MINING, MINERALS AND
SUSTAINABLE DEVELOPMENT
PROJECT, SOUTHERN AFRICA

AN OVERVIEW OF THE IMPACT OF MINING AND MINERAL PROCESSING OPERATIONS ON WATER RESOURCES AND WATER QUALITY IN THE ZAMBEZI, LIMPOPO AND OLIFANTS CATCHMENTS IN SOUTHERN AFRICA

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AN OVERVIEW OF THE IMPACT OF MINING AND MINERAL PROCESSING OPERATIONS ON WATER RESOURCES AND WATER QUALITY IN THE ZAMBEZI, LIMPOPO AND OLIFANTS CATCHMENTS IN SOUTHERN AFRICA

EXECUTIVE SUMMARY

The original Terms of Reference for this study (**Research Topic 4**) were extremely broad and required an overview of all mining impacts on the biophysical environment throughout southern Africa. Though this objective was desirable, and would provide an excellent background for management strategies in each of the SADC countries, it was unrealistic in view of the time and budget constraints. Therefore, the main focus of this research topic was restricted to water resources, in particular water quality, and attention confined to three key river basins, namely the Zambezi, Limpopo and Olifants basins. Whilst the revised Terms of Reference remain challenging, they represent a compromise that enabled a useful body of work to be produced.

The Project Team who conducted the investigation and report writing for Research Topic 4 comprised the following individuals:

- Dr Peter Ashton – CSIR-Environmentek, South Africa – Research Co-ordinator and Project Manager;
- Mr David Love – Mineral Resources Centre, University of Zimbabwe – Principal Investigator;
- Professor Paul Dirks – Mineral Resources Centre, University of Zimbabwe – Project Supervisor and Reviewer (Zimbabwe sector); and
- Ms Harriet Mahachi – Mineral Resources Centre, University of Zimbabwe – Assistant Investigator.

This report provides an overview of the impacts that mining and mineral processing activities have had, or are likely to have, on the water resources (in particular, water quality aspects) of the Zambezi, Limpopo and Olifants river basins. The report is the output of a collaborative research process involving scientists from CSIR-

Environmentek, South Africa, and the Mineral Resources Centre of the University of Zimbabwe, and forms part of the MMSD SOUTHERN AFRICA project.

The report has been structured into eight sections to provide a logical framework for synthesis of the information and to facilitate transfer of insights, conclusions and recommendations to stakeholders.

The different types of typical chemical and physical impacts associated with diverse mining and mineral processing operations are described to provide an overview of the specific types of impacts that are normally associated with the mining or processing of specific minerals. In several cases, it was difficult to determine the specific impact exerted by a mining operation, because the impact(s) also depended on the degree of management control exerted during mining. Based on defined criteria, the impacts of mining and mineral processing operations were classified into high, medium and low impacts. These descriptors were then used to describe the scale and variety of impacts linked to mining activities in each of the sub-catchments.

Within the time and budget constraints of this Research Topic, it was not possible to collect high quality quantitative data for each of the three river basins. Indeed, it was difficult to obtain water quality data for Botswana, Malawi, Mozambique and Zambia and there was some sensitivity regarding possible misinterpretation of the few data available for South Africa and Zimbabwe. Nevertheless, despite these constraints, it was possible to estimate the extent and variety of historical and current mining and mineral processing operations within each sub-catchment for each river basin. This information allowed the Project Team to derive qualitative or semi-quantitative estimates of the probable extent of any impacts on water resources and water quality, based on existing information and professional judgement. These were described briefly in terms of both their potential severity and the spatial scale of the area they would be likely to affect.

In addition to this system of qualitative descriptions, attention was also paid to evaluating whether or not a series of impacts within a single sub-catchment could interact or combine to exert a greater, cumulative effect on water resources and water quality. In some cases, the cumulative effect of a group of otherwise relatively "low-" or "medium-scale" impacts from individual mines in a single catchment can be seen as a dramatic increase in both the severity and extent of adverse impacts exerted on catchment water resources and other water users. In such cases, remediation often requires concerted management attention from the mines concerned, as well as the relevant water authorities. Wherever possible, available water quality data were used to substantiate descriptions of impacts.

Data for mining operations located in Zimbabwe and South Africa were restricted to those mining operations that had achieved a minimum production specific to each commodity. This process of selection was not possible for other basin states due to the scarcity of data; all mining operations identified for the Angola, Botswana, Malawi, Mozambique, Namibia and Tanzania sectors of the Zambezi and Limpopo basins were located on appropriate maps.

For all three of the river basins, numerous mining operations have been closed, abandoned or not proceeded beyond initial prospecting and feasibility assessments. Unless these operations were likely to have a significant impact on water resources and water quality in their immediate vicinity, these operations were not dealt with.

The study has confirmed the diverse array of mining and mineral processing activities that take place in the Zambezi, Limpopo and Olifants basins. The extent and severity of the impacts is dependent on the commodity exploited, the size of the facility, the climatic region in which the facility is situated and the efficiency and effectiveness of management control. The variety and extent of impacts in the three river basins has been segmented into the individual sub-catchments making up each basin. The overall impacts within each basin are then summarized for clarity.

