record the resource value (amount x price or value).

NRA provides valuable information to water managers on:

- Trends in water resources. How much is being mined? Are there under-utilised water resources? Are there changes in regeneration, for example related to GEC?
- Indicators of water stress and scarcity;
- The costs and net benefits of water abstraction, for example, ground water and surface water;
- Trends in the user efficiency (e.g. output per m^3 in a given sector);
- The extent of allocative efficiency and possible improvements; and
- Degree of cost recovery and compliance with water pricing policy.

Given the current situation, there is need to develop and record a comprehensive set of water scarcity indicators.

Chapter 3
International experiences with water resource accounts

3.2 Introduction

The framework for water accounts integrates stocks and flows of water with national or regional economic accounts, providing policymakers with an essential tool for Integrated Water Resources Management (IWRM). While other databases about water are sufficient for monitoring availability and quality of water resources, only by integrating water accounts with economic accounts can the socio-economic aspects of water be addressed. This chapter provides an overview of international experiences with water accounting with particular emphasis on the treatment of groundwater. The discussion begins with a review of those countries constructing water accounts, then describes stock and flow accounts. The chapter concludes by summarising the country experiences, identifying where progress has been made and where the major challenges remain.

Water resources are addressed in a general way in the newly revised handbook on the System of Integrated Environmental and Economic Accounting (SEEA) and in a more detailed manner in a forthcoming manual by the UN and Eurostat for constructing water accounts (Alfieri and DiMatteo, 2001; Eurostat and UN, forthcoming; UN, 2003). Water accounts consist of stock and flow accounts; these accounts record physical volume, monetary value, and water quality. While the construction of water accounts is very challenging, a growing number of countries are doing so. In addition to initiatives of individual industrialised and developing countries, Eurostat sponsored a programme of case studies of water accounts, mainly in European countries (Table 3.1).

Table 3.1 shows that most countries construct only water flow accounts and water quality or pollution accounts; few construct comprehensive accounts that integrate stocks and flows. A few countries compile accounts only for water pollution and wastewater treatment cost; in those countries and in much of northern Europe, water is not especially scarce but water quality is a major concern. The classification of water usually distinguishes surface water and groundwater and in some countries is disaggregated by region or river basin as well. Most countries compile at least part of the monetary accounts. Initially, accounts for the market cost of providing water and wastewater treatment were most common because these data were available from official statistics. Now, it is increasingly common to collect information about water tariffs and to construct some indicators of economic benefit.

3.2 Stock accounts for water

The SEEA stock classification for water includes the following categories:

Environmental Asset (EA)13 Water resources (cubic meters)
- *EA. 131 Surface water*
  - EA. 1311 Reservoirs
  - EA. 1312 Lakes
  - EA 1313 Rivers
- *EA.132 Groundwater*

Table 3.1: Countries that have constructed water accounts.

		Flow Accounts		
	Stock Accounts	Physical Use	Monetary: cost of supplying water, water tariffs, wastewater treatment cost	Water Quality, Emissions to water
DEVELOPED COUNTRIES				
France	X	X	X	X
Spain	Partial	X	X	
Netherlands	Surface water	X	X	X
Ireland		X	X	X
Greece		X		
Finland				X
Germany		X	X	X
Sweden		X	X	X
Denmark		X	X	X
Norway			Wastewater treatment cost only	X
Australia	Partial	X	X	X
Canada	Partial	X	X	X
DEVELOPING COUNTRIES				
Botswana	Partial	X	X	
Namibia	Partial	X	X	
South Africa	Partial	X	X	
Philippines		X	X	X
Chile (for one river basin)	Partial	X	X	X
Moldova	Partial	X	X	Partial
Indonesia (Jakarta only)		X		
Turkey		X		

Sources: France: INSEE, 1986; Spain: Luengo, undated; Naredo and Gascó,1995; Netherlands: Brouwer et al., 2002; CBS, 1997; de Haan et al., 1993; Ireland: Economic and Social Research Institute, 1998; Scott et al., 2001; Greece: Mylonas, 2000; Finland: Manninen, 1999; Germany: Schoer and Flachmann, 2000; Sweden: Brånvall et al.,1999; Statistics Sweden, 1999; Denmark: Bie, 2000; Bie and Simonsen, 1999; Jorgensen, 1999; Pedersen and Tronier, 2001; Norway: Sorenson and Hass, 2000; Australia: ABS, 2000; Canada: Statistics Canada, 1997; Botswana: Lange et al, 2001; 2003; Namibia: Lange, 1998; Lange et al, 2003; South Africa: Lange et al. 2003; Philippines; NSCB, 1998; Chile: Meza et al., 1999; Moldova: Tafi and Weber, 2000; Indonesia: Anwar and Nugroho, 2002: Turkey: Tafi and Weber, 2002.

The SEEA acknowledges that countries may want to disaggregate this classification further to reflect additional water characteristics. For example, they may distinguish fossil from renewable groundwater, perennial from seasonal rivers, and reservoirs by primary purpose (e.g., hydroelectric power or water supply). In addition, many countries disaggregate water stock accounts on a geographical basis, constructing accounts by water catchment or river basin.

Water stock accounts record the amount of the total resource and changes in the resource over the accounting period[3]. The framework for groundwater stock accounts is shown in Table 3.2 for a system with three aquifers. The changes during the accounting period can be separated into those due to human activities (abstraction and return flows) and those due to natural processes (recharge from precipitation, natural inflows and outflows, and other changes in volume).

Abstraction is the total volume of water withdrawn in a given year. Return flows represent the amount of water that infiltrates to the aquifers from other uses such as irrigation or wastewater. Recharge from precipitation measures the volume of rainfall that actually reaches an aquifer. Natural inflows and outflows show the volumes of water exchanged among different natural bodies of water, for example, the transfer of water from one aquifer to another, or the release of water by an aquifer to a river. Other volume changes refer to any other change not recorded elsewhere. It is usually calculated as a balancing item between the closing and opening stocks and the entries in the table.

Table 3.2: Groundwater stock accounts (cubic meters)

		Aquifer 1	Aquifer 2	Aquifer 3	Total
Opening volume					
	Abstraction (-)				
	Return flows from economic uses (+)				
	Recharge from precipitation (+)				
	Net natural inflows, outflows and transfers (+/-)				
	Other changes to volume of reserves (+/-)				
Closing volume					

Although the stock concept is most clear for groundwater, construction of these accounts is difficult and expensive. Less information is available about groundwater supplies than about surface water. River water that is stored behind dams can be accounted for in the same way as groundwater in Table 3.2, with an additional entry for evaporation. Flowing rivers share characteristics of both a stock and a flow, so other characteristics that indicate availability may be used for the stock accounts, such as annual runoff.

Many of the countries in Table 3.1 rely more on surface water than groundwater so that groundwater stocks are often a lower priority for water management than surface water. Those that have constructed partial stock accounts most often focus on measures of surface water stocks, mainly reservoirs storage and annual river runoff. Australia has constructed stock accounts for groundwater in one province, Victoria, but this account focuses on changes in water quality over time rather than on sustainable abstraction (See section on water quality accounts and Table 3.5).

3.3 Physical flow accounts for water

[3] The accounting period is usually a year, although in the case of surface water seasonal stock accounts can be useful.

The SEEA water flow accounts, in their most comprehensive form, measure the flow of water between the economy and the environment, and within the economy between water suppliers and end-users. The former begins with abstraction of water from natural sources, including rainfall, and ends with return flows to the environment. The latter includes the supply of water from one sector to another: mostly this entails direct abstraction from natural sources for own use (for example, farmers' boreholes) and abstraction by a water utility company to supply water directly to end-users, or to intermediaries who eventually supply the water to end-users. It also includes the treatment of wastewater before returning the water to the environment.

The flow accounts include the direct use of water for human activities such as agriculture, industrial production, hydroelectric power production, domestic use, recreation and navigation. The accounts include the use of recycled water, and the use of return flows[4]. In principle, the flow accounts also include indirect uses such as transportation and maintenance of ecological function, although in practice, many countries do not include all these aspects of water use.

As portrayed in the water accounting handbook, the flow accounts distinguish the institutional source of water used by each sector. In principle, the flow accounts also distinguish the supply and use of water classified by natural characteristics: groundwater, surface water, which may be further disaggregated by geographic characteristics of water, etc. In practice, the water accounts may be compiled from detailed water information, but the national or regional accounts often do not maintain that detail. The accounts for the three southern African countries do maintain the detail both of the institutions supplying water and the classification of water by natural source.

The framework for the SEEA flow accounts also explicitly includes losses of water during abstraction and treatment, leakages and other unaccounted for losses. Unaccounted for losses can occur for a variety of reasons, such as broken water metres, incorrect reading of water metres and illegal use. Most water accounts do not report these losses and leakages, mainly because of a lack of data.

A typical example of physical water flow accounts is shown for Sweden in 1995 (Table 3.3). The physical accounts distinguish water supplied by a water utility ('distributed water') and water abstracted directly by the user (water supplied by the environment). Water distribution companies, households and agriculture are the largest users of groundwater in Sweden. Seawater is an important source for industrial processes where it can be used for cleaning and cooling (basic metal and chemical industries and power generation). Of the natural resource, i.e. water supplied by the environment, water utilities abstract only about 28%; the pulp and paper industry alone uses nearly 30%. For water utilities, losses and water consumed during production and treatment is given as a use of distributed water, 180.6 Mm^3, which is the difference between water utilities' use of water from the environment (936.3 Mm^3 = 444.9 Mm^3 groundwater + 491.4 Mm^3 surface water) minus the amount the utilities supply to end-users (755.7 Mm^3). No estimates of losses are provided for users abstracting their own water. Sweden also has wastewater accounts that follow a similar format: distinguishing private discharge from discharge to a wastewater treatment utility company.

[4] Water that returns naturally without human intervention or treatment and is available to downstream users.

In many developed countries, information about costs and revenues for water and wastewater treatment are readily available because these services are often provided by water utilities, which keeps records. Most of the developed countries listed in Table 3.1 construct accounts for costs and revenues. An example for Sweden is shown in Table 3.4. Sweden only compiled costs for revenues paid by each sector for marketed water; a single figure is given for supply costs although supply costs vary by region. Costs differences between groundwater and surface water sources are not considered. It is less easy to construct these accounts for self-providers who abstract their own water, often with little monitoring. Often, the self-providers do not maintain financial records that would allow them to determine the total cost of water abstraction costs independent of other business costs. Sweden, and most other countries in Table 3.1 do not provide information about supply costs for self-providers.

Equally important are two additional components of the monetary accounts: the economic *benefits* of water use in each sector, and the economic *value* of water in each sector. The former measures the general contribution of a particular use of water to socio-economic well-being, such as employment or value-added per cubic meter of water input. The latter isolates the contribution of water to product value from the contribution of other factors of production, such as labour, capital, and other resources (land, minerals, etc.). Calculation of socio-economic benefits is relatively easy and has a well-developed history in environmental and resource policy analysis. Most countries listed in Table 1 use their water accounts to measure the sectoral value-added per cubic meter of water input, comparing this figure across sectors and over time.

Economic valuation of water resources, on the other hand, has not been undertaken by any of the countries in Table 3.1. In virtually all countries, competitive market processes do not determine the price of water, although there are some local exceptions. The application of non-market valuation techniques to water on a national level is difficult and costly. Where the issue has been addressed, the price for water is treated as an indicator of minimum willingness-to-pay. Australia introduced a system of tradable water rights in some parts of the country, aimed at its irrigation farmers, and notes that the trading prices set in such markets can be a good indicator of price. However, this system is not widespread. In large cities in some developing countries where public water supply is poor, informal vendors may provide water. Where vendors operate in a competitive market, the prices charged can also provide an indication of local water value.

3.4 Water quality accounts

Water quality accounts are extremely important in many countries, both developing and industrialised. In most developing countries, safe drinking water is still not available to the entire population. Industrialised countries, which already provide safe drinking water to their populations, are concerned with the potential health hazards from agriculture and industry, and the cost of treating water to potable standards.

Water quality accounts include two components in the SEEA framework: the emission from each sector of effluents into water bodies and some indication of the quality of water resources. In developed countries, water pollution has been monitored closely for several decades already; accounts for the sectoral emission of water pollutants are constructed in all industrialised countries that have environmental accounts. However,

relating emissions to water quality is rather difficult because it is the concentration of emissions in a receiving body of water that determines the quality standard.

Table 3.3: Physical supply-and-use table for water in Sweden (1995; (M m^3)

		Water supplied by environment			Supply of distributed water	Use of distributed water	Total use of water resources
		Ground water	Surface water	Sea water			
1	Agriculture	66 418	70 873			0	137 291
10/14	Mining and quarrying	15 229	24 845	2 521		1 312	43 906
15/16	Food products, beverages, tobacco	10 600	7 709	29 802		25 917	74 029
17/19	Textiles, textile products, leather	913	8 307			2 459	11 679
20	Wood, products of wood, cork, straw, etc.	946	15 924	1 661		1 249	19 780
21	Pulp, paper and paper products	16	975 059			3 327	978 402
22	Publishing, printing and reproduction	3	42	19		2 466	2 530
23	Coke, refined petroleum and nuclear fuel	8	117			271	397
24	Chemicals and chemical products	2 968	180 639	309 274		18 891	511 772
25	Rubber and plastic products	450	11 286	5 045		995	17 777
26	Non-metallic mineral products	3 947	6 305	1 923		2 716	14 891
27	Basic metals	2 843	160 193	188 826		8 592	360 454
28	Fabricated metals, except machinery	721	11 366	38		4 164	16 290
29	Machinery and equipment n.e.c.	270	19 545			5 473	25 288
30	Office machinery and computers	42	24	2		406	473
31/32	Electrical machinery, radio, TV, etc.	1 303	1 990	1 753		3 385	8 430
33	Medical, precision, optical instruments, etc.	77	44	61		1 025	1 206
34/35	Motor vehicles and other transport eq.	238	9 885	7		6 446	16 576
36/37	Other manufacturing	111	238	11		695	1 055
40	Electricity, gas, steam and hot water supply	897	68 480	44 174		6 681	120 232
41	Collection, purification, distribution of water	444 948	491 353		755 705		180 596
41/95	Other industries, excluding 90.01					86 522	86 522

	Not allocated industries	1 474	4 192	1		6 469	12 136
Households*		88 449				527 975	616 424
Unspecified use						38 269	38 269
TOTAL		642 871	2 068 416	585 118	755 705	755 705	3 296 405

Source: Adapted from (UN and Eurostat, forthcoming) based on (Statistics Sweden, 1999)

Table 3.4: Monetary accounts for water in Sweden (1985; SEK million)

NACE code and activity		Payments for distributed water
1	Agriculture	0
10/14	Mining and quarrying	7
15/16	Food products, beverages, tobacco	132
17/19	Textiles, textile products, leather	12
20	Wood, products of wood, cork, straw, etc.	6
21	Pulp, paper and paper products	17
22	Publishing, printing and reproduction	13
23	Coke, refined petroleum and nuclear fuel	1
24	Chemicals and chemical products	96
25	Rubber and plastic products	5
26	Non-metallic mineral products	14
27	Basic metals	44
28	Fabricated metals, except machinery	21
29	Machinery and equipment n.e.c.	28
30	Office machinery and computers	2
31/32	Electrical machinery, radio, TV, etc.	17
33	Medical, precision, optical instruments, etc.	5
34/35	Motor vehicles and other transport eq.	33
36/37	Other manufacturing	4
40	Electricity, gas, steam and hot water supply	34
41	Collection, purification, distribution of water	
41/95	Other industries, excluding 90.01	728
	Not allocated industries	33
Households*		2 681
Unspecified use		194
TOTAL		4 127

Source: adapted from (UN and Eurostat, forthcoming) based on (Statistics Sweden, 1999).

Separate accounts for the quality of water stocks are defined based on the issues facing a particular country or region within a country. Water quality is affected by the concentration of specific substances, such as total dissolved solids or organic matter liked biochemical oxygen demand (BOD). Quality classes of water are defined by the concentration of pollutants relative to established standards. Water stocks are then classified according to these classes. Ideally, the SEEA water quality accounts would follow the same general pattern as the stock accounts for groundwater, reservoirs and lakes, but with quality classes added. An example is given for the Victoria province of Australia in Table 3.5, the only country which has constructed groundwater stock and

quality accounts. The Australian accounts distinguish four quality classes; information about annual abstraction, recharge and other changes was not provided since the emphasis was on changes in quality.

Table 3.5: Accounts of the groundwater quality in Victoria province, Australia (1985 and 1988; in million m^3)

	Fresh	Marginal	Brackish	Saline	Total
1985	477.5	339.2	123.3	32.3	972.3
1998 (incomplete)	(39.1)	(566.6)	(141.1)	(n.a.)	(746.8)

Source: Australian Bureau of Statistics, 2000

For groundwater resources where the volume of water stocks is not known, the quality of groundwater can be indicated for major aquifers and geographic area. This can then be matched with water use accounts by geographic region. Water of lower quality may not be suitable for human consumption, but may be adequate for mining or for livestock watering.

3.5 Concluding remarks

Many countries are now compiling water accounts. There has been more emphasis on flow accounts than on stock accounts and no country has constructed comprehensive stock accounts for groundwater. Most stock assessments, where they are provided at all, are limited to estimates of long-term sustainable supply. In many European countries, the quality of the stocks, often surface water stocks, is of greater importance than the quality *per se*.

The core of the flow accounts in all countries are the physical flow accounts for water supply and use, wastewater treatment, and, where important, water pollution. These accounts are constructed to extend the supply-and-use tables of the economic accounts in order to improve policy analysis of water-related issues. Such issues include projecting future water demand and pollution loads, assessing the economy-wide consequences of changes in water pricing or water pollution regulations, and assessing the potential for water demand management.

In all countries, self-providers account for a significant share of water abstraction and wastewater discharge. The physical flow accounts in each country include both water utilities and self-providers. However, the monetary accounts are limited so far to utilities companies; there is very little information about the costs incurred by self-providers. The monetary accounts most often include payments for water compiled on a very detailed sectoral basis. However, information about the costs of supply is mostly limited to total costs of utilities companies; accounts for the cost of supply to individual end-users are not available.

A wide range of indicators is constructed from the accounts, and the socio-economic benefits of water use are often calculated. No country estimates the economic value of water, although the price paid is taken to be a minimum economic value and is even referred to as the value of water in the Danish water accounts.

Chapter 4
Exploration of the impact of global climate change on water resources

4.1 Introduction

Global environmental changes are understood to comprise a variety of environmental changes such as climate change, biodiversity loss and land use change. Climate and land cover changes have the largest impact on water resources and the hydrological cycle through changes in rainfall, evapotranspiration and runoff. Both climate and land use changes are important in southern Africa. Land use changes are driven by population growth, urbanization and economic growth. Their impacts on recharge and runoff are poorly documented and often ignored in water resource management. This chapter reviews the current knowledge on the impact of global climate change on water resources based on available literature. It seeks to determine what may happen to water resources in southern Africa, especially groundwater.

Climate change is caused by the increased emission of green house gasses (GHG) and takes the form of temperature rise and change in the level and variability of rainfall as well as in evapotranspiration. Climate change is expected to have significant direct effects on the hydrological cycle (IPCC, 1996). Although climate change is expected to affect many of parts of the environment, water is one of the most critical resources affected by climate change (Ringius *et al*., 1996; Maclever, 1998). Several studies have been undertaken to analyse the impact of climate change on water resources (Werritty, 2002; Schulze and Perks, 2000; Yu *et al*, 2002; Tao et al., 2003; Glassley et al., 2002; Legese et al., 2003). Moreover, water resources have been selected for one of the four integrated global change research programmes.