Several generic and specific conclusions were formed on the basis of the material examined during this study and are reported in **Section 6**. Based on these conclusions and the supporting information, specific recommendations have been listed in **Section 7**. These recommendations (**Table 7.1**) are listed here for convenience.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

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In Zimbabwe:

- Mr Gambara, Assistant Chief Mine Engineer at the Mine Ventilation and Environmental Control Offices, Ministry of Mines and Energy, Gweru;
- Ms Zimba, Head Office, Zimbabwe National Water Authority (ZINWA);
- Ms Matenga, Manyame Catchment Council, Zimbabwe National Water Authority;
- Ms Danda, Geology Department, University of Zimbabwe;
- Ms Mabvira, Geology Department, University of Zimbabwe;
- Dr Love, Chemistry Department, University of Zimbabwe;
- Ms Mutambirwa, Southern African Regional Documentation Centre;
- Mr Ian Wylie, Executive Director: Rio Tinto Zimbabwe Limited; and
- Mr Eric Booth, Group Manager: HSE Affairs, Rio Tinto Zimbabwe Ltd, Kadoma.

In South Africa:

- Mr Peter de Wet, Geological Information Systems Manager, Exploration and Acquisitions Division, Anglo American plc, Johannesburg;
- Mr C.J. Vorster, Database Manager: South African Mineral Deposits Database (SAMINDABA), Council for Geoscience, Pretoria;
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- Mr Mike King, Manager: Exploration, Richards Bay Minerals, Richards Bay;
- Mr Adrian van Tonder, Manager: EHS, Richards bay Minerals, Richards Bay;
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1. INTRODUCTION AND BACKGROUND INFORMATION

1.1 Introduction

The Mining, Minerals and Sustainable Development Project (MMSD) is an independent, participatory project aimed at understanding how the mining and minerals sector can best contribute to the global transition towards sustainable development. The enormous diversity of views and definitions of "sustainable development" have created considerable uncertainty in the minds of many people. In an effort to reduce some of this uncertainty and provide greater focus and cohesion for the research teams, the final MMSD report will provide greater clarity on what is implied by the term "sustainable development", as well as precise recommendations on how the sector can best contribute to the global transition towards this ideal.

The range of views and issues amongst different groups and individuals across the world prompted the project originators to launch six MMSD Projects in different geographical regions. The MMSD southern African regional project (MMSD SOUTHERN AFRICA) is one of these six projects and addresses issues important to the mining and minerals processing sector in southern Africa. In the context of this project, southern Africa has been taken as the twelve mainland African countries forming the Southern African Development Community, namely (in alphabetical order): Angola, Botswana, Democratic Republic of Congo, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Tanzania, Zambia and Zimbabwe.

The primary objective of MMSD SOUTHERN AFRICA is to place the mining and minerals processing sector in southern Africa within the context of the stated SADC goals for sustainable development, as outlined in **Text Box 1.1**, below.

> The goals for sustainable development in the Southern African region are to:
> - Accelerate economic growth with greater equity and self reliance;
> - Improve the health, income and living conditions of the poor majority; and
> - Ensure equitable and sustainable use of the environment and natural resources for the benefit

Text Box 1.1: Goals for sustainable development in southern Africa.

The context provided by acceptance of the defined goals for sustainable development in SADC countries (above) precludes the necessity to become engaged in the protracted debates that surround the numerous definitions of sustainable development. Concentrating on the generic concepts or principles of sustainable development will ensure that MMSD SOUTHERN AFRICA has regional relevance as well as applicability to the mining and minerals processing sector. However, in addition to the three primary principles listed in **Text Box 1.1**, the transition towards sustainable development within the SADC region also requires stakeholders to:

- Actively contribute to processes and structures that support good governance;
- Participate in initiatives aimed at strengthening regional co-operation; and
- Recognize that the profits gained at the expense of environmental or social systems are short-term and therefore non-sustainable.

Within the MMSD (SOUTHERN AFRICA) framework, six critical issues were identified as research topics during a series of stakeholder meetings. Each of the six MMSD SOUTHERN AFRICA research topics is addressed in separate studies undertaken by research teams drawn from organizations in different SADC countries. One of these issues, Research Topic 4, "*the impact of mining and mineral processing activities on the biophysical environment*", forms the focus of this report. In the context of the MMSD project, the "biophysical environment" was taken to include all aspects of the natural environment, and excluded aspects that dealt specifically with social, economic, institutional and governance issues taken up in the other research topics.

1.2 Terms of Reference

The original Terms of Reference for this study (Research Topic 4) were extremely broad and required an overview of all mining impacts on the biophysical environment throughout southern Africa. Though this objective was highly desirable, and would provide an excellent background for management strategies in each of the SADC countries, it was unrealistic in view of the time and budget constraints imposed. Therefore, the main focus of this research topic was restricted to water resources, in particular water quality, and attention confined to three key river basins. The essential elements of the revised Terms of Reference for Research Topic 4 are shown in **Text Box 1.2**, with details of the actual scope of work to be covered. Whilst the revised Terms of Reference are still challenging, they represent a constructive compromise that will enable a useful body of work to be produced.

1. Background

The objective of this study is to determine how **biophysical environmental impacts associated with the mining and minerals sector** can be managed in line with sustainable development in Southern Africa.

This work must be undertaken within the context of sustainable development provided by the MMSD SOUTHERN AFRICA document: "Locating The Mining and Minerals Sector Within The Southern African Vision For Sustainable Development"*.*

2. Scope of Work

- The report will provide an introductory, broad-brush overview of the types and significance of impacts associated with the mining and minerals sector in southern Africa;
- This will set the scene for the main emphasis of the report, namely: a close focus on impacts on the water environment;
- The focus on the water environment will be further restricted to focus on three specific catchments in southern Africa, namely: the Zambezi, Limpopo and Olifants basins;
- Close attention will be paid to the approaches that are in use across the SADC region to manage and mitigate impacts on the biophysical (and especially water) environment;
- The report will pay close attention to the various methodologies such as stakeholder engagement processes, statutory requirements, and best industry practices, to achieve good environmental performance;
- The key success factors, as well as the principles and guidelines that guide management actions, will be highlighted; and
- Recommendations will be made as to the roles, responsibilities and accountabilities of key stakeholders in the process

Text Box 1.2: Key elements of the Terms of Reference for Research Topic 4.

The specific Terms of Reference for all six MMSD SOUTHERN AFRICA research topics are listed on the MMSD SOUTHERN AFRICA website shown above (**Text**

Box 1.2). Each research team is required to ensure that the emphasis of their work is directed towards helping stakeholders understand how the mining and minerals processing sector in southern Africa can best contribute to the region's transition to sustainable development. Whilst it is imperative to identify the variety and scale of impacts exerted by the mining and minerals processing sector on the environment, it is then equally important to determine the most appropriate ways to minimize and manage these impacts.

1.3 Approach to the project

1.3.1 Project team

The Project Team who conducted the investigation and report writing for Research Topic 4 comprised the following individuals:

- Dr Peter Ashton – CSIR-Environmentek, South Africa – Research Co-ordinator and Project Manager;
- Mr David Love – Mineral Resources Centre, University of Zimbabwe – Principal Investigator;
- Professor Paul Dirks – Mineral Resources Centre, University of Zimbabwe – Project Supervisor and Reviewer (Zimbabwe sector); and
- Ms Harriet Mahachi – Mineral Resources Centre, University of Zimbabwe – Assistant Investigator.

Project Team members from the Mineral Resources Centre at the University of Zimbabwe focused on the Zimbabwean sectors of the Zambezi and Limpopo basins; the remaining portions of the Zambezi, Limpopo and Olifants basins were dealt with by the CSIR-Environmentek researcher.

1.3.2 Information collection

The time and budget constraints placed on this research topic necessitated a very structured and tightly controlled approach to achieving the respective objectives within the time allowed. This required members of the Project Team to focus attention only on the most relevant and important information that was readily available, and precluded large data gathering campaigns to collect new data.

In view of these constraints, most attention was focused on:

1. Structured interviews with selected individuals who have long experience with general water management issues in the mining and minerals processing sector;
2. Consultations with a few key stakeholders in the mining industry to obtain information related to specific mining operations in the selected river basins;
3. Consultations with key stakeholders in relevant Government departments who are concerned with water resource management and pollution control to obtain information related to the three river basins investigated;
4. Retrieval of information and policy documents available from the SADC Mining Sector Co-ordinating Unit website;
5. Retrieval of information from Internet sites maintained by major mining companies that are active within the three river basins under investigation;

6. Literature searches of large databases containing references to mining and minerals processing activities, as well as to water management activities;
7. Retrieval of maps and specific published information relating to the location and size of mining operations in the Zambezi, Limpopo and Olifants basins, as well as any details of their water management practices;
8. Consultation with the SAMINDABA Minerals Database Manager at the South African Council for Geoscience to obtain the latest available information on the location, size, and materials produced by operating mines in the South African sector of the Limpopo and Olifants river basins;
9. Discussions with knowledgeable individuals who have long experience with assessing and managing the impacts of mining and minerals processing operations on the biophysical environment;
10. Compilation, synthesis and integration of information contained in scientific and technical publications on the mining and minerals processing sector; and
11. Professional judgement of the members of the Project Team.
12. In Zimbabwe, staff members of the Mineral Resources Centre held meetings and discussions with various persons and experts, notably:
    - Mr Gambara, Assistant Chief Mine Engineer at the Mine Ventilation and Environmental Control Offices, Ministry of Mines and Energy, Gweru;
    - Ms Zimba, Head Office, Zimbabwe National Water Authority;
    - Ms Matenga, Manyame Catchment Council, Zimbabwe National Water Authority;
    - Ms Danda, Geology Department, University of Zimbabwe;
    - Ms Mabvira, Geology Department, University of Zimbabwe;
    - Dr Love, Chemistry Department, University of Zimbabwe; and
    - Ms Mutambirwa, Southern African Regional Documentation Centre.
13. Consideration and classification of the potential impacts of each type of mining or minerals processing operation on the Zambezi and Limpopo catchments;
14. Discussion of the potential impact of mining and minerals processing operations on each sub-catchment within the Zambezi and Limpopo catchments and implications for water quality and quantity management; and
15. Discussion of the general impact of mining and minerals processing operations on each catchment as a system.

1.3.3 Disclaimer

In compilation of this report, specific attention should be given to the disclaimer given by the Mineral Resources Centre, University of Zimbabwe, relating to the information provided for Zimbabwe. It is reproduced in full, below.

Considering the tight timing and budgetary constraints of the project no original fieldwork, field verification or sampling has been possible. The data presented has therefore been restricted to that readily available in the public domain, along with some confidential data supplied under specific confidentiality agreements. Data sources have been quoted in all instances.

All data contained in this report have been compiled and are presented by the MRC in good faith. The MRC can make no guarantees as to the completeness and accuracy of the data supplied. Inferences made in the course of this report, especially those relating to potential impact are meant as an attempt of assessing the situation on the ground. They should not be construed as statements of fact or allegations of misconduct.

The MRC cannot be held responsible for any conclusions made or actions taken by the client based on data presented in this report.