The impacts of and interactions between climate change and water are usually estimated from hydrological models' responses to shocks representing the output of various climate change scenarios obtained from the general circulation models (GCMs) (Monirul and Mirza, 2002; Ragab and Prudhomme, 2002; Arnel, 1999; Kamga, 2001; Baltas et al., 1998; Risbey, 1998; Werritty, 2002). Other approaches use the relationship between precipitation trends and changes in runoff to predict the impact of climate change on water resources (Jose et al., 1996; Wu, 2002). Even though there are still many data gaps and uncertainties, the impacts of climate change on water resources is now better understood (IPCC, 2001).

4.2 Impacts of climate change on water resources

Climate change affects the water balance, and particularly the amount of runoff and recharge, which in turn determines the water resources available for human and ecosystem uses (IPCC, 2001). Most of southern Africa is projected to receive less rainfall and higher variability, particularly in the arid and semiarid parts leading to greater frequency of extreme events such as droughts and floods. Tyson et al. (2002) offers detailed review of the global climatic change (GCC) literature and its impacts on southern Africa. In the Tyson et al. (2002) review very little was said however, about the impact of GEC on groundwater resources, presumably because of lack of data. According to Tyson et al. (2002), potential evapotranspiration (PET) is much higher than rainfall (three to ten times) and the variability in runoff is much higher than that of rainfall (a unit change in rainfall leads to 300% change in runoff) in most of southern Africa. It is

expected that in general, tropical regions will experience higher rainfall and runoff with doubling of green house gas emissions, while subtropical areas in southern Africa are expected to become drier. An increase in temperature will lead to a much larger increase in PET (i.e. about 5 folds in areas below 10 degrees South). This will affect evaporation from dams and evaporation reduction will become increasingly important in water management. Like most other studies of climate change impacts, the Tyson et al. (2002) study predicts that marginal areas will be hardest hit by GEC and that increased variability, especially in runoff will become a key factor in future water and land management, especially the impacts on erosion and groundwater recharge.

The impact of climate change on water resources is not evenly distributed across regions and seasons. Some parts of the world will experience a reduction while others will see an increase in water resources as a result of global warming for instance. Similarly, climate change impacts vary between seasons. According to Arnell (1999), average annual runoff will increase in high latitudes, in equatorial Africa and Asia, and Southeast Asia, and will decrease in most sub-tropical regions with warming. There is also evidence that there is a general trend of increasing precipitation in Northern Hemisphere and mid latitudes (particularly in autumn and winter) and a decrease in the tropics and sub-tropics in both hemispheres (IPCC, 2001). Jose et al. (1996) also showed that inter-annual and seasonal variations of rainfall in response to climate change vary by region in the Philippines. Moreover, studies by Arnell and Reynard (1996) indicated that simulations with the wettest model scenario (higher precipitation) increase runoff while driest scenarios decrease runoff, with different catchments responding differently to the same climate change scenario.

In areas where climate change decreases runoffs, navigation, hydroelectric power generation and water quality could be affected, and the supplies of water available for agriculture, residential, and industrial uses be reduced (USIPA, 2003). Moreover, changes in the flows of rivers would have a direct impact on the amount of hydropower generated, because hydropower production decreases with lower flows. Climate change will impact the future availability of water resources for agriculture through changes in precipitation, potential and actual evaporation, and runoff at the watershed and river basin scales (Strzepek, et al., 1999).

As indicated by IPCC (2001), the sensitivity of water resource systems to climate change is a function of several physical features and, importantly, societal characteristics. Physical features that are associated with maximum sensitivity include:

- Current hydrological and climate regimes that are marginal for agriculture and livestock production;
- Highly seasonal hydrology as a result of either seasonal precipitation or dependence on snow melts;
- High rates of sedimentation and reservoir storage;
- Topography and land-use patterns that promote soil erosion and flash flooding conditions; and
- Lack of climatic variety across the territory of the national state, leading to inability to relocate activities in response to climate change.

Societal characteristics that maximize vulnerability to climate change include:

- Poverty and low-income levels, which prevent long-term planning and provisioning at a household level;
- Lack of water control infrastructures;
- Lack of maintenance and deterioration of existing infrastructure; and
- Lack of skills for system planning and management.

4.3 Impacts of climate change on groundwater resources

Groundwater is the major source of water supply in many countries, particularly in rural areas in arid and semi-arid regions. Ground water resources have come under increasing pressure as a result of recent trends in population growth and reduced availability of surface water, especially due to global warming, which reduces precipitation levels and consequently runoff in most arid and semi arid regions of the world. Nonetheless, there has been very little research on the potential effects of climate change on groundwater resources (IPCC, 2001). Solley et al. (1993) estimated that over 50 % of the US population depends on groundwater for their water supply, and that in some regions abstraction of water exceeded the recharge rate (Alley et al., 1999).

The demand for and pressure on ground water increase as population grows and global warming, wasteful use and contamination threaten availability of surface water. Brown (2001) approximated the current rate of global groundwater depletion to be $1.6 * 10^{11}$ m^3 /year. Postel *et al*. (2001) estimated that if present rates of depletion continue, the number of people on the planet living in water stressed countries would increase from 500 million to 3 billion over the next 25 years.

Vaidya (2003) summarised the impact of climate change on groundwater resources as:

- Change in amount of effective rainfall will alter recharge and will change the duration of recharge season;
- Increased winter rainfall will result in increased groundwater recharge. However, higher evaporation and soil moisture deficit will persist longer, offsetting increase in total effective rainfall;
- Unconfined aquifers recharged directly by local rainfall, rivers and lakes and hence are more sensitive to local climate change, abstraction and seawater intrusion; and
- Increase in sea level could cause saline water intrusion in coastal aquifers.

Effective rain, rivers and lakes generally replenish aquifers. This water may reach the aquifer rapidly, through macro pores or fissures, or more slowly by infiltrating through soils and permeable rocks overlaying the aquifer. A change in the amount of effective rainfall and a change in the duration of recharge season will alter recharge. For instance, increasing winter rainfall for mid latitudes increases recharge (IPCC, 2001). Sandstorm (1995) modelled recharge to an aquifer in central Tanzania and showed that a 15 % reduction in rainfall with no changes in temperature resulted in a 40-50 % reduction in recharge, indicating that small changes in rainfall could lead to large changes in recharge and groundwater resources. If one uses the inference of the Sandstorm's study to predict the impact of climate change on groundwater resources, one will conclude that climate change reduces the groundwater resource of Africa as global warming was predicted to reduce rainfall and hence runoff for almost all parts of Africa (Mendelson *et al*., 2000).

A study by Schulze and Perk (2000) assessing the hydrological impacts of climate change in Southern Africa showed that recharge of groundwater is more sensitive than runoff to changes in rainfall in the winter rainfall regions. On the other hand, another study showed that net irrigation requirements (total amount of water applied minus return flow and evaporation) are insensitive to changes in precipitation (Lowe, 1997).

4.4 Concluding remarks

This chapter has mostly dealt with global climate change. The predictions for southern Africa are not optimistic, even though findings are not yet conclusive due to data limitations. Temperatures will increase, and rainfall will decrease in large parts of the region. The dry areas and winter rainfall areas are expected to be most adversely affected.

The impacts of GCC on water resources are determined by non-linearity or amplification process. Firstly, a modest temperature increase will lead to much higher changes in PET. Increased evaporation losses from dams will become an important water management issue, and the benefits of artificial recharge will increase. Secondly, a change in rainfall will lead to a much higher change in recharge rates. GCC is an ad-on factor. Human factors such as population dynamics, governance and land use changes are expected to have a much bigger impact on water resources.

Chapter 5
Botswana water accounts

5.1 Introduction

Botswana produced its first water accounts in 2001 as part of the NRASA project (NCSA and CSO, 2001). The accounts had flow or user accounts and covered some economic aspects of water production and consumption. Overall user trends were identified together with the water consumption by economic sector and water service providers. Groundwater and surface water sources featured partly in the flow accounts by water service provider. The accounts covered the period 1990-1998. The water accounts did not deal with water stocks or with water quality aspects, primarily due to lack of data.

The accounts proved useful to identify overall trends in water consumption, to demonstrate the role of different water suppliers, to indicate the amounts of water lost during reticulation and the value added generated per unit of water. In addition, the initial accounts showed the inadequate data on costs and revenues, which are vital to integrated water resource management and the treatment of water as an economic good.

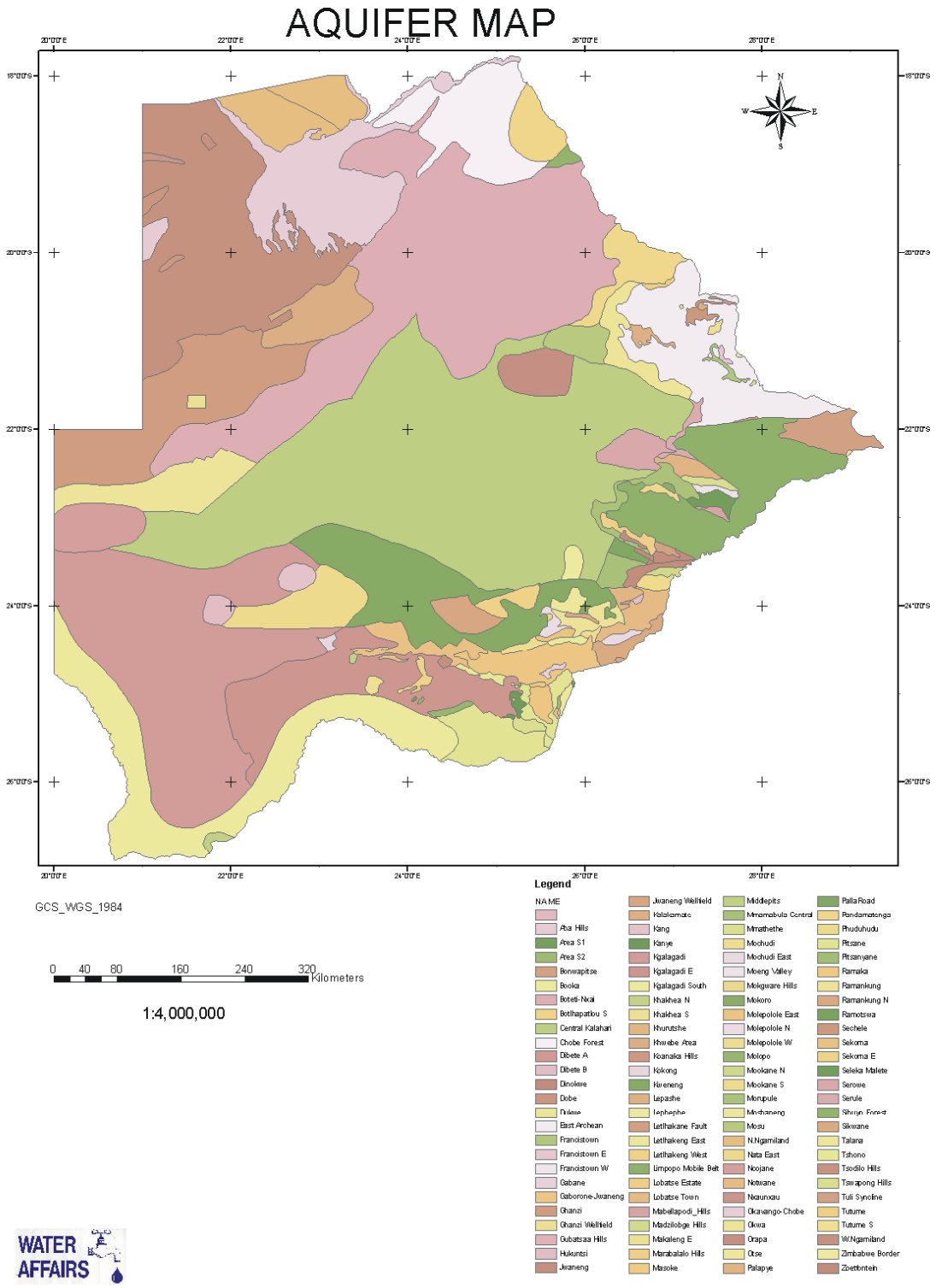
The main purpose of this specific country study was to systematically separate groundwater and surface water resources throughout the existing water accounts. This required the expansion of the flow accounts as well as work on water stock accounts. In the process, the accounts were up-dated to 2001.

Two new developments have taken place since the first accounts were prepared. Firstly, the North-South Water Carrier (NSWC) was completed and became operational in the late 1990s. The NSWC supplies water to the capital Gaborone from the Letsibogo dam through a 400 km pipeline. The NSWC also provides a growing number of major villages with water, where the Department of water Affairs is responsible for water reticulation. The commissioning of the NSWC led to increased water transfers between institutional suppliers as well as increased use of surface water. Secondly, groundwater data has improved, particularly through the establishment of the computerised well field monitoring system (WELLMON).

As explained in chapter three, the SEEA classifies the following categories of water resources (EA 13): EA 131 surface water (subdivided into reservoirs, lakes and rivers) and groundwater (EA 132). For the water accounts, data are needed for following variables; opening volume, abstractions, recharge and inflow, other changes to reserves (e.g. evaporation, ecological requirements, aquifer leakages). This would lead to the closing volume. Ideally, these variables would be available for different water qualities.

Data are inadequate to construct comprehensive stock accounts. As will be shown, most data refer to developed water sources such as reservoirs and well fields. Developed water resources only constitute a small portion of the total resources, and therefore the stock estimate is an underestimate of total water resources. Accounts for developed resources are important, as they indicate the resources, immediately available for use in society.

Map 5.1: Main reservoirs and aquifers of Botswana.



The recharge of well fields has been estimated, but the opening volume of well fields is not known. As a result, the degree of sustainable use of well fields could be assessed, but not their lifetime.

Map 5.1 shows the main water resources and water works of the country.

5.2 Surface water resources

Botswana surface water resources are restricted to ephemeral and perennial rivers and water stored in reservoirs. The perennial rivers (Limpopo, Chobe, Zambezi and Okavango) are shared watercourses, and their use is subject to the SADC Protocol on Shared Water courses. Botswana's surface water resources are limited and unevenly distributed over the country. The average annual run-off is 1.2 mm, ranging from zero in western and central Botswana to over 50 mm per annum in the north. The average annual run-off implies a total annual run-off of 696 million m^3. Most of the run-off cannot be captured due to the lack of suitable dam sites, high variability of run-off in time and high evaporation rates.

The country has more than nine-four reservoirs, most of them (88) small and used for agriculture. Water Utilities Corporation (WUC) operates four large reservoirs for urban areas, accounting for over 90% of the total reservoir capacity. The Department of Water Affairs (DWA) currently operates one reservoir with highly variable yields and water levels. Plans exist for two additional reservoirs.

Table 5.1 provides the contours of a surface water account for reservoirs. It has been possible to complete part of the accounts, but the accounts remain partial at this stage. The inflow data are restricted to the large reservoirs run by WUC and DWA. No inflow data are available for the agricultural reservoirs, leading to minor inaccuracies. The row with 'Other changes' should cover evaporation and water use for vegetation, but no reliable figures can be given. Evaporation data are only available for WUC dams for a brief period (2001-02). During that period evaporation exceeded abstraction by 20%. The in-flows reached 42% of the estimated total run-off for Botswana.

Table 5.1: Reservoir water accounts (EA 1311; millions of cubic meters)

		1992	**1995**	**2001**
Opening volume		124.5	238.6	293.0
	Abstraction (-)	46.0	49.9	65.1
	Inflows (+)	133.2	133.3	193.5
	Other changes to volume of reserves (+/-)	55.2	59.9	78.1
Closing volume		84.5	262.1	343.3

Notes: figures for the agricultural reservoirs are safe yields. The actual amount of water stored is not recorded. WUC inflow estimated on mean annual run-off (MAR) from SMEC et al (1991). Other changes refer to evaporation, which is estimated at 20% above abstraction (WUC figures for 2002).

There is need for further data collection on evaporation, as this data gap becomes more serious with Global Climatic Change (GCC). In addition, accounts need to be developed for ephemeral and perennial rivers (EA 1312).

5.3 Groundwater resources

5.3.1 Data sources

Groundwater resources are limited in quantity and quality, and the limited resources are unevenly distributed over the country. Groundwater collects in aquifers, and is abstracted through well fields (larger village, mines, power plant and irrigation) and individual boreholes (livestock and small villages). It is possible to have several well fields tapping into the same aquifers. Only a small part of the groundwater resources can be economically abstracted due to high abstraction costs, low yields, poor water quality, and remoteness of aquifers in relation to consumer centres (SMEC et al, 1991, Masedi et al, 1999). Recharge is virtually zero in western Botswana, rising to 40 mm. in the north.

In principle, groundwater resources should be subcategorised in:

- Renewable and non-renewable resources; and
- Economically viable and non-viable groundwater resources as determined by the hydro-geological characteristics of aquifers as well as abstraction technologies and costs.

Botswana's total groundwater resources are estimated at around 100 billion m^3 with an average annual recharge at 1.6 billion m^3 (National Atlas and SMEC, 1991). Based on SMEC et al, 1991, Bolaane estimated that well fields and individual boreholes abstract some 75 million m^3 of groundwater or 4.8% of the annual recharge. It is therefore unlikely that all groundwater resources will be depleted. The major water resource management concern is that the developed groundwater will run dry, requiring more boreholes in the same well field, development of new well fields or greater reliance on surface water resources. The groundwater concerns have a strong economic rationale in terms of escalating water costs and possible water constraints to economic development, particularly in rural areas and in the mining sector. Indeed, fears exist for groundwater mining in well fields near large villages and for mining (Masedi et al., 1999).

Two data sources were used for the groundwater accounts. The most important one is WELLMON, an excellent well field database that has been established by the departments of Water Affairs (DWA) and Geological Surveys (GS). WELLMON results are computerised and evaluation reports are available. The following parameters were used for this study: aquifer characteristics, water depth and recharge. In addition, groundwater quality data were obtained for a number of well fields from the DWA water quality division (organic pollution, NO_3, TDS and pH).

The data sets have two limitations. Firstly, the water amount stored in well field (i.e. opening volume of Table 5.2) is not known, and therefore the lifetime of well fields cannot be estimated[5]. Secondly, only four well fields have known recharge areas with recharge rates. For the other well fields, recharge was estimated crudely as the estimated recharge multiplied by the entire well field area. This is a crude method as recharge only occurs from recharge areas.

[5] DWA staff argued at a project seminar that stock estimates could be made with certain assumptions. This requires further investigation.

Botswana currently has thirty well fields[6], and another thirteen have been proposed. Out of the thirty existing well fields, twenty-seven are operational, two are rested after the commissioning of the North-South Water Carrier (Palla Road and Mochudi), and one well field was closed in 1995 due to pollution. Government operates twenty-two well fields. The mining company Debswana and two parastatals (BPC and BDC) operate five well fields. Water is abstracted by at least[7] 340 production boreholes (241 operated by government and 99 operated by companies). This is an average of thirty production boreholes per well field. Each well field has a number of monitoring boreholes to monitor the yields, water levels and quality of well field.

5.3.2 Groundwater accounts

Due to the above data limitations, the groundwater accounts remain incomplete. The findings mostly relate to well fields. Little information exists for the individual boreholes, as District Councils keep poor records and livestock boreholes are not metered nor monitored. Livestock owners are only required to submit basic borehole data in order to get a water abstraction license from the Water Apportionment Board.