In addition, it is important to note that the time and budget constraints limited the ability of the Project Team to provide a complete picture of every aspect of mining-related impacts on the water resources of the three river basins considered. In particular, very little information was available for mining-related activities in the Angola, Malawi, Tanzania and Mozambique sectors of the Zambezi basin. Nevertheless, in the professional opinion of the Project Team members, sufficient information could be compiled and synthesized to provide an overview that would meet the requirements set out in the Terms of Reference for this research topic.

1.3.4 Estimation of impacts

The impact of a particular mining or minerals processing operation on the biophysical environment can take the form of either or both chemical and physical impacts. Chemical impacts include changes in acidity or alkalinity levels, and the release of arsenic, mercury and other heavy metals, and the release of cyanide from gold mining operations. These impacts are mainly the result of treatment of ore. Additional impacts occur as the result of washoff of chemicals deposited onto the catchment surface from dusts, vapours and gases emitted from mining operations. Typical physical impacts on the biophysical environment include: salinization, siltation (increased levels of suspended and deposited solids), changed patterns of water use, the excavation of large pits, the diversion of rivers and streams from their original courses, and deforestation / de-vegetation of sites.

The different types of typical chemical and physical impacts associated with different mining and mineral processing operations are shown in **Table 1.1** and **Table 1.2**, respectively. These descriptions provide an overview of the specific types of impacts that are normally associated with the mining or processing of specific minerals. In several cases, it is difficult to determine the specific impact exerted by a mining operation, because the impact(s) will also depend on the degree of management control exerted during mining. The criteria used to segment impacts into "high", "medium" or "low" categories are given in **Table 1.3** for each mining type.

Chemical impacts relate mostly to waste rock and low-grade ore dumps, which are present at all sites, and to chemical treatment, with associated tailings dams, which are present at many mining sites. A wide variety of chemical impacts are possible and these can include acid mine drainage, the less common alkaline mine drainage, the release of highly toxic metals (most notably arsenic, antimony and mercury), the release of heavy metals, such as nickel, copper, cobalt, lead and zinc, and the release of cyanide from gold mining operations.

Physical impacts on water resources include the use of water for a variety of mining operations, siltation of water courses by contribution to suspended solids loads, salinization by contribution to dissolved solids loads, the creation of large pits (that act as rain water traps), diversions of watercourses and sometimes associated extensive deforestation or de-vegetation of mine sites with concomitant erosion problems. The area affected can be segmented into three typical classes or groups, namely: the mine environs only (typically consisting only of the mine property), the local area (one or more properties that are adjacent to the mine property), or more widespread (regional).

On the basis of these impacts, mining and mineral processing operations could be classified into high impact, medium impact and low impact, as shown in **Table 1.3**. These descriptors were then used in descriptions of the scale and variety of impacts linked to mining activities in each of the sub-catchments.

Within the time and budget constraints of this Research Topic, it was not possible to collect and determine high quality quantitative data for each of the three river basins. Indeed, it was difficult to obtain water quality data for Botswana, Malawi, Mozambique and Zambia. In contrast, some water quality data could be obtained for South Africa and Zimbabwe, though there was some sensitivity regarding possible misinterpretation of these data. Nevertheless, despite these constraints, it was possible to derive an estimate of the extent and variety of historical and current mining and mineral processing operations within each sub-catchment for each river basin. This information allowed the Project Team to derive a qualitative or semi-quantitative estimate of the most probable extent of any impacts on water resources and water quality, based on existing information and professional judgement. These impacts were described briefly in terms of both their potential severity and the spatial scale of the area they would be likely to affect.

Where possible, identified impacts were segmented into direct effects of the mining or mineral processing activities, and indirect effects that arise as a result of ancillary activities linked to the mining operations. For example, mine housing developments with their associated water supply and sanitation systems, as well as clearing of land and planting of crops for food cultivation by the families of mineworkers, are considered to be indirect impacts associated with mining operations. In contrast, the water required for mine processes, dust suppression and hydraulic transport of tailings or other waste materials, as well as any effluent seepages or discharges, would be considered to be direct impacts of mining. The qualitative system of impact descriptors is described in **Table 1.4**.

In addition to this system of qualitative descriptions, attention was also paid to evaluating whether or not a series of impacts within a single sub-catchment could interact or combine to exert a greater, cumulative effect on water resources and water quality. In some cases, the cumulative effect of a group of otherwise relatively "low-" or "medium-scale" impacts from individual mines in a single catchment can be seen as a dramatic increase in both the severity and extent of adverse impacts exerted on catchment water resources and other water users. In such cases, remediation often requires concerted management attention from the mines concerned, as well as the relevant water authorities. Wherever possible, available water quality data were used to substantiate descriptions of impacts.

Table 1.4: Explanation of the management implications associated with the qualitative system of impact descriptions used in this study.

Descriptor	Type and Extent of Impact
Very large / Very high	Impacts are considered to be very serious and require continual management attention; Impacts often consist of gross damage or disturbance to water resources and aquatic ecosystems, rendering these unfit for other water users and requiring extensive remedial actions; Impacts often extend for considerable distances from the site of origin.
Large / High	Impacts are considered to be serious and require frequent management attention and remedial actions; Impacts often have large-scale (extensive) effects on water resources and aquatic ecosystems, with deleterious effects on water resources, aquatic ecosystems and other water users.
Medium	Impacts are considered to be important, but seldom require frequent or continual management attention; Impacts may be experienced as temporary or continual loss

	of amenity or deterioration in water quality, and can extend over both small and large areas; Other water users are likely to experience moderate loss of amenity, and may need to implement remedial treatment of the water before use.
Low	Impacts are considered to be important but are easily controlled by routine management actions; Impacts can be experienced as low-intensity nuisances over a relatively large area, or as minor disturbances over a smaller area; Other water users are unlikely to experience significant loss of amenity and seldom need to implement remedial actions before using the water.
Very low	Impacts likely to consist of minor disturbance to aquatic ecosystems or local water resources; Impacts often temporary in nature or, where they occur continually, extend over a very small area.
Negligible	Impacts are unlikely to have a measurable or discernable effect on water resources or water quality, often due to the innocuous nature of the waste material or to the lack of mobility of the waste material in a specific geographic area.

An additional important consideration was the need to provide some assessment of the associated impacts of mining and minerals processing on water resources and water quality. Here, particular attention was paid to other emissions such as dusts, explosive residues, metal vapours, gases and fumes, which often settle out onto land surfaces and are then washed into nearby watercourses during rainstorms. In addition, the disposal and discharge of sanitary waste from mines also poses potential problems for water resources and especially water quality. Virtually all of these associated impacts can be controlled effectively by the use of appropriate technologies and management systems.

1.4 The availability of water

1.4.1 Introduction

Throughout the world, water is recognized as the most fundamental and indispensable of all natural resources and it is clear that neither social and economic development, nor environmental diversity, can be sustained without water. Today, virtually every country faces severe and growing challenges in their efforts to meet the rapidly escalating demand for water that is driven by burgeoning populations (Biswas, 1993; Gleick, 1998; Ashton & Haasbroek, 2001). Water supplies continue to dwindle because of resource depletion and pollution, whilst demand is rising fast because population growth is coupled with rapid industrialization, mechanization and urbanization (Falkenmark, 1994, 1999; Rosegrant, 1997; Gleick, 1998). This situation is particularly acute in the more arid regions of the world where water scarcity, and associated increases in water pollution, limit social and economic development and are linked closely to the prevalence of poverty, hunger and disease (Falkenmark, 1989; Gleick, 1998; Ashton & Haasbroek, 2001).

In comparison to the rest of the world, the distribution of water resources in Africa is extremely variable and water supplies are unequally distributed in both geographical extent and time. Large areas of the African continent have been subjected to series of prolonged and extreme droughts; very often these droughts have been "broken" or "relieved" by equally extreme flood events. There is also compelling, though as yet unproven, evidence that projected trends in global climate change will worsen this situation. In addition to climatic variability, a significant proportion of the continent's water resources are comprised of large river basins or underground aquifers that are shared between several countries. The countries sharing these water resources often have markedly different levels of social, economic and political development, accompanied by very different levels of need for water. The wide disparities between socio-economic development and needs for water further complicate the search for equitable and sustainable solutions to water supply problems (Ashton, 2000, 2001).

In virtually every African country, population numbers have grown dramatically during the past century; these trends are expected to continue. Despite obvious inequalities within a variety of social, economic and political dispensations, this population growth has been accompanied by an equally dramatic increase in the demand for water. Several African countries have already reached or passed the point considered by Falkenmark (1989) to indicate severe water stress or water deficit, where the scarcity of water supplies effectively limits further development. Based on present population trends and patterns of change in water use, many more African countries will reach, and exceed, the limits of their economically usable, land-based water resources before the year 2025 (Ashton, 2000, 2001). These sobering statistics emphasize the urgent need to find sustainable solutions to the problem of ensuring secure and adequate water supplies for all African countries.

Equitable access to water is recognized as a fundamental right of all peoples (Gleick, 1999). However, in parallel with this right of equitable access, it is vitally important that we develop a shared appreciation of the true value of water, and understand the critically important need to change or redirect our approaches to water management and utilization on regional and continental scales (Ashton & Haasbroek, 2001). Whilst water allocation and distribution priorities in each country need to be closely aligned with national and regional development objectives, greater emphasis now needs to be placed on concerted efforts to ensure that the continent's scarce water resources are used to derive the maximum long-term benefits for the peoples of Africa as a whole. However, this goal can only be achieved if water resource management is both judicious and cautious. A key consideration is the pressing need to ensure that all sectors of society have equitable access to and use of the available water resources. This aspect is particularly important in the case of Africa's shared river basins. Ideally, each country's water resource management strategies needs to be closely aligned with those of its neighbours if peace and prosperity are to be maintained and conflict is to be avoided (Pallett, 1997; Turton, 1999a; Ashton, 2000; Ashton & Haasbroek, 2001).

1.4.2 Availability of water in southern Africa

Both the southern and northern portions of Africa receive considerably less rainfall during any given annual cycle than their equatorial neighbours. These drier areas also experience greater variability in year-to-year rainfalls and generally have more extreme air temperatures and higher rates of evaporation. In combination, these features reduce surface water flows in rivers and streams, and provide little recharge to ground waters.

Typically, river flows in the countries of southern Africa and North Africa range from some 20% of mean annual rainfall in the wettest areas to zero in the deserts. On average, flows in the rivers draining the northern and southern areas of Africa comprise less than 10% of the mean annual rainfall. This is in marked contrast to many equatorial African countries where surface runoff often comprises over 30-40% of the mean annual rainfall (**Figure 1.1**). Across the African continent, the geometric (spatial) average annual rainfall amounts to some 650 mm; this is approximately 24% less than the world average annual rainfall of 860 mm (SARDC, 1996).