A comprehensive outline of groundwater accounts is presented in Table 5.2. The accounts cover well fields as well as abstraction from individual boreholes. Important data gaps exist with respect to the opening volumes and 'other changes' (e.g. ecological use and leakages). It is, however, possible to compare the estimated recharge and abstraction amounts. This gives an indication about the draw down of water resources. If abstraction exceeds recharge, the available water resources are decreasing, but without a figure for the opening volume it is impossible to state the lifetime of the well field.

The recharge could be calculated for twenty-six well fields, and the total recharge was estimated to be 13.4 million m^3 per annum. Assuming a similar recharge for the well fields for which no estimate could be made, total recharge of the current and planned well fields is 15.5 million m^3 (see Table 5.2). The recharge capacity outside well field is not known. Abstraction for the livestock sector and rural villages has been estimated. The risk of groundwater depletion by livestock is very low due to the even distribution of livestock boreholes, and the relatively modest abstraction from each individual borehole (see e.g. Oageng, 1999). Therefore, it is assumed that recharge outside the well field and accessible with current infrastructure equal to or exceeds the abstraction.

The aggregate findings of Table 5.2 have limited meaning, as the 'real' water management issue is resource depletion of individual well fields. It is important for water planners and managers to develop accounts such as the top part of Table 5.2 for individual well field. Current data do not permit the construction of well field sub-accounts, but improvements in WELLMON could be made to establish well field accounts.

[6] Jwaneng, Kanye and Orapa are each treated as one well field.
[7] Data are incomplete for some well fields.

Table 5.2: Groundwater accounts (EA 132; millions of cubic meters)

		1992	1995	2001
Opening volume well fields				
	Abstraction (-)	46.3	49.8	55.7
	Recharge (+)	15.5	15.5	15.5
	Other changes to volume of reserves (+/-)	Not known	Not known	Not known
Closing volume				
Opening volume individual boreholes				
	Abstraction (-)	42.1	42.6	39.7
	Recharge (+)	Likely to exceed abstraction	Likely to exceed abstraction	Likely to exceed abstraction
	Other changes to volume of reserves (+/-)	Not known	Not known	Not known
Closing volume		Not known	Not known	Not known
Opening volume total developed groundwater				
	Abstraction (-)	88.4	92.4	95.4
	Recharge (+)	At least 57.6	At least 58.1	At least 55.2
	Other changes to volume of reserves (+/-)	Not known	Not known	Not known
Closing volume		Not known	Not known	Not known

Notes: well field capacity assumed constant.

In the mean time, it proved possible to make a rough comparison of recharge estimates and abstraction rates for most well fields. The results are summarised in Table 5.3.

Table 5.3: Comparison of recharge and abstraction for well fields (no. of well fields).

All well fields

	No	% of total
Over-utilised	14	30.4
Almost certainly over-used	1	2.2
Under-utilised	2	4.3
Not yet used	12	26.1
Reserve (used in the past)	3	6.5
Not known	14	30.4
Total	46	100.0

Operational well fields

	No	% of total
Over-utilised	14	70.0
Almost certainly over-used	1	5.0
Under-utilised	2	10.0
Reserve	3	15.0
	20	100.0

The abstraction of most operational well field exceeds the estimated recharge. Only in a few well fields is the abstraction below recharge (under-utilised), and two well fields are currently not in use. The existing concerns about groundwater depletion appear justified. In the absence of a figure for the 'opening stock' figure, it is impossible to indicate *when* well fields will run dry with the current data. This is a critical water management variable that needs to be identified in order to start searching for substitutes in time.

From more than half of the operational boreholes, it is not known whether abstraction is sustainable. Clearly, focused data collection and analysis is urgently needed to fill this information gap.

If abstraction exceeds recharge, the groundwater table is expected to drop. For seventeen well fields, time series data were obtained for the water depth of boreholes. The findings of the time analysis are presented in Table 5.4 below.

The results show that the groundwater table is decreasing in seventeen well fields. The drop is most serious in Dukwi, Chidumela, Kanye, Molepole and Letlhakeng. An increase was observed in three well fields (Ramotswa, Thamaga and Matsheng). One of these is no longer used and one is used in conjunction with another well field. Resting of well fields could be a good strategy to ensure high yields during periods of scarcity, but the effectiveness probably depends on the hydro-geological conditions (e.g. leakages).

Water quality data were available for seven operational well fields. All samples remained within the Botswana water quality standards. Pollution, however, occurs locally as shown by the example of Ramotswa well field's closure because of pollution. Salinity is a natural water quality problem in most of western and northern Botswana. It is therefore necessary to incorporate water quality (salinity and organic pollution) in WELLMON and the groundwater accounts. The following categories would be most relevant to Botswana: drinking water for humans; water suitable for livestock production, and Water suitable for 'Other Uses' (e.g. irrigation).

5.4 Flow accounts

Flow accounts offer the link between natural resources and economic development and growth, as recorded in the national economic accounts. The first water accounts had flow accounts by institutional supplier and economic sector, and covered the period 1990-1998 (NCSA and CSO, 2001). While reference was made to ground- and surface water, no separate flow accounts were constructed for ground and surface water sources.

This study added separate surface and groundwater flow accounts, up-dated the existing flow accounts to the year 2001 and collected better data for mining and domestic use in rural villages. The flow accounts now cover the period 1990-2001. Better water consumption data were obtained for the mining sector, especially for diamonds and copper-/nickel. For rural villages, existing estimates were improved, using the 2001 Population Census figures and new per capita consumption data obtained from the Ministry of Local Government. Flow accounts by source of water have been added; a start has been made with linking groundwater flow accounts with the well field stock sub-accounts.

Table 5.4. Recharge and trends in water level of well fields.

Wellfield	Trend	Rate (m/year)	Period of analysis	Number of boreholes used	Boreholes identification codes
Dukwi	Declining	1.18 (1.43)	1988-2002	10 (8)	7676 2016 3112 4628 4649 4675 4702 4769 4788 7392
Pitsanyane	Declining	0.152	1988-2002	3 (3)	4120 4127 4128
Chidumela	Declining	0.642 (0.708)	1993-2002	3 (2)	6732 6655 6657
Ghanzi-Makunda	Declining	0.054 (0.027)	1996-2002	6 (1)	7763 7747 7753 7754 7758 7767
Ghanzi	Declining	0.360 (0.465)	1991-2000	6 (5)	5276 5711 5277 5286 5709 5710
Metsemotlhabe	Declining	0.087 (0.0068)	1988-2002	4 (3)	2550 3070
Molepolole	Declining/ (increasing)	0.535 (1.27)	1988-2002	9 (6)	4417 6968 6993 7000 6786 4296 6783 6843 6851
Gaotlhobogwe	Declining	0.642 (0.589)	1990-2002	10 (6)	6875 6514 6517 6500 6515 6516 6609 6613 6614 7931
Malotwane-Mochudi	Declining	0.757 (not enough record time)	1999-2002	4 (not enough record time)	4346 4195 6872 6867
Kanye	Declining	0.261 (0.272)	1988-2002	9 (7)	5488 1560 4301 4632 4634 5705 5704 5649 4870
Palapye	Declining	2.49 (2.49)	1988-2000	3 (3)	4522 4524 4525
Tsabong	Declining	2.44 (not enough record time)	1994-2002	2 (not enough record time)	5887 3678
Thamaga	Increasing	1.73 (1.73)	1992-2002	3 (3)	3029 5876 6077
Khurutse	Declining	0.610 (0.610)	1992-2002	3 (3)	7145 7179 8417
Malotwane	Declining	3.20 (3.20)	1988-1998	3 (3)	4317 4346 5119
Matsheng	Increasing	0.052 (not enough record time)	1995-2002	5 (not enough record time)	4237 7851 7866 6762 7876
Ramotswa	Increasing	2.35 (not enough record time)	1999-2002	5 (not enough record time)	4886 4974 6501 4165 4155
Serowe	Declining	2.89 (2.89)	1988-1999	3 (3)	4139 4143 4149
Palla Road	Declining	0.035 (0.047)	1991-2000	7 (4)	5520 5540 5542 5419 7451 6271 7492
Letlhakeng-Botlhapatlou	Declining	0.774 (1.34)	1991-2002	7 (4)	6764 6829 6784 6762 6739 6741 6827

Notes: 103 boreholes used; bracketed values are from the analysis using only boreholes with at least 5-years continuous record

Source: based on data from WELMON, O+M and own recharge estimates.

Due to the growing importance of water transfers among water providers, the institutional accounts should in principle make provision for the purchases and sales of water to other water providers (cf. Namibia). Due to data limitations as well as the fact that current transfers mostly concern surface water, this study has not been able to fully integrate water transfers[8] into the flow accounts; the reader is referred to Chapter six and Appendix B for Namibia's treatment of water transfers in their accounting framework).

Details of the three different flow accounts are summarised in Table 5.5. The accounts are linked, making it possible to identify groundwater use by water provider and economic sector. Data problems are most serious in rural areas (District Councils), and for estimating water flows by economic sectors.

[8] The NCSA should address this issue in their resource accounting programme that will be carried out in 2003-2007.

Table 5.5: Details and problems associated with the flow accounts

Type of flow account	Main sub-divisions	Data availability, estimates, and problems
Water source	Groundwater, dams and rivers	Data incomplete for years 1990 and 1991.
For ground-water by well field	30 operational well fields; 14 are in preparation	Incomplete data; differences between DWA O+M data and WELLMON.
Water provider	WUC, DWA, DCs and self providers	Data are missing for 1990-1991 (DWA and DCs) Substantial differences between WUC-water use figures published in different sources
Economic sector	12 major economic sectors and 37 economic sub-sectors	DWA and WUC use different classification of economic sectors; which do not fully link with the NA-classification. No data for rural villages. Total consumption has been estimated as the population X est. per capita consumption. It has been assumed that domestic use accounts for 100% of the water consumption in rural villages. For WUC: data for 1993-98. It is assumed that the sectoral breakdown for 1990-2001 conforms to the average of 93-98. For DWA: no data for 1990 and 1991.

Note: DC = District Council; DWA = Dep. of Water Affairs; WUC Water Utilities Corporation

The water flows incorporate water consumption by end-users and unaccounted water losses (system losses and unaccounted consumption). Ecological requirements have not been included in the flow accounts.

The aggregate flow accounts show that the total water production has increased from 144.5 million m^3 in 1992 to 171.3 million m^3 in 2001. This is a modest increase of 17.8% in ten years. This increase is below the population growth (2.4% per annum), and it is lower than the forecasted water demand growth in the Botswana National Water Master Plan (BNWMP; SMEC et al, 1991). In the BNWMP, water demand was predicted to grow by 57.0% in the period 1990-2000, leading to a water demand of 183.5 million in the year 2000, compared to the 168.7 million m^3 of this study)[9].

Key findings of the flow accounts are:

- A modest overall growth in water use, mostly in reservoir use;
- WUC expanded its supply most rapidly in terms of provision to end-users and water transfers;
- The NSWC has alleviated the pressure on well fields that supplied six large villages; and
- The increase in groundwater use is mostly due to the mining sector and large villages.

These and other findings are discussed in more detail below.

[9] The reasons for the different findings need to be analysed, and the result of this analysis should be used in improving future demand scenarios.

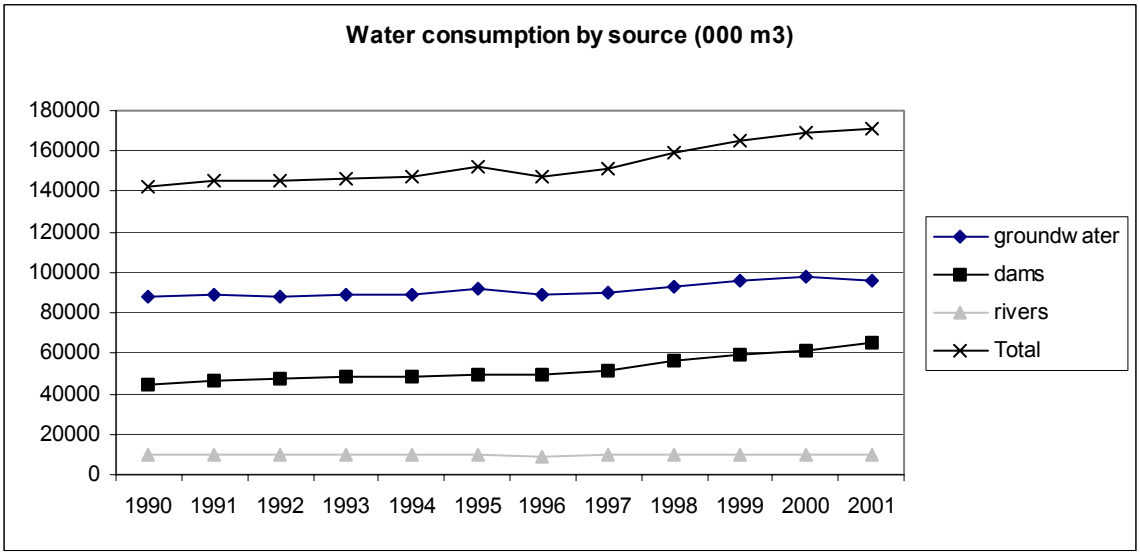
5.4.1 Water flows by source

Data are available for three sources: direct abstraction from two perennial rivers (Chobe and Okavango), reservoirs in ephemeral rivers (mostly Boro) and well fields.

The flow accounts by source show that the growth in surface water use has been much faster than the growth of groundwater use, entirely due to increased use of reservoir water. For the period 1990-2001, the use of reservoir water grew by 39.4% compared to a modest increase of 9.0% in groundwater abstraction. The use trends by main source are shown in Figure 5.1.

Botswana's has reduced its reliance on groundwater from 61% in 1992 to 56% in 2001. Groundwater remains most important as it continues to supply more than half of the water, but the sources of supply are more balanced than before.

Figure 5.1:



Source: this study.

Further analysis of the groundwater flows indicates that the livestock sector, rural villages and diamond mines are the largest users of ground water. Table 5.7 shows that diamond mining[10] and to a lesser extent large villages are largely responsible for the increase in groundwater use with growth rates of 64.7% and 34.8% respectively in the period 1992-2001. The water use by the livestock sector has decreased due to a stagnation of the national herd and that of rural villages only slightly increased due to the slow population growth in rural villages.

[10] The production capacity of diamond mines has expanded substantially in the late 1990s, causing higher water consumption.

Table 5.6: Use of groundwater by major users (million m^3)

Sector	1993	1998	2001	Growth rate 92-01
Livestock sector	39.3	38.0	38.0	- 4.2%
Diamond mining	11.0	14.0	17.9	64.7%
Rural villages	19.5	21.5	22.1	7.5%
Large villages	7.0	9.7	9.6	34.8%
Total	88.7	92.8	96.4	9.0%

Source: this study.

5.4.2 Water flows by service provider

Four water service providers are distinguished in the accounts. The parastatal Water Utilities Corporation (WUC) provides reticulated water to urban areas, and operates the North-South Water Carrier (NSWC) that supplies Gaborone and other settlements. The department of Water Affairs is responsible for the water provision of sixteen large villages[11], while the District Councils operate and maintain the water supplies of rural villages. Self-providers are responsible for meeting their own needs after the Water Apportionment Board has granted them water rights. Self-providers include livestock and irrigation farmers, mines and other productive activities outside settlements such as the Moupule Power Plant. Water transfers between service providers have become more common with the operation of the NSWC, and complicate the supply picture. While DWA is the service provider for large villages, almost half of the water originates from the NSWC operated by WUC. DWA, DCs and self- providers mostly rely on groundwater (and DWA also on water transfers from WUC).

The water production by service provider is shown in Figure 5.2. This production includes sales to the end-users and other water service providers (i.e. transfers) as well as losses.

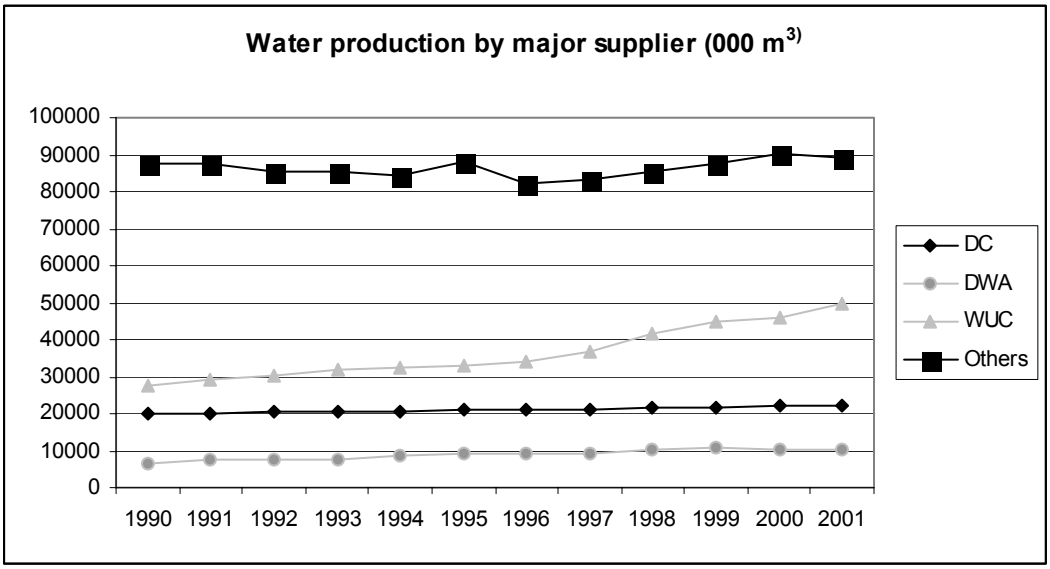
Self-providers remain the largest water supplier, even though their production has not increased a lot in the 1990s. The production share of WUC has rapidly increased (by 62.4% in the period 1992-2001) due to the construction of the Letsibogo dam and the NSWC and the associated increase in water sales to DWA. In 1998/99, such sales amounted to P 38.4 million, but they had more than doubled three years later (P94.2 million)[12]. WUC transfers to DWA account for 49% of the consumption of large villages. As a result of the transfers, DWA production could grow more slowly (34.1% in the same period), and pressure on well fields could be reduced. Some well fields are being rested and kept in reserve.

Details of the main consumers of each institutional supplier are presented in Table 5.7 For WUC, government is the fastest growing customer (70.3 % in period 1993-2001) due, among others to the water transfers to DWA. Water consumption of urban households is also rapidly expanding (55.4% growth in same period). For DWA, the switch from standpipes to yard and house connection is the main reason for the phenomenal consumption growth of 187.7% in 1993-2001. The consumption growth

[11] Large villages are villages with more than 5 000 inhabitants and villages that function as District Administrative Centres.
[12] The WUC water is sold to end-users by DWA at around tow-thirds of the purchase price.

among self-providers is due to the expansion of the diamond mines in the second half of the 1990s (64.9% growth in water use in period 1992-2001).

***Figure 5.2*:**



Source: this study.

Table 5.7: Consumption details of major users by water service provider

	Ranked major users	**2001 consumption in million m^3**	**Growth rate in %**
WUC	Urban households Central government Copper-nickel mine Local government Total	14.8 6.1 1.7 1.6 49.6	55.4% period 93-01 70.3 37.6 50.7
DWA	House/ yard connections rural households Standpipes Schools Total	4.2 4.8 1.7 10.4	187.7 period 92-01 96.9 34.6
DCs	Rural households	22.2	8.4%
Self providers	Livestock owners Diamond mines Total	50.6 17.9 89.1	- 4.2 period 92-01 64.9
Total		171.2	17.8

Source: this study.