The variable and erratic rainfall patterns, extremes of temperature and high evaporation rates across the continent result in a striking absence of perennial rivers and lakes in both North Africa and the western parts of southern Africa (**Figure 1.2A**; Ashton, 2000). A comparison between the distribution pattern of perennial rivers and lakes, and those areas where some form of dispute or conflict has occurred or has been threatened, either over the availability of water or over some aspect of water supply, shows a remarkable correspondence (**Figure 1.2B**).

The climatic, and especially rainfall, characteristics of Africa, outlined briefly above, indicate very clearly that the average quantity of water available at a given time and place (within a country) will be a finite amount. Years of above-average rainfall will provide short-term relief in the form of additional water, whilst lower rainfalls during drought conditions will cause, or accentuate, water shortages. Several authors (e.g. Falkenmark, 1989; Ohlsson, 1995a; SARDC, 1996; Gleick, 1998; Ashton, 2000, 2001) have repeatedly stressed the fact that freshwater resources in Africa and elsewhere represent a finite and vulnerable resource.

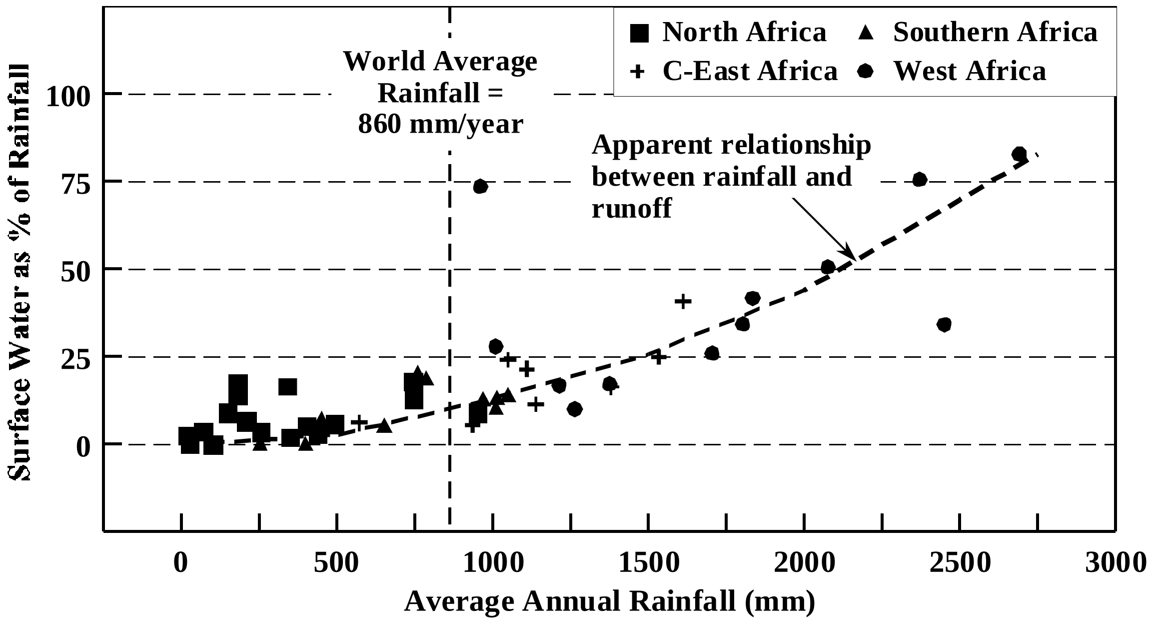

Figure 1.1: Comparison of surface runoff (expressed as a percentage of annual rainfall) versus average annual rainfall for African countries. Data taken from (FAO, 2000a).

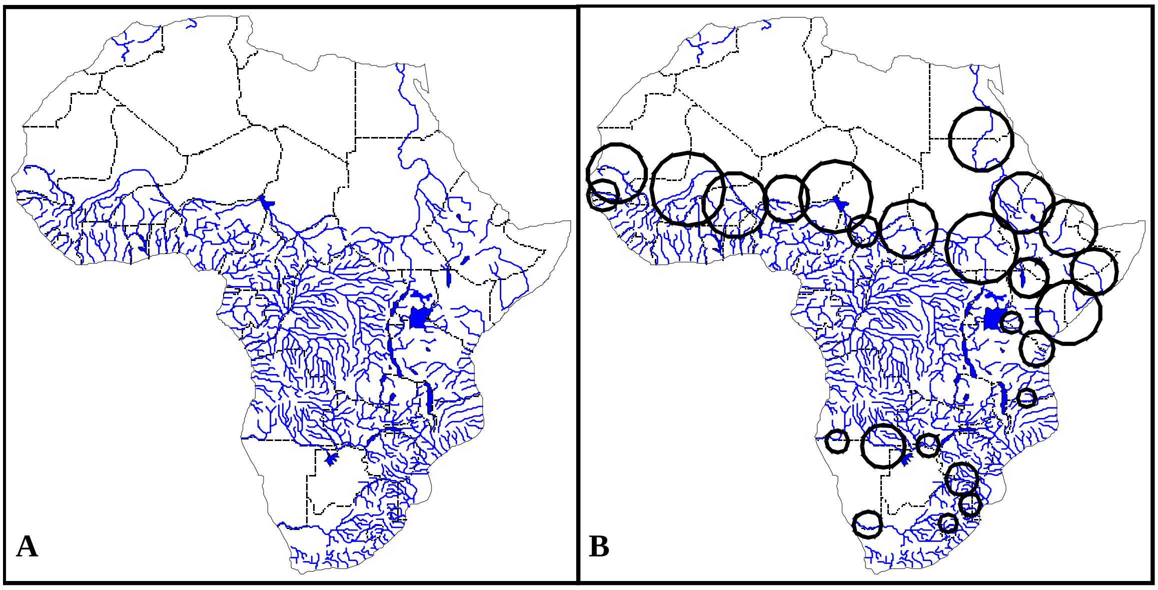

Figure 1.2: Diagrammatic maps comparing (A) the distribution of larger perennial rivers and lakes in Africa, with (B) the locations of actual or potential water-related conflicts. It is clearly noticeable that rivers form the international boundaries between several African countries (redrawn from Ashton, 2000).

A direct result of this realization is a growing awareness that increased population numbers and improved quality of life (i.e. "development" in its widest sense) contribute to a continual and inevitable reduction in the quantity of water that is available per person. This reduced *per capita* availability of water, coupled to an escalating trend in the degradation of its quality, represents the most serious and tangible single threat to the flows of various goods and services required by society (FAO, 2000b). However, on a very positive note, the threats posed by the impending water crisis have enhanced public recognition of the values generated by or linked to water, and have also expanded our understanding of the significant social and economic values that are embodied in the many ecosystem services that depend on water (Falkenmark, 1994, 1999; FAO, 2000b).

1.4.3 The extent of the water crisis facing southern Africa

The potential threat to society posed by increasing pressures for finite quantities of water is one that is not unique to Africa. Nevertheless, the broad scale and imminence of the threats posed to many African countries demand our urgent attention if we are to avoid large-scale hardship and possible future conflicts. Many authors have stressed the apparent inevitability of serious inter-state conflict over competition for diminishing water resources in different parts of the world (Smith & Al-Rawahy, 1990; Gleick, 1993; Ohlsson, 1995b; Homer-Dixon & Percival, 1996; Rosegrant, 1997). Some authorities have extended these arguments even further and postulated the strong likelihood that reduced availability of water could ultimately lead to "water wars" between countries that may compete for the same scarce resource (Smith & Al-Rawahy, 1990). Many of these arguments appear to be based on two groups of similar assumptions, namely: that communities, societies and even governments of countries have little or no choice in the matter, and that their only logical (or possible) reaction to the crisis of water shortage is one that is based on strong (even violent) competition for the resource.

In simple terms, all of the proponents of these arguments rely on a relatively simplistic interpretation of what Falkenmark and her co-workers call “the numbers game” (FAO, 2000b). Clearly, the “numbers” tell everyone that there is a continual and dramatic decline in the quantity of water available per person. This is incontrovertible. However, it is important to understand the emphasis that different authorities place on the numbers. For example, most arguments state the problem in terms of the continual decline in the quantity of water available per person (e.g. SARDC, 1996; Basson *et al*., 1997). Again, this is accepted fact: the quantity of water available for each person in the world is declining steadily; nowhere is the rate of decline as dramatic as we continue to see in Africa. Even a cursory examination of the geographic and demographic statistics listed for each southern African country confirms this decline and highlights the severity of the water crisis (Ashton, 2000).

However, importantly, the available statistics also reveal that the decline in water available per person is not uniform across Africa. Several countries will remain in a state of so-called “water abundance” (Falkenmark, 1986) for many years to come, whilst others will experience increasing levels of “water scarcity” and “water deficit”.

It is important to remember that these purely numerical forecasts assume a steady (and unchanged) rate of population growth with no change in the total quantity of water available; according to these forecasts, the population of southern Africa will increase by over 50% (increasing from almost 198 Million to 334 Million) between 2000 and 2025. However, the estimates of population growth should be treated with caution. Given the widespread incidence of water-borne diseases such as malaria and cholera (SARDC, 1996; Pallett, 1997), together with the enormous implications of the African HIV+/Aids pandemic (Whiteside & Sunter, 2000; Ashton & Ramasar, 2001), and declining levels of social and economic stability (Biswas, 1993; FAO, 2000b), these forecasts may well be an over-estimate for the southern African population in 2025.

An important consideration here is the availability of the necessary social, economic and technical resources that are needed to take advantage of the available water. These features have been referred to as “the coping capability” or “social adaptive capacity” of a society that enable it to take advantage of the available natural resources (Ohlsson, 1995a, b; Turton, 1999b; Turton & Ohlsson, 1999; Ashton, 2000; Ashton & Haasbroek, 2001). In particular, this capability of a society depends on a high degree of human ingenuity and the ability to adapt and adopt plans, strategies and tactics that will help to promote more effective and efficient use of water (Ashton, 2000; Turton, 2000; Ashton & Haasbroek, 2001). Indeed, there is convincing evidence that countries (such as Israel) which display a highly developed social adaptive capacity, have been able to overcome severe water shortages, whilst other countries (such as Burundi) where there is less evidence of social adaptive capacity, have not been able to do so (Turton, 1999b).

Societies with low or high levels of social adaptive capacity will have different abilities to deal with changing levels of water availability (Turton, 1999b; Turton & Ohlsson, 1999). The typical set of consequences is demonstrated in **Figure 1.3**. A society with low social adaptive capacity will be unable to deal effectively with water scarcity, thereby entering a situation that Turton (1999b) has called “water poverty”.