5.4.3 Water flows by economic sector

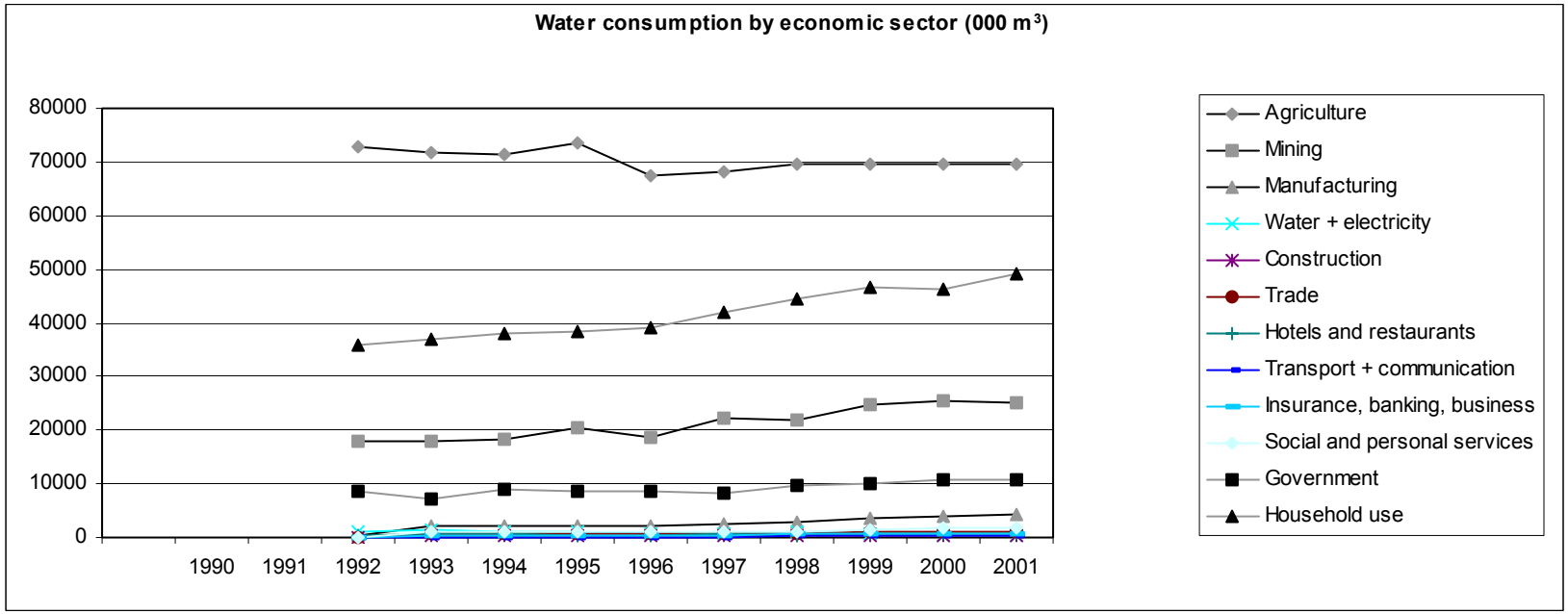
Due to data limitations, time series covered the period 1993-2001 only. The up-date (1999-2001) with empirical WUC sectoral data would have required a major effort, which was not justified in view of the groundwater focus of this study. Instead, sectoral use has been estimated based on the assumption that the sectoral breakdown of WUC consumption for the period 1999-2001 is the same as the average for the period 1993-

1998. As the total WUC-consumption for the period 1999-2001 is known, the sectoral breakdown was calculated by multiplying this percentage with the total annual water consumption for the period 1999-2001.

The sector analysis was carried out at an aggregate level (12 sectors) and a detailed level (37 sub-sectors). The results of the 12-sector analysis are summarised in Figure 5. 3.

The agricultural sector is the country's largest water consumer, but at the same time it is the only major consumer whose consumption is not increasing. Consequently, its share has declined from 51% in 1993 to 42.4% in 2001 due to agricultural stagnation. Domestic use is the second largest sector, and its use is rapidly growing; domestic use accounted for 30% of total consumption in 2001. Its consumption growth is due to increasing house and yard connections that lead to substantially higher per capita water consumption. Mining and government are the third and fourth largest water-consuming sectors with shares of 15.3% and 6.7% in 2001 respectively. The mining sector has expanded its share as a result of the expansion of the capacity of the diamond mines.

Figure 5.3:


Water consumption by economic sector (000 m³)
80000
70000
60000
50000
40000
30000
20000
10000
0
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Agriculture
Mining
Manufacturing
Water + electricity
Construction
Trade
Hotels and restaurants
Transport + communication
Insurance, banking, business
Social and personal services
Government
Household use

5.5 Economic aspects of water accounts

The initial accounts showed that the data on the costs, revenues and value of water resources are incomplete. This situation has not improved much since 2000 since water has been treated more as a public than an economic good. The expansion of water supplies has been a long-standing development priority, the costs of which did not matter to a large extent. Certainly, the costs of ground and surface water were not compared as IWRM would require, and no comparison was made between the expansion of traditional supplies, non-traditional supplies and water demand management. Escalating marginal supply costs and rapidly increasing water prices are, however, raising concerns about the costs and price of water resources.

Below, we review the available incomplete information on costs, prices and values of water. It is clear that Botswana is still focusing on direct water supply costs. Environmental externalities, ecological water needs, and foregone future benefits are not yet considered. Even the supply costs are incomplete, fragmented and not routinely collected and analysed.

5.5.1 Water costs of self-providers

The policy dictates that self-providers, mostly mines and livestock farmers, are responsible for the full direct user costs. Livestock farmers may receive a subsidy under the Livestock Water Development Programme and under SLOCA, and in that case a substantial part of the capital costs are subsidised. Self-providers do not pay a resource price nor for opportunity costs, hence pay well below the marginal opportunity costs of water. In the absence of a volume related charge, there is no incentive to reduce water consumption.

No data are available for the costs of water supplied of mines. Given the location of the mines and limited alternative economic opportunities, the opportunities costs of water for mining are thought to be low, mostly related to livestock production. The economic benefits of diamond mining are huge and probably warrant groundwater depletion given the low opportunity costs.

Several studies have investigated the average borehole water cost of the livestock sector, and have yielded a wide range of water costs ranging from P 0.91/m^3 in Kgatleng to around P 2.50/m^3 in other studies (Bailey, 1980; Motsomi, 1983, Oageng, 1996; SMEC et al, 1992). It is difficult to compare the results as details of the estimates are often missing, and the estimates refer to different years (1980 up to 1996). The depth of boreholes, the yields and location and the driller determine the actual supply costs.

As the self-provider sector accounts for close to half the water consumption, it is imperative to gain better insight into their costs of water supply. Since water need to be treated as an economic good, a volume related resource charge need to be considered on top of the direct user costs paid by the self providers.

5.5.2 Water costs of service providers

WUC, DWA and DCs are the major service providers, and each is governed by different costs and pricing structures. WUC has to recover the full capital and operation costs through its tariff structure. The existing block tariff structure offers subsidised water in the

lifeline band, and escalating charges for the higher user bands. DWA tariffs aim at recovery of the operational costs, but in recent years the stated policy is to recover some of the capital costs as well. DWA uses a similar, but lower, block tariff structure as WUC. DCs aim at recovery of the operational costs for the private connections. Water from standpipes is free of charge, but the intention is to reduce the standpipes.

Data are particularly poor for DCs. The costs of (ground) water supply through DCs have been estimated based on cost figures of operation and maintenance as well as rehabilitation from Hagos (1994) and estimated capital expenditures from the Design and Construction Division, DWA. The estimated unit supply costs (2000) are P1.53/ m^3, of which capital costs are P 1.14/m^3 and P0.39/m^3 recurrent expenditures

DWA has better expenditure and revenue data, but data remain fragmented and incomplete. Three cost scenarios have been used to estimate the unit water costs. The estimated costs exceed P 10/ m^3 and appear to be higher than those of other suppliers.

No unit costs could be calculated for WUC's surface water supply. Instead the average revenue per m^3 sold was calculated for the period 1990-2001. Assuming that WUC meets it obligation of full cost recovery, this figure would be indicative of the supply costs. The average unit revenue has increased from P 2.51/m^3 in 1990 to P 6.15 m^3 in 2000.

Despite the relatively weak data, several important conclusions can be drawn. There is a wide range in the supply costs of water, probably related to the local water resource endowments, transport and storage systems. The range in costs of surface and groundwater shows some overlap, consequently there is structural cost advantage of either ground or surface water. IWRM requires that in each instance the best supply source be identified and compared with the costs of water demand management. Currently, the water pricing principles cannot be properly implemented without comprehensive cost and revenue data.

The above cost figures differ from the findings of BNWMP that estimated the long run marginal supply costs of water to be highest in rural villages (LRMC of P 7.10/m^3) followed by large villages (P 3.75-5/ m^3) and urban areas (North-East P 1.53/m^3) and Gaborone P 4.53/m^3). Economies of scale were the main determinant of declining water unit costs in larger settlements and urban areas. More detailed analysis of water costs is urgently needed to fill the gaps and come up with more reliable data and conclusions.

5.5.3 Allocative efficiency of water

Allocative efficiency refers to the production achieved with one unit of water in various economic sectors. Optimisation of allocative efficiency is not yet a policy objective. Table 5.8 presents trends in the value added per m^3 by sector for the period 1993-1999.

Table 5.8: Value added by water unit by economic sector (constant 93/94 prices; Pula 000).

User category	1993	1994	1995	1996	1997	1998	1999	2000	2001
Agriculture	6.50	6.43	6.67	6.73	7.05	6.37	5.81	6.24	6.08
Mining	220.97	211.57	200.73	231.87	213.97	208.15	207.09	237.11	232.17
Manufacturing	194.27	235.98	255.98	298.92	250.60	223.74	190.17	179.89	162.81
Water + electricity	190.07	222.61	228.33	366.90	409.44	357.19	500.91	796.56	895.79
Construction	2294.25	2999.12	3189.95	2269.05	2766.54	4889.56	2629.59	2565.12	2596.33
Trade	1116.19	1396.79	1653.76	1635.61	1631.08	1799.96	1522.98	1613.83	1570.70
Hotels and restaurants	275.65	3199.90	367.99	364.84	380.04	372.69	281.75	277.32	303.24
Transport + communication	2447.82	2758.13	2649.87	2869.92	2971.32	3220.92	2739.03	2758.44	2853.47
Insurance, banking, business	2421.34	2821.44	3025.64	2770.76	2901.15	2883.80	2657.51	2692.61	2807.68
Social and personal services	381.65	435.46	436.30	497.49	511.82	494.27	415.64	1631.55	1708.88
Government	236.34	199.61	218.47	238.06	261.76	237.48	244.53	247.06	261.69
Household use	NA.	NA.	NA.	NA.	NA.	NA.	NA.	NA.	NA.
Grand total	74.00	88.23	78.17	87.11	89.42	88.79	90.98	98.89	99.45

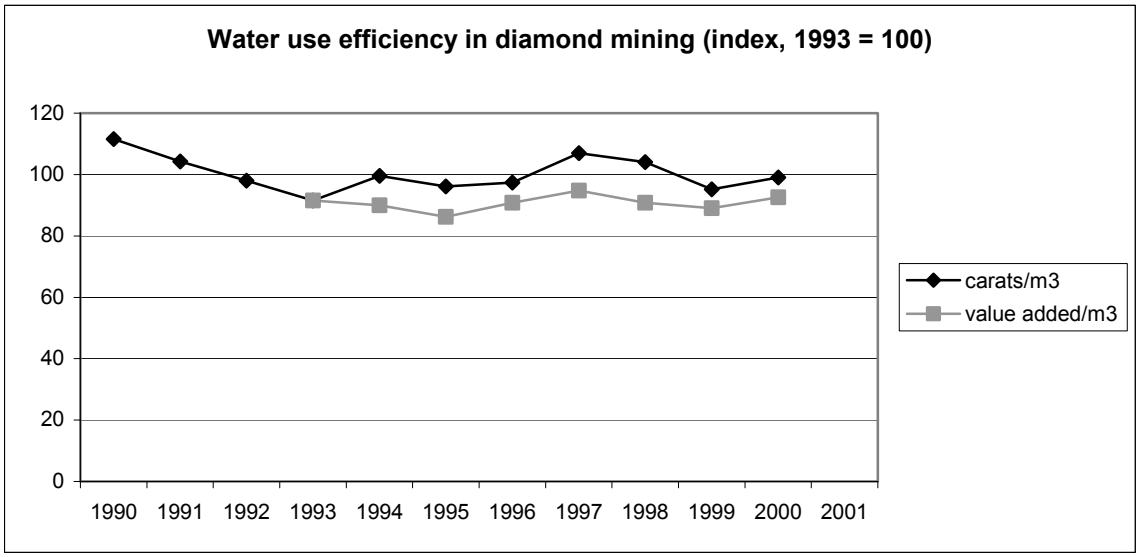
The value added per m^3 does not show a clear trend, but instead fluctuates between P 74 in 1993 to P 99.45 in 2001. The sectoral breakdown shows that the transport sector, the banking/ insurance sector and the construction sector use water most productively. The transport, construction and trade sectors have achieved an increase in output per m^3, indicative of increased water efficiency within these sectors. Agriculture generates by far the lowest value added of P 6 to 7/m^3. The government, mining and manufacturing sectors have fairly similar water efficiencies.

An increase in water scarcity will necessitate an increase in overall water efficiency, i.e. creating more value added per average m^3. This may not be easy because Botswana's water efficiency is already higher than that of Namibia and South Africa, and rapidly growing domestic use may lead to a decrease in productive water due.

5.5.4 Sectoral water efficiency: the case of diamond mining

The expansion of diamond mining has led to an increase in water consumption of the mining sector in the late 1990s. Because diamond mining relies virtually fully on groundwater resources, the water efficiency of the sector was further investigated in order to assess what has happened to sectoral water use efficiency. Two indicators were used: carat production per m^3 and value added per m^3, and the results are shown in Figure 5.4. Both indicators show a similar pattern, although the value added index is lower than output measured in carats. Water efficiency has proven to be fairly volatile during the period 1990-1999, but there has been no structural improvement in water use efficiency in diamond mining. The 1999 index figures were, in fact below the 1993 level (carats at 95 and value added at 89). Efficiency peaked in 1997, but consistently declined after 1996. This may be due to the recovery of lower grade deposits, requiring more water per ton of earth material.

Figure 5.4:



5.6 Concluding remarks

The country study demonstrated that progress could be made with the proper incorporation of the distinction between groundwater and surface water resources in the water accounts. In particular, the study showed that:

- Stock accounts can be prepared, and a start with the accounts was made. National groundwater stock accounts have limited value, as the risk of overall groundwater depletion is minimal. The risks of depletion and the cost aspects refer to individual well fields, and need to be reviewed at that level through a set of well field sub-accounts;
- The available, incomplete data suggest that groundwater mining is common in many well fields. It is not possible to estimate the lifetime of current aquifers. This research is needed to determine the total economically viable amount of water in each well field; and
- The need to study interactions between surface and groundwater sources is growing due to global climate changes leading to increased evapotranspiration, growing opportunities for conjunctive use through the NSWC and the move towards integrated water resource management.

The development of comprehensive stock accounts exceeded the scope of this project, but need to be carried out in the planned NCSA water account activities. Evaporation of reservoir water and run-offs in river stocks are critical for improving surface water accounts. On the groundwater side, details of the annual development of well fields and production boreholes and estimates of total accessible water resources by well field are critical for improving groundwater accounts. This would make it possible to estimate the lifetime of well fields. Identification of the recharge areas for each well field would improve the accuracy of recharge estimates and assist groundwater protection. Given the large differences between well fields, sub-accounts need to be developed for each well field. The total groundwater account would be the summation of the well field sub-account plus the ‘non-well field sub-account’.

Future stock accounts should also incorporate the growing amount of wastewater, based on information provided in the forthcoming National Sanitation and Wastewater Master Plan.

Resting of well fields could be a good strategy to ensure high yields during periods of scarcity, but the effectiveness probably depends on the hydro-geological conditions (e.g. leakages).

Chapter 6
Water resource accounting in Namibia

6.1 Introduction

Work to construct water resource accounts for Namibia began in 1995 under the Namibian Natural Resource Accounting Programme. This program was initiated by the Ministry of Environment and Tourism in cooperation with the Department of Water Affairs in the Ministry of Agriculture, Water and Rural Development (MAWRD). The first set of water accounts were constructed to demonstrate that it was possible to construct such accounts and that the water accounts can provide policy-makers with a comprehensive economic assessment of water use in Namibia.

The first set of water accounts included both stocks and flows of water, but the information was limited (Lange, 1997). Stock accounts could only be constructed for the surface water stored in dams. The rest of the stock accounts consisted of a range of indicators of water availability for ephemeral surface water and groundwater such as annual rainfall, runoff of major rivers, and the annual abstractions from 'problem' boreholes. 'Problem' boreholes were defined as those for which the water table was dropping continuously for five years or more without recovery from major rainfall events. It was assumed that the continuously falling water table indicated unsustainable abstraction.

Water flow accounts included the annual volume of water used by each economic sector, the cost of providing water, the tariffs paid, the subsidies received, and the socio-economic benefits of water use in each sector. The first water accounts classified water into nine categories based on a combination of institutions supplying water (three) and natural sources (three). Water users were classified according to the classification of economic sectors used for the national accounts (seventeen industries and government) and two categories of households, urban and rural.

Since the initial accounts were constructed several developments have occurred that increased the demand by policymakers for water accounts and that have made it easier to construct water accounts. From the policy perspective, Namibia has reviewed its water resources management process aimed at revising water policy and the institutions that manage water. This review has resulted in a new Water Bill, which emphasises, among other things, an economic approach to water management.

In parallel, Namibia participated in a regional Water Demand Management study (van der Merwe et al. 2001), which undertook case studies of water use by selected sectors and an economic assessment of water demand management as an alternative source of supply. The need to relate these case studies to national water use and water policy, through water resource accounts, was very clear.

In terms of data availability and quality, the provision of bulk water, which had been part of central government, was privatised and required to operate on a commercial, cost-recovery basis. Namwater, the new parastatal, introduced a new database system that provides much more detailed information about water use, costs and tariffs. In recent years, municipalities have introduced or upgraded computerised billing systems that make annual information about water use and tariffs by end-user more accessible.

The next stage in the development of water accounts for Namibia included several improvements:

- expanded data collection about water use from municipal authorities and others water suppliers;
- construction of water accounts by river basin which would be aggregated to obtain national water accounts; and
- an expanded framework to account explicitly for transfers among water supplying agencies and for losses.

These developments are described in greater detail in the section on the Namibian water accounts.

Groundwater resources are a particularly important component of Namibia's water supply, providing roughly 50% of Namibia's water demands. In recent years, there has been an increased effort to measure groundwater stocks and flows and to introduce monitoring systems, especially for abstraction. Many of these research efforts are still in their early stages and complete data are not yet available. This section reports on the water accounts presently available for Namibia.

The Appendix B provides a detailed description of the new framework under development; new accounts should be available by the end of 2003.

In Namibia, the classification of natural sources of water supply include groundwater, ephemeral surface water, perennial surface water, recycled water, and unconventional water, which will include desalinated water if the planned desalination plant on the coast is implemented (Table 6.1). Groundwater is the most important source, accounting for roughly half of annual water use. The rest is almost evenly split between ephemeral and perennial surface water. Recycled water accounts for less than 1% of Namibia's annual water use, but it has formed a significant share of Windhoek's water supply since 1968. Water from unconventional sources is limited to desalination, which is expected to provide a major component of the water supply along Namibia's coast.

Table 6.1: Classification of natural sources of water in Namibian water accounts

Groundwater	Groundwater can be classified as fossil and renewable.
Perennial surface water	Rivers that run all year. Namibia's perennial rivers all cross national boundaries and the use of this water is therefore subject to international agreements.
Ephemeral surface water stored in dams	Rivers flow only after periods of heavy rainfall. Captured in large dams for distribution as well as in small, on-farm dams for own-use.
Recycled water	Water that has been used once, treated and reused
Unconventional water sources	Desalination is planned for the coast but has not yet been implemented.

6.2 Water stock accounts

The stock accounts for water along with some supplementary information can be used to assess the status of Namibia's water resources. Groundwater is characterised by great

uncertainty over the extent of reserves, the problem of depletion, and conditions of groundwater recharge. Surface water is characterised by a high degree of annual variability due mainly to variations in rainfall and increasing dependence on international water resources. Namibia has no perennial river entirely within its borders.

No stock accounts exist yet for recycled water and for water from unconventional sources.

6.2.1 Groundwater

Groundwater is often the cheapest and most reliable source of water for much of Namibia's dispersed population since it can be tapped at the point of use and it is not directly dependent on annual rainfall. It is difficult and expensive to measure groundwater reserves in Namibia since it occurs in many different aquifers of different shape and size throughout the country. In addition, the quality of groundwater, measured, for example, in terms of saline content, also varies a great deal from one aquifer to another.

Ideally, groundwater accounts would have the form of Table 3.2, but no comprehensive information about the total volume of groundwater is available. As part of a study of the options for long-term water supply to Namibia's central area, which includes its capital, Windhoek, the Department of Water Affairs estimated the sustainable yield of the major aquifers in the central area (DWA, 1995 and 2001). In some instances it was possible to estimate groundwater stocks as well, but no estimate of recharge from rainfall was made, so it is not possible to compile that groundwater accounts for these aquifers on an annual basis.

Because of the lack of data about groundwater stocks, supplementary accounts and indicators are used for the water accounts. The first is an account for groundwater potential (Table 6.2). This account is similar to other types of land accounts that classify the area of a country by important environmental and economic characteristics, such as agro-ecological zones or land-use accounts. The source for this information is the hydro-geological map of groundwater in Namibia compiled by DWA (2001).

According to this assessment, only 3% of Namibia's land area has high potential aquifers. A further 40% have aquifers with moderate potential and 30% have low overall potential but may have locally significant flows. An aquifer with low potential may yield sufficient flow, for example, to support dispersed livestock watering, but the flow is too low to be tapped for municipal use. Finally, 27% of Namibia has extremely limited groundwater potential.

Table 6.2: Groundwater potential of Namibia

		km^2	percentage of land area
High potential			
	Porous aquifers	9,000	1%
	Fractured, fissured or karstified aquifers	14,000	2%
Moderate potential			

	Porous aquifers	210,000	26%
	Fractured, fissured or karstified aquifers	115,000	14%
Low potential with moderate local potential		250,000	30%
Very low, limited potential		225,000	27%
Total land area of Namibia		823,000	100%

Source: DWA, Geohydrology unpublished data, 2003

Groundwater potential was also assessed for known or likely water quality, especially salinity of water, classified into four categories ranging from water fit for human consumption to unfit to human consumption. The potential risk from pollution was also assessed based on aquifer type, groundwater flow, depth to groundwater, and annual recharge. At this time, Namibia does not suffer any serious groundwater pollution or actual risk. On-going research is focused on establishing the volume, recharge and sustainable yields for aquifers known to have good quality water. There is no research into the potentially low quality water resources at this time.

The storage potential of some aquifers was assessed in the early 1990s for a study of options for future water supply of Namibia's Central Region, which includes the capital Windhoek. Estimated stored reserves and sustainable yield are shown in Table 6.3; figures for each aquifer are disaggregated by aquifer sub-system in the Appendix B, Table B1. The figures cover only aquifers in central Namibia. Data for Stampriet, an agricultural area in southeastern Namibia, were obtained during a recent study of that particular aquifer. The Tsumeb aquifer is presently undergoing study. Many other aquifers have not been studied, so the accounts for groundwater are not complete. Some aquifers, such as the one supplying the coastal town of Luderitz are known to be fossil aquifers.

Namibia has around fourteen aquifers with an estimated sustainable yield of 68.3 Mm^3 and a stored reserve of 1.2 billion m^3.

Depletion of groundwater resources is a major concern and it would be useful to compare annual withdrawals for each aquifer to estimated sustainable yield. However, such data are not available[13]. The parastatal Namwater regularly metres its water abstractions, but accounts for only 24% of groundwater abstractions (see water flow accounts discussed below and detailed water flow accounts in Appendix B). Most aquifers are exploited by other users too, especially self-providers, who do not metre their withdrawals.

[13] A monitoring program has recently been put into place by DWA's geohydrology section for groundwater provided by DWA's Rural Water Supply division, but data is not yet available.

Table 6.3: Stored reserves and sustainable yield for selected aquifers

Aquifer	Stored Reserve	Estimated Sustainable Yield (Mm^3/annum)
GROOTFONTEIN KARST	NA	14.6
OTJIWARONGO	13	3.2
KHORIXAS	5 to 10	2.2
OMARURU	4.4	2.5
NEI-NEIS	4.2	0.6
OMDEL	150	8.2
KARIBIB	1.4	0.183
USAKOS	1.2	0.28
KUISEB	649	5
OSONA	4	1.25
REHOBOTH	27	2.5
WINDHOEK	30	1.75
TSUMEB AQUIFERS (including Asenab)	Nav	18
STAMPRIET ARTESIAN BASIN	283.3	8
TOTAL	**1,175.0**	**68.3**

NA: Not applicable. The concept of stored reserves only has meaning for aquifers where water can be 'banked' in closed systems. It is not meaningful to attempt calculation of karst aquifers, which are not closed. *Nav:* not available; presently under study
Note: Many of the figures for sustainable yield are preliminary and are undergoing re-evaluation at this time, particularly those in the Grootfontein area.

Source: DWA, 1995 and unpublished studies by DWA; Groom et al. 2001 p. 69; JICA, 2002.

Furthermore, given the highly variable rainfall, it is not always certain what time frame to use in assessing the sustainability of water withdrawals. An aquifer's water table may decline continuously for several years, then experience a complete recovery from a 1-in-twenty-year rainfall event. A subsystem of the Southeast Kalahari Aquifer recently experienced recovery after a one-in-fifty-year rainfall event (JICA, 2002). Namwater had defined as potential problem areas boreholes where the water level dropped continuously for five years or more. According to this definition, in 1993 14% of the water provided by Namwater was from aquifers under watch for moderate to serious depletion. Since that time some boreholes have recovered; but the concept of groundwater stress and depletion is undergoing review and more recent assessment is not available at this time.

6.2.2 Perennial surface water

The volume of all perennial rivers is subject to considerable variation over time (Table 6.4). There are no water storage dams on the perennial rivers, although there is a dam used to generate hydroelectric power on the Kunene. While a river is by definition a flow rather than a stock, it is useful to distinguish the amount of river water potentially available in a given year from the amount actually used. The amount potentially available, measured as annual runoff for each major river, is included in the stock accounts of the natural resource accounts at this time. The long-term average runoff from perennial rivers is much larger than the estimated borehole yields. However, the

mean annual runoff of these rivers is not directly related to the amount available for Namibia to use for two reasons.

First, all perennial rivers originate outside of Namibia and pass on either to other countries or to the sea. Consequently, the amount of water actually available to Namibia each year is subject to international agreements among the countries sharing the perennial river. Namibia's obligations under these agreements are given in Table 5.2.4. Agreements have been concluded with South Africa for the Orange River and with Angola for the Kunene for abstractions of 110 Mm^3 and 180 Mm^3, respectively. The sum of these, 290 Mm^3, is less than 3% of the long-term average runoff. Most of the abstraction from the Orange River is used for commercial agriculture and mining, while the water from the Kunene is used for hydroelectric power, some irrigation, and domestic use by the heavily populated rural north.

There are no agreements for the other rivers at this time. Namibia has indicated its intention to tap the Kavango River but this has met with strong objections from Botswana, where the Kavango River empties into the Okavango Delta, a major tourism destination and World Heritage Site.

Two other important claims on river water include in-stream requirements and ecological requirements. In-stream requirements have only been established for the Orange River. Ecological uses of stream flow have not been recognised in Namibia's water policy.

The second factor limiting exploitation of the perennial rivers is the considerable distance of these rivers from the major sources of demand. Long-distance water transport infrastructure in Namibia is extremely limited and water transportation costs are prohibitive at this time.

6.2.3 Ephemeral surface water

The amount of ephemeral water in a given year depends on annual rainfall; in some instances, there may be carry-over from a previous year stored in dams. For the natural resource accounts, three sets of information are collected about ephemeral surface water, the first is a stock account and the other two are supplementary statistics useful for understanding the stock accounts:

1. Annual volume of water stored in a dam at the beginning of April in each year[14] (Table 6.5). Detailed accounts for each of the eighteen major dams are given in the appendix, Table B2;
2. Annual runoff from the major ephemeral rivers, an indicator of potential stock;
3. Annual rainfall and percent deviation from long-term average rainfall of roughly 200 meteorological stations throughout the country (Table 5.2.5); and
4. Annual abstractions from major dams (Appendix Table B.2)

While only dam storage can be considered an actual stock of water, additional data can provide a dynamic assessment of changes in the stock. The stock will vary greatly from one area to the next based on the annual distribution of rainfall and runoff, as well as the

[14] April 1 marks the beginning of the planning year for water, and generally, the end of most rainfall.

amount abstracted. From this, one should be able to calculate evaporation as in Table 3.1.

Table 6.4: Stock accounts for perennial and ephemeral surface water in Namibia (1980-2001; Mm^3)

	Annual Runoff of Perennial Rivers						Ephemeral Rivers	
	Kavango	Kunene	Orange	Zambezi	Kwando	TOTAL	Runoff	Dam storage
1980/81	3,513	1,561	3,583	40,153	1,732	50,542	67	241
1981/82	5,164	1,980	3,308	36,290	923	47,665	78	164
1982/83	4,651	2,868	1,125	26,048	837	35,529	70	105
1983/84	6,699	7,565	1,592	22,532	870	39,257	335	157
1984/85	6,975	7,307	932	24,528	880	40,622	666	277
1985/86	4,409	8,094	2,200	26,666	913	42,281	430	428
1986/87	5,049	4,338	2,731	35,559	929	48,607	221	386
1987/88	3,881	3,684	21,885	26,419	787	56,657	764	477
1988/89	6,225	5,333	10,897	38,550	1,026	62,030	753	465
1989/90	4,335	3,624	2,415	40,048	1,064	51,485	212	345
1990/91	4,654	5,474	3,534	25,706	795	40,163	303	323
1991/92	5,376	6,362	2,800	24,775	661	39,974	81	204
1992/93	4,066	3,340	2,529	17,845	785	28,565	177	273
1993/94	3,349	2,201	1,445	38,406	844	46,245	354	311
1994/95	2,403	4,686	647	17,844	585	26,165	135	200
1995/96	3,405	2,974	8,201	15,492	473	30,546	272	181
1996/97	2,928	2,156	10,480	15,142	523	31,228	908	593
1997/98	4,036	3,584	5,650	30,301	480	44,050	179	426
1998/99	4,351	4,770	1,800	38,229	517	49,668	204	355
1999/ 2000	5,378	5,424	7,006	32,126	650	50,584	3,988	588
2000/ 1	4,383	6,666	4,654	37,430	*	53,132	185	403
2001/ 2	5,954	7,521	14,180	NA	*		568	469
2002/3								310
Long Term Average	5,201	5,005	5,659	38,038	814	53,904		

NA: not available; *unreliable daily records; data missing for 300 days or more; Note: The year runs from April 1 through 31 March. Ephemeral surface water accounts are based on data only from major rivers and dams.

Source: unpublished data from DWA, Hydrology

Table 6.5: Water abstraction agreements for international rivers

River	Agreed quantity
Orange	110 Mm3 per annum First 50 Mm^3 – free Next 20 Mm^3 – 0.7 cents per m^3 Next 40 Mm^3 – 1.5 cents per m^3 The last 40 Mm3 is only agreed upon until 2007. Discussions are currently taking place regarding future allocations. Violsdrift and Noordoewer Irrigation Authority has a signed agreement to abstract 20 Mm^3 per annum of which 11 Mm^3 is for farmers in South Africa and the remaining 9 Mm^3 is for Namibian farmers.
Kunene	180 Mm^3 per annum.
Kavango	No international agreement has been made, therefore, allowing unlimited abstraction, in principle. However, funding for projects utilising large quantities of water are unlikely to be approved unless there is an international agreement. There is presently an international river basin commission reviewing the situation.
Zambezi	Same as for the Kavango

Source: DWA

Table 6.6: Rainfall in Namibia (1980-2002)

Year	Rainfall (millimetres)	Percentage Deviation from Long-Term Average
1980	197.2	-39%
1981	219.2	-32%
1982	215.7	-33%
1983	313.4	-2%
1984	269.0	-16%
1985	340.1	6%
1986	268.7	-16%
1987	338.3	5%
1988	387.0	21%
1989	287.4	-11%
1990	336.7	5%
1991	255.8	-20%
1992	277.3	-14%
1993	341.4	6%
1994	138.8	-57%
Long-Term Average (1915-1994)	321.1	

Sources: based on Lange, 1997 and 1998

Table 6.7 Institutional suppliers of water in Namibia

Institution	Description
Namwater	Bulk water supplier. Provides water directly to some end users as well as to other suppliers for ultimate delivery to end users
Municipal water authorities, Town and Village Councils, Regional Councils	Deliver bulk water purchased from Namwater to end users mainly in urban areas, and in some cases supply water themselves
Rural Water Supply	RWS provides water to some end-users in rural areas at no charge. RWS obtains part of this water from Namwater and part from local boreholes operated by RWS.
Rural Communities	Communities that now manage their own water through Local Water Committees and Water Point Associations. Water is purchased from Namwater and partly subsidised by RWS.
Self-providers	Users that supply their own water such as livestock farmers, tourism sites and mining companies. In some instances, such as mining and agriculture, excess water may be sold to other end users.

Since the local availability of water is a critical factor for water supply and there is little infrastructure for moving water from surplus to deficit areas, the stock accounts are compiled separately for each of the eighteen major dams, and are reported Appendix B, Table B2. The annual runoff is largely determined by the amount and distribution of rainfall. Rainfall data are provided for roughly 200 meteorological stations operating over the period 1915 to 2000, but are not compiled on a catchment basis, which would allow estimation of the correlation between rainfall, runoff and dam storage. For the sake of brevity, rainfall is reported here only for the years 1980 to 2000. Figures for abstraction from major dams operated by Namwater should also be included in the accounts, but the data collected do not cover all dams and only begin in 1993; many of the figures are estimates. The available information is reported in Appendix B, Table B.2

6.3 Flow accounts for water

The framework for water flow accounts represents the following components of the water supply and use system: natural characteristics of water sources, institutions that deliver water to end users and end users.

Institutional sources represent the agents that deliver water, directly or indirectly to end users (Table 6.7). Namwater, the parastatal responsible for bulk water supply, abstracts water from primary sources and supplies some end users directly, but much of the bulk water supply is delivered to other suppliers who provide local reticulation systems for delivery to end users. Municipal water authorities purchase most of their water from Namwater and deliver it to end-users. In some cases, municipalities also operate their own facilities to abstract water from primary sources such as local boreholes or well fields. The water accounts will be compiled separately for each of roughly 20 municipalities.

Rural Water Supply (RWS), a part of the Ministry of Agriculture, Water and Rural Development, is responsible for providing water to some rural communities in the

communal areas, mostly for domestic use and livestock watering. RWS purchases some water from Namwater and provides the rest through local boreholes. It is government policy to decentralise rural water management to local communities that will eventually take over the management of most rural supply from RWS (and some rural communities are already doing so). These rural communities have organised Local Water Committees and Water Point Associations. Self-providers, as the term implies, are those who abstract water directly from natural sources primarily for their own use, mainly farmers and mining companies. In some instances, excess water may be sold to other water providers for delivery to other end users.

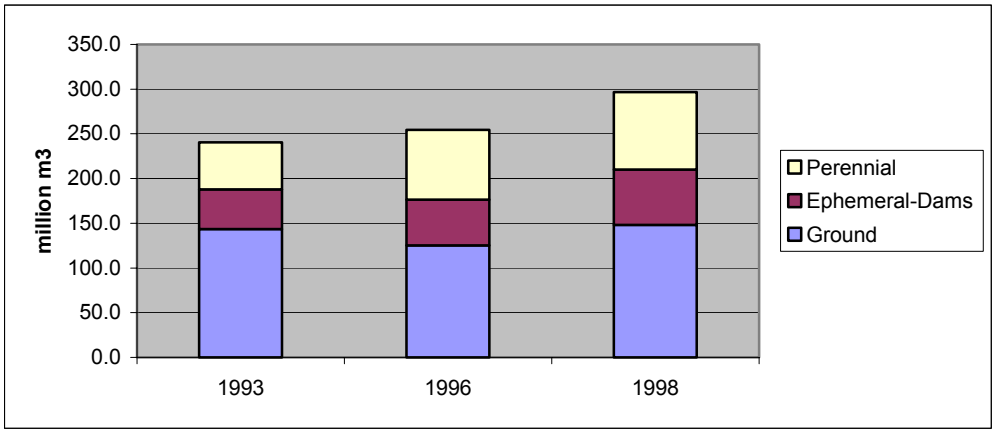
6.3.1 Physical flow accounts

The early framework for water flow accounts in Namibia only showed the relationship between the end-user and the institution that first abstracted the water. Information about losses and wastewater were not included. Only three major institutions supplying water were included: Namwater, RWS, and self-providers. The classification of end-users was limited to twenty: seventeen industries, government and two categories of households. Accounts based on this early framework were constructed for 1993, 1996, and 1998, and are given in the Appendix B, Table B3.

The new, expanded framework for water flow accounts represents explicitly the role of all institutions, including the transfer of water from one agency to another. Namwater produces roughly 40-45% of Namibia's water, about half of which is sold to municipal authorities and RWS for distribution to end-users. The framework for the new accounts is fully described in Appendix B.

Water use is summarised in Figure 6.1. Total water use has increased from 240 Mm^3 to 297 Mm^3 between 1993 and 1998. The total amount of groundwater has not changed very much, averaging 139 Mm^3 over the period, but accounting for an exceptionally high share of total water (60%) in 1993, which was a drought year. By 1998, inflows into dams increased, and the use of perennial river water along the borders grew substantially, mainly for irrigation, but groundwater still accounted for half the water used.

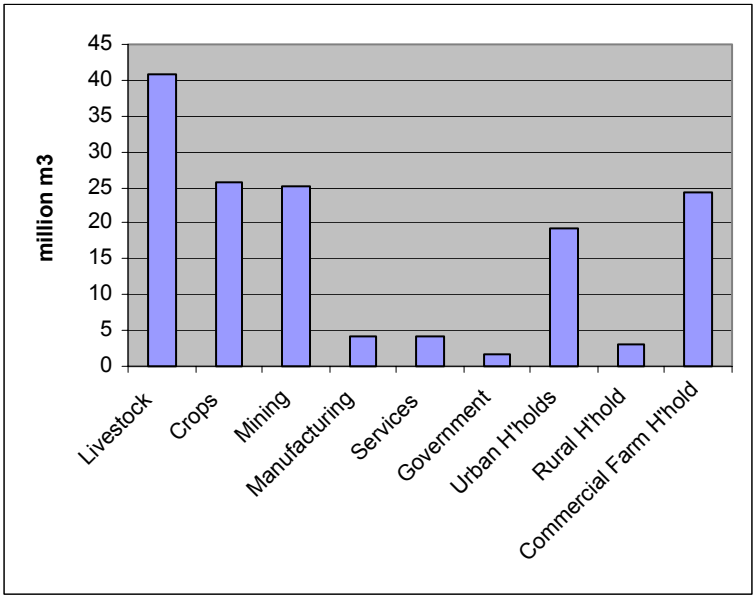
Figure 6.1 Water use by natural source (1993-1998)



Source: Based on Appendix Table B3.

The three largest users of groundwater are livestock, crops, and mining (Figure 6.2). Following very closely behind is the estimated groundwater use by commercial farm households for gardening. The only significant change from 1993 to 1998 was the rapid increase in groundwater used for irrigation, from 8Mm^3 to 26 Mm^3. While livestock still accounts for more water use than crops, the economic value generated by livestock is much higher, as will be discussed in the next section.

Figure 6.2 Use of groundwater by sector (1998)



Source: Appendix B, Table B3

The heavy reliance of self-providers on groundwater (65% of all water abstracted) is a concern because their use is not metered. Under conservative assumptions, it is estimated that self-providers use about half of all water, mostly for livestock and crop irrigation.

6.3.2 Monetary flow accounts

The water accounts framework calls for corresponding physical and monetary accounts; the monetary accounts consist of the cost of water delivery, revenues paid for water, water subsidies, and the economic value of water. Data for the cost of water supply and the revenues received are incomplete. Estimating the economic value of water is very difficult for most water use and no country has yet done this on a national level. Namibia has undertaken case studies to test different valuation techniques (see Lange, 2002), but will not construct accounts for the value of water. The Namibian accounts do, however, construct measures of the socio-economic benefits of water use, such as the sectoral national income generated per cubic metre of water input.

The costs and associated subsidies include full financial costs (operating plus capital costs) only; no work has been done at this time to estimate scarcity costs or environmental externalities. The original framework for constructing these accounts is

shown in Table 6.8. The Table can be compiled for the cost of supplying water, water tariffs and the level o subsidies. Only Namwater provides sufficient information to construct accounts for water cost by end-user. RWS only has information about total expenditures, and cannot assign costs to specific end-users. However, end-users are limited to agriculture and rural households, so it is not unreasonable to split the costs in proportion to water use. There is no information about the cost of water to self-providers at this time, but some cost estimates might be possible for agricultural use, based on information about boreholes and the costs of pumping water.

Table 6.8 Framework for monetary accounts for water

		INSTITUTION & NATURAL SOURCE OF WATER								
		Namwater			Rural Water			Self-provider		
		Ground	Ephemeral	Perennial	Ground	Ephemeral	Perennial	Ground	Ephemeral	Perennial
END-USER	Agr				Information about total expenditures only			Not Available		
	Mines									
	Manuf.									
	...									
	Services									
	Govt.									
	H'holds									
	Total									

Regarding water tariffs, Namwater also provides sufficient information to construct accounts for water charges levied on end-users. These accounts represent the tariffs levied but not necessarily the revenues actually collected because of non-payment of user-charges. In rural areas, more and more communities make some form of payment for water, but hitherto water was free. Self-providers clearly do not pay a water fee. The subsidy as a percent of water supply cost, is the easiest to calculate. For the Namwater component, the percent of costs not covered by tariffs can be calculated from Parts A and B. For RWS, the subsidy, until recent years, was 100%. And for Self-providers, the subsidy was 0%.

6.4 Socio-economic benefits of water allocation

The socio-economic benefits of water allocated to a particular sector are often evaluated by calculating the income or employment generated per cubic metre of water input. Namibia does not have employment figures for the years of the water accounts, so the analysis is limited to sectoral income (value-added). The national accounts report output and value-added separately for commercial agriculture and subsistence agriculture. Within each subsector, the values of output for crops and livestock are recorded, but not their values-added. Value-added is recorded only for combined crop plus livestock output. An estimate of values-added for crops and livestock in each sub sector was

made by applying the share of value-added for each sub sector to crops and livestock. This approach underestimates the value-added from livestock and overestimates the value-added from crops, but it is the best that can be done at this time and the overall trend in relative values is reasonably accurate. Within crops, a further estimate was made of the crops produced under irrigation, since it would be misleading to combine irrigated and rained crops when considering only irrigation water.

Not surprisingly, agriculture generates the least national income per cubic metre of water input, N$ 5.03 in 1998, and crops generate much less income than livestock (Table 6.9). There has generally been a move toward improving water efficiency in commercial agriculture by introducing more water efficient irrigation technologies (drip rather than flood) and by moving to higher-value crops. The income generated from irrigated crop sin 1993 was considerably lower than in 1996 or 1998.

The income generated by subsistence agriculture appears larger than commercial agriculture due to two reasons. First, the dominance of relatively low-value irrigated crop production in commercial agriculture; comparing the livestock components, commercial agriculture generates much greater income than subsistence agriculture. Secondly, subsistence agriculture includes household production activities, which require relatively little water.

Income per cubic metre of water input increases as the economy progresses to secondary and tertiary activities: mining generate N$40.74, manufacturing N$268.06, and services generating the highest income, N$1251.44. There is no clear time trend; both agriculture and fish processing are buffeted by highly variable environmental conditions, and mining is subject to volatile international prices. The 1998 economy-wide average of GDP per m^3 of water input has not changed from 1993, and appears slightly lower than the figure for 1996. This reflects a number of factors, including the sensitivity of data estimates, but also the large expansion of crop irrigation (water use increased more than 40%), which tends to pull down the economy-wide average.

With respect to groundwater, it is not possible at this time to distinguish the value-added generated by groundwater within a sector from the value-added generated by other types of water within that sector, except for three sectors in which groundwater constitutes 100% of the water use: commercial livestock, diamond mining, and fish processing.

Because so much data for the monetary accounts are missing, only the summary tables for water subsidies by sector are presented here. Complete figures for 1998 are not yet available, so estimates were made based on earlier figures and general increases in water tariffs charged by Namwater. Four categories of subsidies are provided:

- No subsidy
- Low to medium: water subsidies less than 50% of cost
- High: water subsidies greater than 50% but less than 100% of cost
  100% subsidy.

Table 6.9 Sectoral income per cubic metre of water input (1993-1998; constant 1995 prices)

	N$ GDP/m3		
	1993	**1996**	**1998**
Agriculture	5.22	6.83	5.03
Commercial	4.66	5.23	3.24
Livestock	15.07	21.88	17.34
Crops*	0.18	0.31	0.30
Subsistence	7.98	12.52	15.12
Livestock**	-2.15	4.15	5.99
Crops		NO IRRIGATION	
Mining	41.57	43.67	40.74
Diamond mining	47.65	57.57	58.31
Other mining	31.36	27.35	23.44
Manufacturing	282.26	230.48	268.06
Fish processing	549.28	283.67	581.22
Other manufacturing	239.11	225.07	231.59
Services	1185.57	1277.14	1251.44
Economy-wide average	47.39	51.51	47.58

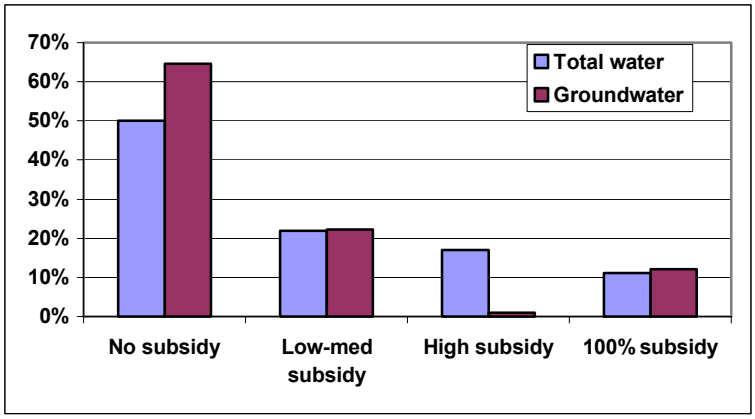
*Estimate for irrigated crop production only.
**Livestock value-added is negative in 1993 because reduction of inventories (herds) was larger than output, meaning that farmers were slaughtering more than the natural increase in herds.

Sources: Lange, 1998; Lange et al. 2003, and author's calculations

High subsidies are provided only to commercial crop irrigation, mainly from non-groundwater sources. Water subsidies of 100% are provided only to communal households for livestock and domestic use; groundwater accounts for more than half the water used in these sectors. The sectors that receive no water subsidies are those where self-providers play an important role: commercial livestock farming, mining, commercial farm households, and some commercial crop farmers.

Figure 6.3 provides the overall picture of water subsidisation. Groundwater is less subsidised than other sources of water: 65% of groundwater is not subsidised at all, whereas the figure for total water use is only 50%; only 1% of groundwater use is highly subsidized compared to 12% for total water. The shares of water with low to medium subsidies and 100% subsidy is roughly the same.

Figure 6.3 Distribution of water use by level of water subsidy in 1998



Note: Low/medium subsidy is 50% or less; High subsidy is greater than 50% but less than 100%.
Sources: Lange, 1998; Lange et al. 2003, and author's calculations

6.5 Conclusions

The Namibian economy has a high degree of dependence on groundwater, roughly 50% in years of average rainfall, and considerably higher in years of poor rainfall.[15] Namibia's economy and population are growing and so is its water use, notably the expansion of irrigation. The water accounts show that much of the increase in water demand has been met by international surface water sources. Groundwater abstraction is in the range of 130 to 150 Mm^3, but its use of groundwater for irrigation has also increased rapidly. Self-providers, whose water use is not regularly monitored, abstract most groundwater. Water managers have realised that an integrated water management strategy must include these self-providers. Subsidies for groundwater are lower than for surface water. At this stage, it is impossible to compare groundwater abstraction with the estimated sustainable yields, as the latter is only known for selected aquifers.

It is important that data on stocks and sustainable yields for the major aquifers are improved. Options for storing surface water in aquifers are under consideration. There is also discussion of mandatory metering of all boreholes including self-providers. This will make it possible to link the use of groundwater (water flow accounts) with the status of groundwater resources (water stock accounts). The water accounts need to distinguish fossil groundwater resources from renewable ones.

Namibia's policy of gradually implementing full-cost pricing will create incentives for water conservation efforts and there have been several studies of the potential for water demand management. However, the water accounts indicate that this is unlikely to affect groundwater as much as other sources of water because groundwater is mainly abstracted by self-providers who already pay the full financial cost of supply.

National water accounts provide a useful overview, but water management is very much a geographically specific issue. It is often not economically feasible to transfer water from a seemingly low-value use to a higher-value use if these alternatives are separated by great distances. The new water accounts framework will provide the possibility for

[15] The time series of water accounts is too short to assess this trend, but when the new water accounting framework is finalized, a consistent set of water accounts will be available for nearly 10 years, providing a sound basis for assessing time trends.

considerable spatial disaggregation. This will allow accounting for specific water schemes—usually a combination of aquifer and catchment area—which will make it possible to assess the pressure on specific groundwater resources.

Finally, IWRM requires balancing the economic and technical components of water management with the social component. The water accounts could be expanded to better represent the social aspects of water, notably, the access to water by different social groups. Presently, only three categories of households are distinguished in the water accounts: urban, rural households in communal areas, and rural households on commercial farms. There is a great disparity of water access and use both geographically and within each category of household. The Social Accounting Matrix (SAM) that is in preparation and will have twelve categories of households can easily be expanded to incorporate the water accounts. This database will be especially useful for assessing the future water demand of different types of households, and the potential for water demand management within households, government and the private sector.

Chapter 7
South Africa's water accounts

7.1 Introduction

Under an initiative funded by the Natural Resource Accounting in Southern Africa (NRASA)[16] project, the first comprehensive national accounts for water resources in South Africa were produced in 2000 (CSIR, 2001). The first national water resource accounts built on and consolidated secondary information from various sources in one comprehensive set of physical and monetary accounts for the country for the period 1991– 1998.

Since then, environmental accounting became part of the regular functions of Statistics South Africa (StatSA), who undertook to periodically update water and other resources' accounts. StatSA carried out a follow-up study to apply the UN environmental accounting frame to water resources in the Upper Vaal Water Management Area (StatSA, 2002). While results of these earlier efforts to construct water accounts remain relatively preliminary, they have been used to inform water management and allocation policies and are currently adopted in integrated economic and environmental management models for qualitative policy analysis by CEEPA and the CSIR[17]. Currently StatSA has embarked on the production of updated, comprehensive national water resource accounts following the UN SEEA framework for water resource accounting (see chapter three for more details).

While groundwater was included in the first national water accounts, limitations on hydrological and economic data on groundwater resources precluded estimation of annual changes in groundwater stocks and its use. Recent efforts however, have been made to improve available data on groundwater resources and their use (Vegter, 1995; Baron et al., 1998; Seward and Baron, 2001). The present study focused on improving the information on groundwater in updated water accounts, drawing heavily on these new sources. The following section provides a summary of the structure and contents of existing physical water accounts updated with additional new information on groundwater resources. Section 7.3 synthesises existing monetary accounts for water resources in SA again, updated with recent information on groundwater. The final section concludes the chapter.

7.2 The physical water accounts

The first national water resource accounts produced physical stock and flow accounts summarising the pattern of water supply and use in the country for the 1991/92 – 1998/99 period. The following sections provide a synthesis of these early water accounts and supplement them with new information on the stock and flows of groundwater resources for selected time intervals.

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[16] The NRASA project was funded by the USAID Regional Centre for Southern Africa (RCSA) and focused on Namibia, Botswana and South Africa as its initial target countries with some pilot activities in Swaziland and Zimbabwe.

[17] Work on building and using economy-wide quantitative policy analysis models using environmental accounts in SA is currently in progress under a new collaborative research initiative between CEEPA, CSIR and the Institute of Environmental Studies at Vrije University, the Netherlands.

The first physical water accounts produced asset tables recording physical stocks of surface and groundwater. Surface water stocks were measured as average annual runoff into rivers and storage of surface water in dams and transfer schemes (exports and imports). The water asset accounts also provided information on potential and current groundwater yield. While these tables included the same key components of the SEEA classification of water assets, they reflected the annual yield of the system and could not establish opening and closing stocks (Appendix C). This however, is a common problem with the flowing nature of water resources, which receive similar treatment worldwide including the efforts in the three countries reported in this volume. As mentioned above, better stock information has become recently available for groundwater resources as provided below.

The physical flow accounts on the other hand, were based on pathways analysis tables tracing the pathways of water from initial sources through all uses to final disposition including evapotranspiration and return flows. Precipitation, runoff and groundwater were included as the primary natural sources of water in South Africa whereas return flows were considered a secondary source of water supply. Water users were grouped into three main categories: social, environmental and value adding. Water used by households (disaggregated as rural and urban) was considered a social use while water used by the rivers' system as in stream flow requirements was considered an environmental use. All other production activities such as agriculture, industry, mining and services were classified as value-adding users, which were further disaggregated in the accounts into specific economic activities following the standard industrial classification (Appendix C).

7.2.1 Water supply in South Africa: natural sources

Water supply information in the existing accounts is organised under two categories namely natural and institutional sources, which are discussed hereunder. Although South Africa uses surface and groundwater resources, the country relies heavily on surface water for the country's total supply of fresh water as explained below.

Surface water resources
According to the physical water accounts, the major source of fresh water supply in South Africa is surface runoff, which constitutes only a small share of the total annual precipitation. Table 7.1 shows that about 91% of the annual precipitation is lost to evapotranspiration and deep seepage and only the remaining 9% of rainfall forms the gross annual runoff, which flows into rivers and stored in a massive system of dams and water transfer schemes. The 9% represents the gross annual runoff, part of which supports river flows providing the in-stream flow requirements (IFR) of about 18 billion m^3. Annual runoff net of IFR includes two components:

- the surface runoff constituting about 70%; and
- the remaining 30% provides the base flow, which is also referred to as the underground component of river flow.

An elaborate system of water storage and inter-basin water transfer has been developed between a number of rivers providing the current fresh water supply in South Africa. While some of the rivers are entirely contained within the country, the most important rivers, which provide the largest portions of the country's water, are shared (the Orange, Limpopo and Komati). The physical stock accounts of South Africa are based on the

annual yield of the system with no distinction between ephemeral and perennial rivers. The total water storage capacity has steadily grown over the past decade and currently stands at more than 30 billion m^3 holding about 57% of all net annual runoff or water flow in 1998/99 (Table 7.1). Abstraction of groundwater contributes only about 3% of the total net annual water supply.

Table 7.1: Natural sources of water supply in South Africa (1991-1999)

	1991/92	**1994/95**	**1998/99**
1. Precipitation (billion m^3)	630.19	635.70	783.95
2. Evapotranpiration and deep seepage (billion m^3)	573.20	578.21	713.06
3. Gross annual runoff[a] in Billion m^3 (1–2) (% of precipitation)	56.99 (9%)	57.49 (9%)	*70.89 (9%)*
4. In stream flow requirements (IFR) in billion m^3	17.74	17.74	17.74
5. Net annual runoff (billion m^3) [b] (3 – 4)	39.25	39.75	53.13
% of total net annual water supply (row 7)	96%	96%	97%
3.1 Surface runoff (% of net annual runoff – row 5)	70%	70%	*68%*
3.2 Base flow[c] (% of net annual runoff – row 5)	30%	30%	*32%*
6. Groundwater supply (extraction) in billion m^3	1.45	1.45	1.45
(% of total net annual water supply – row 7)	*(3.2%)*	(3.5%)	*(2.7%)*
7. Total net annual water supply in billion m^3 (5 + 6)	40.70	41.20	54.60
8. Storage in dams (billion m^3)	29.97	30.13	31.28
(% of total net annual supply-row 7)	*(68%)*	*(73%)*	*(57%)*

a. Gross annual runoff measures water flow volumes after losses through evaporation and seepage
b. Net annual runoff measures annual yield of the natural water supply system after providing for in stream flow requirements
c. The base flow represents the groundwater component of river flow or net annual runoff.

Sources: CSIR, 2001; WSAM (DWAF, 2000a); Vegter, 1995; Baron et al. ,1998.

It is estimated that over the past five years more than 20 billion m^3 out of the average total supply of about 55 billion m^3 of water are used annually and about 15 billion m^3 more are also potentially available for use through the extensive water storage system[18]. The rest of the total annual supply (20 billion m^3) supports rivers' base flow and other natural leakages (CSIR, 2001).

[18] Note that annual runoff fluctuates significantly between years depending on the amount of rainfall, e.g. compare the wet year 1998 with earlier relatively low rain seasons.

Groundwater resources

As mentioned above, the first water accounts included an estimate of groundwater abstraction of 1.45 billion m^3 per annum and an estimate of groundwater yield potential in the water asset table (Appendix C).

One important feature of the hydrological linkages between surface and groundwater is the fact that groundwater supports a significant share of the net annual runoff as base flow (30% in Table 7.1). The base flow holds the river up, and without groundwater the river would be absorbed into the riverbed. Due to the complex hydrological relationship between base flow and river flow however, it is not possible to determine whether the base flow comes from deeper groundwater sources or from the river itself.

Recent hydrological research assessing the groundwater resources produced a comprehensive database on groundwater including a set of national groundwater maps. The said database and maps include among others, the following information on groundwater resources (Vegter, 1995 and1995a; Baron et al., 1998; Seymor and Seward, 1998; DWAF, 2000a):

1. Groundwater exploitation. National database and maps on dominant uses of groundwater including irrigation and municipal water supply schemes;
2. Groundwater storage and harvest potential;
3. Density of borehole data, which include borehole prospect, depth of groundwater level and strike frequency analysis;
4. Groundwater quality and hydrochemistry;
5. Mean annual groundwater recharge and borehole yield; and
6. Groundwater component of river flow.

The above studies estimated total groundwater stocks to be 24.5 billion m^3/annum (DWAF, 2000a), which amounted to 46% of total net annual runoff (surface water resources) in 1998/99 (Table 7.2). Due to engineering constraints however, not all this volume can be abstracted (some are inaccessible) and hence other measures of exploitable groundwater resources are often used. Groundwater annual recharge (AR) estimated as the mean annual recharge to groundwater stocks is one measure of potential groundwater resources available for abstraction (Vegter, 1995). AR is calculated as the sum of base flow and annual extraction (Table 7.2). The base flow however, provides a lower bound for groundwater annual recharge as some groundwater is usually lost through evapotranspiration along river courses, even in areas where there is no groundwater abstraction through boreholes. Another measure of potentially available groundwater resources is the harvest potential (HP)[19]. Baron et al. (1998) derived an estimate of an average annual HP of 19 billion m^3/annum for South Africa. Although the two measures (AR and HP) may lead to different estimates of the

[19] The HP is defined by Baron et al. (1998) to be the maximum volume of groundwater that may be abstracted per annum from an aquifer without depleting the aquifer. There are nevertheless, other alternative definitions for measuring HP depending on the scenario used to describe the interplay between groundwater in storage, recharge rates and time between recharge events (Baron et al., 1998). Hydrologists' definition of HP however, differs from the same term used by economists to mean exploitable potential rather than total potential.

groundwater potential, the Baron et al. (1998) estimate of HP compares well with the estimate of AR in Table 7.2, especially for the wet year of 1998[20].

Table 7.2: Groundwater physical accounts

	1991/92	1994/95	1998/99
1. Net annual runoff (billion m^3)	39.25	39.75	53.13
2. Base flow (billion m^3) [a]	11.78	11.93	16.87
3. Groundwater supply (extraction) in Billion m^3	1.45	1.45	1.45
4. Annual recharge (billion m^3) (rows 2+3)	13.23	13.38	18.32
5. Total groundwater stocks (billion m^3) [b]	17.07	17.28	24.48
% Of net annual runoff (row 1)	44%	44%	*46%*
6. Groundwater storage (billion m^3) (row 5 – row 2)	5.29	5.35	7.61
7. Net groundwater storage (billion m^3) (row 6 – row 3)	3.84	3.9	6.16
8. Exploitable groundwater potential (billion m^3) [b]	8.93	9.04	12.81
% of net annual runoff (Row 1)	23%	23%	*24%*

[a.] The base flow represents the groundwater component of river flow or net annual runoff (30% of net annual run-off).
[b.] Groundwater stocks measure the theoretically available groundwater whereas, exploitable groundwater potential measures utilisable groundwater that can actually be abstracted at reasonable costs.

Sources: CSIR, 2001; WSAM, (DWAF, 2000a); Vegter, 1995; Baron et al. ,1998.

It should be noted that both measures of groundwater total stocks and net annual runoff include the base flow of 16.9 billion m^3 in 1998/99. Groundwater storage can therefore be calculated by subtracting the base flow from groundwater stocks giving an estimate of potential groundwater resources in storage of 7.6 billion m^3/annum in 1998/99. Using this together with annual flow net of base flow derives an estimate of the total annual water supply in the country of 43.9 billion m^3/annum (7.6 ground water and 36.3 surface water). The share of groundwater resources in storage of this total annual water supply (excluding the base flow) is accordingly lower and becomes only 18% compared to the 46% when base flow is included as part of the total annual water supply. Net groundwater storage thus becomes gross storage minus annual extraction as calculated in Table 7.2.

[20] The large variation between the average annual HP estimate of Baron et al. (1998) and the AR estimates for the other years in Table 7.2 is an indication of the relatively dryer (lower rainfall) seasons of 1991/92 and 1994/5.

One should also note that not all groundwater in storage could be abstracted depending on various determinants of abstractability such as transmissivity[21] and water quality. Low transmissivity requires a large number of low yielding boreholes and low groundwater quality implies higher treatment costs. The abstractable amount of groundwater may be low in South Africa as the bulk of its groundwater resources are in secondary aquifers where water is contained mainly in fractures and pores in weathered rocks (Vegter, 1995). Accordingly, an exploitable groundwater potential of 12.8 billion m^3 was derived as the measure of the actual utilisable potential, which amounts to 24% of the total annual runoff in 98/99. Nevertheless, only about 11% (1.45 billion m^3) of the exploitable potential is currently abstracted.

The recent database on groundwater resources also includes information and GIS maps on other features of the resource (see Appendix 7.2) such as density of borehole data, borehole prospects (number, yield and strike frequency), depth of groundwater level, groundwater quality and exploitation (Vegter, 1995; Baron et al., 1998; Seymour and Seward, 1998; DWAF, 2000a).

As new information on groundwater stocks and exploitable potential in South Africa was only available for the 1998/99, this study applied simple ratio calculations to derive figures for the earlier period intervals. The 1998/99 ratio of groundwater storage to base flow of 1.45 was used to estimate groundwater storage for the other years, using available base flow figures. Similarly, the ratio of exploitable to total storage of 52% for 1998/99 was applied to the estimates of groundwater storage to derive exploitable groundwater potentials for the other periods.

7.2.2 Institutional sources of water supply

Various institutions supply water to different users at different levels. The Department of Water Affairs and Forestry (DWAF) and a large number of irrigation and water boards provide most of the bulk water supply. On the other hand, district councils and local authorities provide water supplies to end-users (domestic, industrial and services sectors). Self-providers of water provided about 9% of total water use from institutional sources in 1998 (Table 7.3). This category includes farmers, mining companies as well as abstraction of runoff by dry land agriculture and forest plantations.

7.2.3 Patterns of water use and flow accounts

The physical flow accounts, which are summarised in Table 7.4, show that productive activities account for ninety percent of the water use in South Africa. Agriculture contributes about 75% of total water use, most of which for irrigation farming. Total water use has increased by 2.3 billion m^3 or 13% between 1991 and 1998.

The expansion of consumption by value-adding activities, especially irrigation agriculture and manufacturing, was the major source of this growth adding 2.1 billion m^3, while household use contributed only 10% of the growth in total consumption.

[21] Transmissivity refers to the rate at which water is transmitted through rock body, usually expressed in m^3 per day.

Table 7.3: Institutional sources of water supply (1998)

	Billion m^3	% of total
A. Total supply by natural source		
Rivers	70.89	68.41
Dam storage	31.28	30.19
Groundwater	1.45	1.40
Total	*103.62*	*100*
B. Provision by institutional source		
Governments (DWAF & Irrigation Boards) [a]	1.82	11.98
Parastatals (WB, DC & local authorities) [b]	11.99	78.95
Self-providers [c]	1.91	9.07
Total	*15.72*	*100*

[a] Government suppliers include the Department of Water Affairs and Forestry (DWAF) and the Irrigation Boards; [b] Parastatals include the Water Boards (WB), District Councils (DC) and local authorities; [c] Self-providers include direct abstraction of runoff by dry land agriculture and plantation forests.

Source: Adapted from CSIR, 2001.

Table 7.4: Water use by end- use sectors (billion m^3 and of total use; 1991/92 – 98/99)

	1991/92	**1998/99**
Agriculture (% of total use)	13.43 (74%)	15.35 (75%)
Irrigation (% of agriculture)	9.61 (72%)	11.36 (74%)
Dry land[a] (% of agriculture)	2.88 (22%)	2.99 (20%)
Livestock (% of agriculture)	0.53	0.52
Other	0.41	0.49
Mining (% of total use)	0.53 (3%)	0.45 (2%)
Manufacturing (% of total use)	1.09 (6%)	1.22 (6%)
Trade & services (% of total use)	1.32 (7%)	1.45 (7%)
Construction (% of services)	0.05	0.04
Transport (% of services)	0.11 (8%)	0.13 (8%)
Electricity (% of services)	0.22 (17%)	0.24 (17%)
Other (% of services)	0.95 (72%)	1.04 (72%)
Households (% of total use)	1.77 (10%)	2.01 (10%)
Rural (% of total households)	0.77 (43%)	0.88 (44%)
Urban (% of total households)	1.00 (57%)	1.13 (56%)
Total water consumption	18.14	20.48
Per capita water use (m^3/person)	490	486
Per capita water use excluding agriculture (m^3/person)	127	122

[a] Dry land agriculture refers to incremental use by cultivated forests, sugar cane and other crops.

Source: Adapted from CSIR, 2001.

Per capita water consumption has seen a slight decline during the period 1991 and 1998, reflection the fact that population grew at higher rates (14%) than growth in water use (13%).

The earlier water accounts included an estimate of 1.45 billion m^3 of annual groundwater use (CSIR, 2001). Recent work however, generated new information on groundwater use (Seward and Baron, 2001). Table 7.5 compares the 1980-groundwater use estimates of DWAF (1986) and the results of this recent research on groundwater utilization (further details are given in Appendix 7.6).

Table 7.5 indicates an overall growth of 15.5% in groundwater utilisation between 1980 and 2001, mainly coming from significant growth in rural domestic use and municipal use, which include urban and industrial use. This rapid growth reflects the fact that most of the new water services extensions to rural households and towns came from groundwater. As recent research did not cover mining, mining has used the 1980-figures for groundwater use by mining for 2001 too.

Table 7.5: Groundwater use between 1980 and 2001 (in M m^3).

Use Sector	1980 (DWAF, 1986)	2001	% change
Stock watering (% of total)	100 (5.6%)	106 (5.1%)	6%
Irrigation agriculture (% of total)	1400 (78.2%)	1423 (68.8%)	1.6%
Rural communities (% of total)	120 (6.7%)	307 (14.9%)	156%
Municipal use (% of total)	70 (3.9%)	131 (6.3%)	87%
Mining (% of total)	100 (5.6%)	100 (4.9%)	0%
Total	1790 (100%)	2067 (100%)	15.5%

Source: Seward and Baron, 2001.

The new estimates of groundwater utilization indicate that about 19% of the exploitable groundwater potential is abstracted in 2001. However, the degree of utilization varied significantly among water management areas. Groundwater is most used in the Luvuvhu and Letaba area (71%) followed by the Fish (45%) and Limpopo and Olifants (36%), but lowest in Mvoti and Mzimvubu (only 2%) (See Appendix 7.6 for more details).

7.3 The monetary water accounts

The monetary accounts provide information on the contribution of water resources to value added and employment by use sectors as well as on other financial aspects of water use and allocation such as water charges and financial subsidies. This section summarises existing monetary water accounts indicators and attempts to analyse new information comparing water charges and tariffs structures currently applied in South Africa on water provided from surface versus groundwater sources.

7.3.1 Economic benefits from water resources

Summary information is extracted for selected time intervals from the first water resources accounts' study (CSIR, 2001) on the economic contribution of water resources in Table 7.6. The table shows the low value added generated per m^3 of water in agriculture compared to other high value economic activities. This is typical of agriculture worldwide and especially where irrigation constitutes a major component due to its water intensive nature compared to less water intensive sectors such as trade and services.

Table 7.6: Value added (in Rand) and employment in number of jobs/m^3 of water in South Africa

	1991/92	1994/95	1998/99

Agriculture	1.5	1.5	1.6
Mining	85.8	83.0	85.2
Manufacturing	105.3	109.3	107.7
Trade and Services	250.6	228.5	238.6
Average for economy Including agriculture Excluding agriculture	 31.2 167.0	 30.2 160.1	 29.3 165.3
Employment (jobs/m^3)	0.81	0.86	0.86

Source: Adapted from CSIR, 2001.

7.3.2 Water tariffs and financial subsidies

This study made an attempt to examine trends in bulk water tariffs applied to various users and to compare the structure of tariffs for users of water supplied from surface versus groundwater sources in South Africa (Table 7.7). The water tariff structure is based on estimates of delivery costs of supplying water from government water schemes, which include a basic charge covering operation and maintenance costs plus a catchment costs charge (DWAF, 2000b).

Tariffs charged on raw water supplied from groundwater sources were much higher than those charged on raw surface water supplies. While this may be a reflection of the relatively higher costs of water supply from groundwater sources compared to surface water, it is also believed to be an indication of a direct financial subsidy to users of surface water resources. One indication of the subsidy component is the fact that the tariff gap has significantly shrunk with recent movement toward cost recovery, especially for urban and industrial users where the ratio of groundwater to surface water charges dropped by about 60% from 3.23 to only 1.5 (Table 7.7). Tariffs on bulk water have in general, been gradually increased for both sources, which is reflected in a steady reduction of subsidies especially on water use for irrigation (figure 7.1).

Table 7.7: Change in water tariffs (Cents per m^3) applied to bulk water users in South Africa (1984-2000)

Year	Raw water supply for irrigation			Raw water for urban and industrial uses		
	Average	Groundwater	Ratio	Average	Groundwater	Ratio
1984/85	0.73	0.98	1.33	6.81	22.0	3.23
1987/88	0.94	1.40	1.49	13.33	27.0	2.03
1990/91	1.52	2.60	1.71	19.21	31.8	1.66
1993/94	1.71	3.50	2.05	24.37	43.9	1.80
1996/97	1.95	4.20	2.15	30.52	49.9	1.64
1999/00	5.49	6.90	1.26	37.69	56.7	1.50
% change/ year	43%	40%		30%	11%	

Source: derived from DWAF, 2000b.

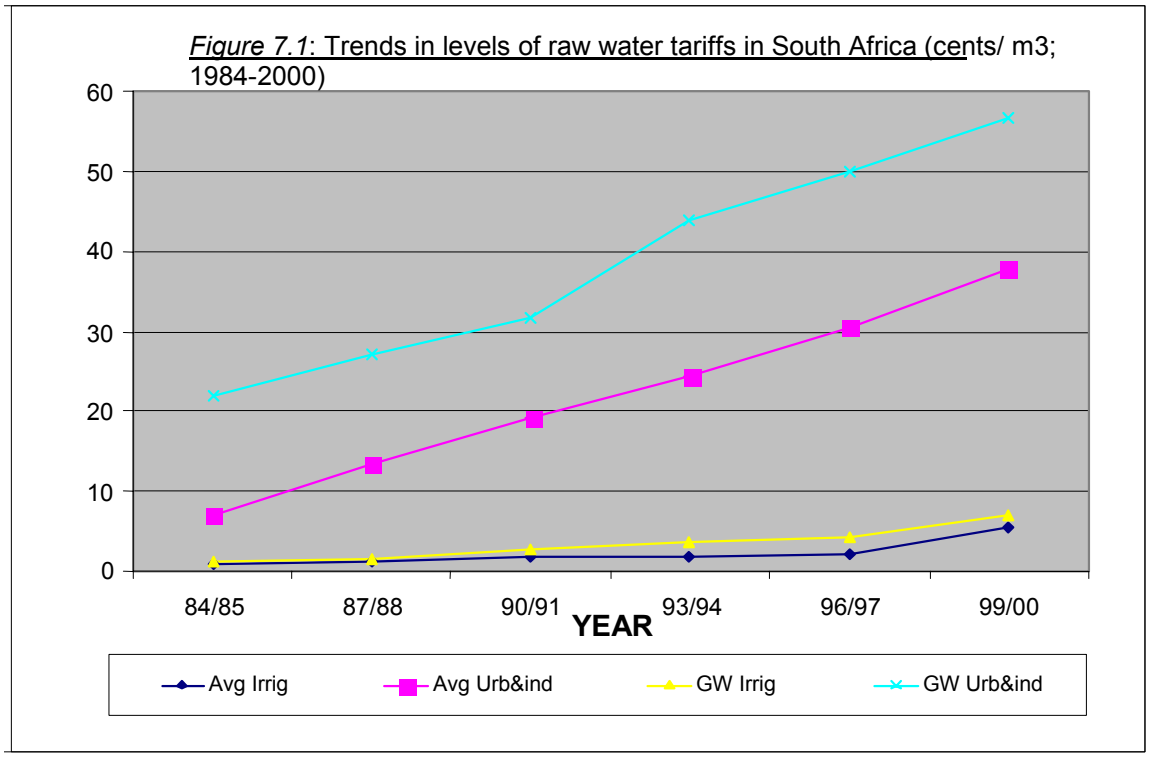


Figure 7.1: Trends in levels of raw water tariffs in South Africa (cents/ m3; 1984-2000)

7.4 Conclusions

Development and use of water resource accounts in South Africa is entering a relatively advanced stage as StatSa has now institutionalised the construction of environmental accounts in which water was accorded high priority. Earlier efforts to construct water resource accounts at both national and water management area levels have powerfully demonstrated the usefulness and value of the developed accounts in providing improved informing for water management decision making and policy design as they have been

used for various such purposes. StatSA is currently engaged in a major effort to update existing water accounts and address some of their shortcomings.

This study focused on improving the information on groundwater to update existing water accounts, drawing heavily on new sources. The study provided a synthesis of the structure and contents of existing physical and monetary water accounts updated with additional new information on groundwater resources. The syntheses presented above provided even more evidence for the importance and stronger motivation for continuing water accounting efforts to improve the formal statistics on and indicators of the state and trends in water resource stocks and the pattern of their use and allocation, which are very critical for shaping future water resources management in the country.

Chapter 8
Synthesis analysis of the study results

8.1 Introduction

The three Southern African countries that have been studied in detail (Botswana, Namibia and South Africa) have adopted the IWRM approach towards water management are in the process of implementing IWRM. This is, however, an arduous journey that has just started (see Arntzen, 2003 for a review of southern Africa). IWRM requires that supply and demand aspects need to be evaluated simultaneously and the advantages and disadvantages of different water sources need to be evaluated (e.g. surface water, ground water and return flows). Furthermore, it requires decentralised water resource management. Namibia and South Africa are in the process of decentralising water management to water-basin level, i.e. a river or aquifer basin. IWRM also implies that water is treated as an economic good, and that existing water management options are carefully considered and their costs and benefits weighed. Finally, IWRM requires participation from all stakeholders, in particular women.

Global climate change (GCC) will pose additional challenges to water management in southern Africa, as GCC is expected to adversely affect surface water through higher evaporation and lower rainfall in the drier parts of southern Africa. Lower rainfall is also likely to reduce recharge. It is therefore necessary to integrate GCC right from the start in IWRM, and to consider the resource implications of it.

The above may be some of the reasons as to why natural resource accounting (NRA) has rooted so well in southern Africa, and that water has been the first resource for which such accounts were prepared. NRA efforts are currently the responsibility of either national statistics offices (South Africa), resource ministries (Namibia) or environmental departments (Botswana). The selection of water for the preparation of the first accounts in each country demonstrates the strategic importance attached to water resources. However, the country studies demonstrate that the NRA potential for IWRM cannot be fully exploited at present due to data limitations. The progress that was made in the country studies demonstrates, however, that water accounts can be continuously improved, as new data become available or become better accessible through computerisation. Therefore, NRA efforts need to be an on-going exercise.

Each of the countries has prepared water accounts, and is up-dating the accounts (Namibia and South Africa) or has plans to do so (Botswana). As few other tools can do, water accounting contributes to integrated water resources management by:

- linking physical resource planning with economic growth and development patterns; and
- monitoring the amount, quality and use of water resources in time.

The country case studies show that the countries are in different stages of water account preparation. Botswana and Namibia pursue the same accounting model, but Namibia has revised and improved its accounting framework with the introduction of water transfers within the flow accounts (transfers of water among water providers) and consideration of waste water flows and stocks. Although it was not yet be possible to get

the new South African accounts for this report, the water accounts constructed by Stats SA will follow the SEEA accounts.

The initial accounts focused on flow accounts and several economic aspects of water supply, in particular subsidies and value added per $m^3$of water. Stock accounts were either absent or incomplete, and water quality aspects were largely missing. Surface water sources were generally better covered than groundwater resources. Since the initial water accounts were prepared, data availability has improved with respect to water quality and groundwater. In addition, computerisation of data has improved accessibility. Therefore, there was scope for the country studies carried out for this project to expand on the initial accounts.

This study has made the following contributions to the improvement of water accounts in southern Africa, particularly related to groundwater:

- provide a SEAA framework for improved stock and flow accounts that differentiate ground and surface water (chapter three);
- make a contribution towards the establishment of stock accounts, particularly for groundwater stocks, in three countries;
- linked hydro-geological information and data bases with economic uses of water (particularly in Botswana and Namibia);
- identify methods to systematically incorporate groundwater in stock and flow accounts; and
- assist with up-dating and improving the data basis of water accounts (particularly in Botswana).

Water resources conditions differ among the three countries. While Namibia and Botswana are predominantly (semi-) arid, South Africa has a wider range of climatic conditions. Surface water is extremely scarce in most of Namibia and Botswana except in a few perennial rivers and the Okavango Delta. It is therefore hardly surprising that groundwater meets over half of the demand in both countries (cf. less than 10% in South Africa). A comparison of basic water parameters in the three countries is given in Table 8.1.

Both Botswana and Namibia are increasing the share of surface water. While this strategy increases the diversity and balance of water sources, it also leads to greater vulnerability to GCC due to increased evaporation losses. The Botswana study found that current evaporation already exceeds consumption from reservoirs, and the situation may worsen in future. Groundwater stocks are poorly documented, and the available appear rough estimates. Particularly the Botswana figure is suspect. The estimate of abtstractable groundwater resources is more relevant for IWRM. An estimate of the abstractable amount was only possible for South Africa, but in Botswana attempts will be made to estimate this figure after discussion at the project workshop. There is need to develop accurate and reliable estimation methods for the region. The abstraction rate seems to be relatively low in comparison to recharge figures. While the risk of overall depletion of groundwater resources may therefore be fairly low, mining of groundwater may be a serious local issue, as demonstrated in particular in the Botswana study (chapter 5).

Table 8.1: Comparison of key water stock and flow parameters.

	Botswana	**Namibia**	**South Africa**
1. STOCKS			
Surface water			
Stored water	293 million m^3	Range from 105 to 469 million m^3 in period 1980-2002	30 billion m^3
Annual run-off in mm.	1.2 mm		45 mm.
Annual average rainfall		Long-term average of 321 mm. (1954-1994); range from 139 to 341 mm.	Long-term average of 488 mm
Total annual run-off	696 million m^3		55 billion m^3
Annual run-off of perennial rivers		Long term average of 53.9 billion m^3; range from 26.1 to 62 billion m^3 in period 1980-2000	
Annual run-off of ephemeral rivers		Range from 57 to 3988 M m^3 per annum in period 1980-2000.	
Groundwater			
Number of aquifers		14 major aquifers	
Number of well fields	30 developed; 13 proposed		
Total estimated stock	100 billion m^3	1.2 billion m^3	24.5 billion m^3 of which 7.6 billion m^3 is base flow to maintain rivers
Annual recharge in m^3	1.6 billion m^3	68.3 million m^3	18.3 to 24.5 billion m^3.
Exploitable groundwater potential		68.3 million m^3	12.8 billion m^3
2. FLOWS			
Groundwater/surface consumption ratio	0.56 (in 2001)	0.52	0.15
Agriculture Mining Manufacturing Trade and services Households		181 M m^3 27 M m^3 6 M m^3 9[a] M m^3 74 M m^3 in 1998	
Total water consumption	171 M m^3	297 M m^3	20.5 billion m^3
Per capita water use (m^3/person)	100	176 in 1998	486 (1998/99)
Per capita use, excluding agriculture (m^3/person)	60	69 in 1998	122 (1998/99)

[a] Government is included in services.

8.2 Groundwater and natural resource accounting

The initial accounts had a limited coverage of groundwater. The three country studies show that the strategic importance and role of groundwater differs between and within countries. The drier countries such as Namibia and Botswana strongly depend on groundwater while in contrast groundwater contributes to less than 10% of water use in South Africa. Groundwater is generally vital for the rural poor and for rural productive activities in areas, where surface water sources are non-existent or too expensive given the small-scale of the use. Agriculture, particularly livestock, and mining are particularly dependent on groundwater. Rural development will imply a growth of rural production, and put serious pressure on rural water sources, particularly groundwater.

None of the countries has developed comprehensive stock accounts. The 'model stock accounts' have been summarised in chapter 3. The major impacts of GCC on water stocks and flows can be traced through these accounts through changes in rainfall, evaporation and recharge. For groundwater stocks in the region, the following distinctions of stocks are pertinent:

- Shared water sources and domestic water sources. Use of the former is subject to regional and bilateral agreements, and therefore cannot be controlled by national water managers alone;
- Renewable and non-renewable groundwater resources. This distinction is incorporated into the model accounts through the recharge;
- Abstractable and non-abstractable water resources; and
- Different water qualities and wastewater.

The case studies showed that national groundwater accounts have limited meaning, and that sub-accounts for aquifers/ well fields need to be constructed. Such accounts could support water basin management, as currently pursued in South Africa and Namibia. From an IWRM perspective, three questions need to be answered:

1. How does abstraction compare with recharge over a period of time? If abstraction is systematically higher, groundwater is being mined, and alternative sources have to be identified.
2. What is the lifetime of the aquifer/ well field, and when do alternative sources have to be on-line?
3. What are the costs of groundwater abstraction in relation to surface water and what could be the costs of groundwater mining?

The country studies presented some answers for the first question. Groundwater mining does occur, certainly locally and in Botswana seemingly in most well fields. However, well field recovery is possible, either by resting of well fields (Botswana) or during high rainfall periods. Artificial recharge could facilitate recovery, and plans for artificial recharge are being mooted for Windhoek.

No definite answers emerged to the second question, as the stock of abstractable ground water resources is not known. The lifetime of the aquifer can be simply calculated as a non-renewable mineral[22]. It is important to fill this info gap as soon as possible. It proved also difficult to quantify trends in costs of groundwater abstraction

[22] The lifetime is the total stock divided by the annual abstraction in excess of the recharge.

due to lack of data. Evidence from the South African and Botswana studies suggest that –contrary to a commonly held view- the costs of ground water may not necessarily be higher than those of surface water. In South Africa, subsidies may have kept the costs of surface water artificially below the costs of ground water. In Botswana, the costs of water appear to depend on local factors such as the depth of ground water, the scale of the water supply systems and the distance to surface water sources. Qualitative evidence suggests that ground water costs are rising due to the need to drill more and deeper boreholes, and/or to develop auxiliary well fields. The increased supply of large villages with surface water is also an indication of ground water mining and rising costs. There is also evidence that the marginal costs of surface water are escalating (cf. Botswana's reservoirs). The costs of groundwater mining can be estimated by the costs of the cheapest alternative supply and or by the costs of lost development opportunities. Generally, groundwater depletion is expected to have rising costs. In the case of groundwater depletion associated with diamond mining, one could argue that the costs of groundwater depletion are relatively low, certainly in comparison with the huge financial revenues generated by diamond mining, and the absence of major alternative future developments of a similar scale other than livestock production.

Important IWRM and groundwater issues that emerged from the case studies include the following. Firstly, the currently used indicators for water scarcity lead to counter-intuitive results. Water scarcity is most serious in South Africa, and currently used water scarcity indicators suggest that Namibia and Botswana are not under immediate threat of water shortages. This finding calls for an urgent review of the indicators used. In the mean time, the indicators should be interpreted with much greater caution than presently exercised, based on a thorough understanding of local resource determinants.

Secondly, groundwater resources need to be classified into economically abstractable and non-abstractable resources. Part of the groundwater resources cannot be abstracted or the costs are prohibitive due to the hydro-geological characteristics of aquifers. To abstract all groundwater resources in an aquifer would require an incredibly dense network of boreholes, and obviously the costs of this would be very high. The relationship is explained in Figure 8.1. The top part of the figure refers to economically abstractically water resources. These can be subdivided into developed (block 1) and un-developed resources (block 2). The lower part of the figure refers to economically non-abstractable resources, i.e. resources that cannot be viable abstracted given the current technologies and water supply conditions (block 3). Technological development and changing water supply and demand conditions influence the size of each block. For example, new or cheaper technologies may increase the economic viability of water abstraction (smaller size of block 3), and may stimulate well field development (enlargement of block 1). IWRM managers are concerned with the size of blocks 1 and 2 in relations to surface water resources and water demand management options.

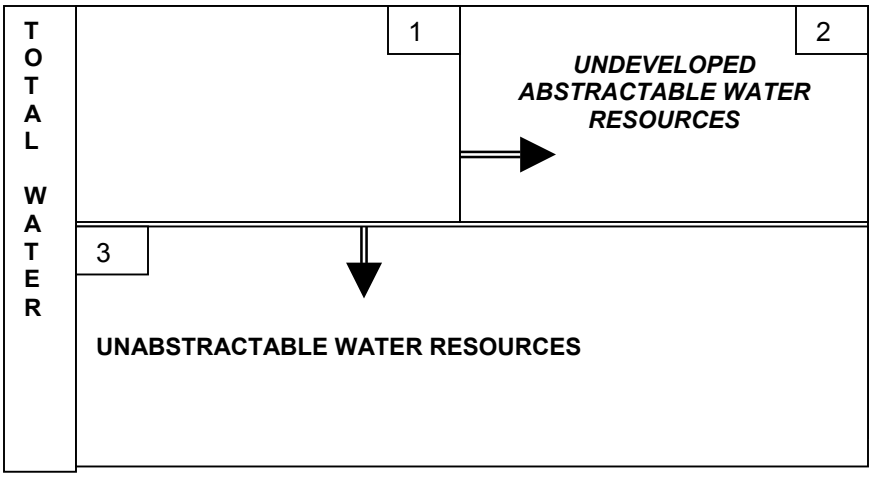
Thirdly, abstractable groundwater stocks should be further classified into:

- Renewable and non-renewable resources. The former determine the sustainable yields of aquifers, but both determine the actual lifetime of the well field;
- Shared and non-shared water resources. The former are aquifers whose water basins are shared by more than one country, and whose use is in principle[23]

[23] Until now, the implementation of the Protocol is restricted to rivers, but the Protocol covers groundwater resorces too.

verned by the Shared Water Course Protocol. Only Namibia seems to record its entitlement to shared (surface) water sources (cf. table 6.5)

Figure 8.1: Characterisation of groundwater resource stocks



Sources: based on Botswana project workshop and South Africa country study.

Fourthly, knowledge about groundwater is incomplete, but more information is available than hitherto used in Natural Resource Accounting. Additional research and computerisation of data sets have improved data accessibility. Countries such as Botswana and Namibia have a national aquifer potential map, but hydro-geological characteristics and quantitative data on recharge are only available for areas where well fields have been developed or are being explored. Recharge rates and water depth fluctuate substantially from year to year, and it is therefore important to monitor long-term trends. The developed resources are only part of the groundwater resources, hence restriction to these resources lead to under-estimates of the total available resources. Some groundwater data are improving and becoming more accessible. In Botswana for example, the department of Water Affairs has stored well field data in a computerised system WELLMON. This offers opportunities to improve ground water accounts as well as to make ground water databases more relevant. Areas for improved ground water data monitoring include the water quality, recharge figures, estimates of the total abstractable stock and cost and revenue figures. It is vital to develop methods to estimate groundwater stocks, by type as indicated in Figure 8.1.

Fifthly, it is necessary to develop sub-accounts by well field or aquifer. An example is given in Table 8.2. Sixthly, water quality is important for groundwater accounts, particularly with respect to salinity in arid areas. Pollution poses mostly local problems (e.g. Botswana). Water quality concerns can be incorporated at the aquifer as well as national level, as the example of Table 8.3 shows. Out of the total abstractable amount of groundwater, 125 million m^3 is suitable as drinking water while a third can only be used for non-human and livestock consumption. Aquifer pollution would lead to a reclassification, i.e. downgrading, of the aquifer.

Table 8.2: Stock account by aquifer (year 1-4)

		Year 1	Year 2	Year 3	Year …
Opening volume					
	Abstraction (-)				
	Return flows from economic uses (+)				
	Recharge from precipitation (+)				
	Net natural inflows, outflows and transfers (+/-)				
	Other changes to volume of reserves (+/-)				
Closing volume					

Source: see chapter 3.

Table 8.3: Groundwater stock by water quality level (2003; million m^3)

	Highest level: drinking water	Highest level: suitable for livestock	Highest level: irrigation/ other uses	Total water resources
Aquifer 1	100			100
Aquifer 2	0	50		50
Aquifer 3		25		25
Aquifer 4			100	100
Aquifer …	25			25
Total	125	75	100	300

The better integration of water and groundwater data sets would permit the preparation of tables such as 8.2.

Seventh, the literature review on the impacts of global climate change on water resources (chapter four) showed that details of the implications of global climate change on the region's and nations' water resources, particularly for ground water, are still inadequately understood despite on-going research efforts such as those at the University of Natal. However as the GCC scenarios for southern Africa appear to be pessimistic for the drier parts of southern Africa, it is important to take into account the possible impacts of GCC on water resources. Temperatures will increase, so does evaporation, reducing the effectively available rainfall and run-off. The non-linearity of GCC-related processes poses the largest challenges:

- a small temperature raise will lead to a much larger increase in evaporation; and
- a small change in rainfall will probably lead to a much larger reduction in recharge.

The NRA framework offers opportunities to trace the GCC impacts on water stocks and flows, and this should be incorporated into on-going activities to up-grade and up-date the national water accounts.

Finally, while water is increasingly treated as an economic good at the policy formulation level, absent and non-accessible cost data demonstrate that this aspect of IWRM is not yet really implemented. The countries emphasise the need for greater cost recovery, but

do not have sufficient data to compare different IWRM options such as the development of additional well fields, construction of a dam and water demand management practices. The limited data from the case studies show that water costs per m^3 vary substantially from region to region, and from supplier to supplier. In Botswana, the costs of surface water supply have increased rapidly due to the new long distance water transfer scheme. Determinants of unit water costs include the scale of the reticulation system, transport and storage costs, depth of groundwater and well field characteristics such as yields. Therefore, there is need to collect and analyse water expenditures and revenues in much more detail.

8.3 Towards scenarios for IWRM and groundwater management

Two countries (Botswana and Namibia) are heavily dependent on groundwater resources, and both have successfully reduced this dependence to around 50%. In stark contrast, South's Africa's groundwater resources make up less than 10% of consumption. In all countries, rural residents, mines outside large settlements and agriculture are large groundwater users. Moreover, pressure is mounting to development the non-agricultural rural productive sector, putting more pressure on rural water resources. Finally, the country case studies showed that the opportunities for conjunctive use of ground and surface water are increasing due to the establishment of water distribution networks that are fed by both surface and groundwater sources.

Global climate change should be viewed as an important *additional* factor that needs to be taken into account in IWRM. Given the prevailing poverty, lack of development and unmet water and sanitation goals, particularly in rural areas, economic growth and development should be the core of any IWRM scenario. In addition, population and health issues (e.g. migration, population growth, impacts of HIV/Aids) are critical for the question how much and where water is needed and where water demand management opportunities will emerge. With the drive for regional integration under SADC and programmes such as NEPAD, solutions should no longer be pursued at the purely national level. Southern Africa has the institutions and expertise in lace to benefit from regional and national solutions to IWRM issues.

Therefore, IWRM scenarios need to distinguish the following clusters of variables:

- Economic growth and development; economic growth, economic structure, formal and informal economies
- Rural development: provision of rural services for people; provision of service for rural productive activities (e.g. clusters of serviced areas);
- Population growth and distribution: growth rate, urbanisation, age structure, health issues;
- Global climate change: for example, temperature, evapotranspiration, rainfall changes, changes in recharge;
- Policy issues and implementation (economic development policies, water resources and general environmental policies, macroeconomic policies, costs recovery policies);
- Regional economic integration and specialisation; economic development and specialisation based on comparative water advantages, virtual water trade, etc.

Table 8. 4 starts to explore contours of different IWRM scenarios with regional and national components. For each component, the table explores some critical variables as well as the possible impacts on ground water and surface water sources. Especially the nation-wide impacts can be traced through water resources accounts. Sub-national and local impacts can at present not yet easily be incorporated as they require, for example aquifer based or river basin accounts. It is important to start NRA work at this level.

Table 8.4: Core elements of future IWRM and GCC scenarios for southern Africa.

Key variable	Sub-variable	Possible groundwater impact	Possible surface water impact
Global climate change	Higher temperatures		Higher evaporation; reduced reservoir yields
	Changes in rainfall	Small rainfall changes lead to larger recharge changes. In areas that will face lower rainfall, recharge is expected to decrease, and renewable GW resources to diminish	Higher rainfall will lead to higher run-off, but this cannot be quantified; Lower rainfall leads to lower run-off and reservoir yields, but the impact cannot be quantified
Economic development	Mining-led growth	Mining expansion is expected to lead to higher GW consumption, and local depletion or mining	
	Inheritance of past economic growth and development	GW-mining and reduced groundwater resources (amount unknown); mostly local impacts	
	Agricultural transformation based on comparative advantages	Shift towards livestock production in large parts of South Africa. Increased consumption, but low risks of GW mining and low opportunity costs	Movement of irrigation to northern parts of southern Africa, releasing substantial amounts of water for households and other productive uses
	Higher incomes	Rapid growth in water consumption, putting more pressure on aquifers around major rural settlements	Rapid growth in water consumption, putting more pressure on reservoirs
	RD zones with basic infrastructure for agriculture and for non-agricultural productive activities	Extra demand on ground water; Risks of ground water pollution	Demand for rural dams
Policy issues and development	Urbanisation	In selected cases (e.g. Windhoek) urbanisation will lead to increased GW consumption and artificial recharge.	Urbanisation will put pressure on surface water and water transfer schemes.
	Increased cost recovery and lower water subsidies	More expensive groundwater, reduced use by irrigation, and agriculture and incentives for water conservation Nation-wide impact	Higher water charges, incentives for more efficient use.
	Boosting rural production	Pressure on groundwater resources in areas with Rural Production Zones	
Population growth		Lower than proportional increase in water consumption	Lower than proportional increase in water consumption
Regional integration	Economic specialisation and trade based on water	Reduction of water demand in water scarce areas	Reduction of water demand in water scarce areas

	endowments		

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