RELATIVE AVAILABILITY OF WATER PER PERSON		RELATIVE ABILITY TO DEVELOP AND ADOPT COPING STRATEGIES: LOW	RELATIVE ABILITY TO DEVELOP AND ADOPT COPING STRATEGIES: HIGH
	SCARCE	WATER POVERTY	STRUCTURALLY-INDUCED WATER ABUNDANCE
	ABUNDANT	STRUCTURALLY-INDUCED WATER SCARCITY	WATER SECURITY

Figure 1.3: A comparison of the likely outcomes of societies with different levels of "second order resources" (i.e. social adaptive capacity) having to deal with two levels of "first order resource" supply (i.e. water abundance or water scarcity). Figure redrawn and modified from Turton (1999b).

In a similar fashion, low levels of coping skills will prevent a society from making full use of abundant water resources, thereby forcing it to enter a condition of "structurally-induced social scarcity". In contrast, a high level of social adaptive capacity will allow a society to develop and implement a series of coping strategies that will permit a situation of so-called "structurally-induced water abundance" (Turton, 1999b; Turton & Ohlsson, 1999). Equally, a country that possesses and deploys a high level of social adaptive capacity and has access to abundant water resources can be considered to be in a state of "water security" (**Figure 1.3**).

This straightforward comparison (**Figure 1.3**) demonstrates very clearly how important it is for societies to develop and implement sets of coping strategies and skills to enable them to deal effectively with conditions of impending water scarcity. Inevitably, every country in Africa will have to face the same prospect: dwindling quantities of water that can be supplied to meet demands. Some countries are already "beyond the water barrier" (Falkenmark, 1999; FAO, 2000b) and are dealing with this urgent matter now; other countries with more water available now will have to deal with the issue in future. In any event, an enormous effort will be needed from every country if the challenge is to be met successfully.

1.4.4 Factors contributing to conflict potential

Against this background, it is important to examine the series of factors or conditions that could contribute to a heightened potential for conflict over scarce water resources. In this process it is useful to distinguish between those sets of circumstances where the issue of water is likely to be incidental to any conflict, from those where water is or will become a central issue. This aspect is particularly significant in the case of river basins that are shared by more than one country, especially where the countries involved have different levels of social and economic development (Ashton, 2000).

One of the remaining legacies of past colonial administrations is the apparently arbitrary fashion in which the national boundaries of most African countries were set (Prescott, 1979). As a result, these boundaries seldom conform to river catchments and virtually all of the larger river systems in Africa are shared by several countries (Pallett, 1997). Consequently, several African countries have had to compete directly or indirectly to derive the maximum possible benefits from the available water resources. This situation has been accentuated in those situations where the downstream countries may be economically "poorer" or politically and militarily "weaker" than their upstream neighbours (Ashton, 2000). This competition between "upstream" and "downstream" countries for the same water resource is considered to pose the greatest potential threat of conflict over water in Africa (Ashton, 2000).

However, the available evidence indicates very strongly that territorial sovereignty issues have been implicated in virtually every dispute or conflict that has taken place over, or near to, water. In most cases, these disputes have been linked to disagreements over the precise positions of territorial boundaries and have tended to involve relatively small areas (Ashton, 2000). Indeed, there is ample supporting evidence that despite many predictions to the contrary (e.g. Homer-Dixon & Percival, 1996), "true" water wars have happened very rarely, if at all (Delli Priscoli, 1998).

More recently, attention has switched to the increasing number of water-related problems that are being recorded from countries that share the water resources within a single river basin. In several reported cases, increased water use by "upstream" countries, combined with increased levels of water pollution, has had adverse effects on "downstream" countries. Whilst many of these incidents may only extend over a small geographic scale, occur for a short period of time, or implicate few water users, they invariably elicit a very strong reaction from the neighbouring state (SARDC, 1996; Pallett, 1997). This situation can be particularly sensitive where the states sharing a river basin make use of the available water without due consideration for each other's needs (Heyns, 1995; Ashton, 2001).

In its widest sense, water is a critical component of the national prosperity of a country because it is inextricably woven into irrigation and food production processes as well as into the provision of energy and, occasionally, into transportation systems. Access to adequate water supplies is usually seen as a "life or death" issue; any threat to disrupt or prevent access to essential water supplies becomes an emotionally charged and volatile topic of intense debate (Ashton, 2001).

Everyone is aware that a river knows no boundaries. Whatever happens to a river at one point will be transported, transformed and expressed along its entire length until it reaches the ocean. Where human activities divert or interrupt the flow of water, or cause degradation in water quality, the consequences are always attenuated, translated and transmitted downstream (Ashton, 2000). Since very few of the larger rivers are contained within the borders of a single country or state, access to wholesome supplies of water increasingly becomes a source of potential conflict whenever a river crosses an international boundary. This issue becomes particularly acute where water resources are unevenly distributed and where a single river system may traverse or form several international borders (Pallett, 1997; Ashton, 2000, 2001). The potential for *conflict in such situations is brought sharply into focus in the case of countries that have to rely on water originating in neighbouring states for the major proportion of their fresh water supplies. For example, Egypt, Botswana and Niger obtain, respectively, 97%, 94% and 68% of their total fresh water from neighbouring states; this undoubtedly contributes to a sense of vulnerability (SARDC, 1996; Ashton, 2000, 2001).*

The tensions characteristic of most "upstream-downstream" situations can be compounded by large seasonal variations in flow and by periodic droughts and floods. In some cases, this has promoted international trade in water; Lesotho is a case in point, earning valuable foreign exchange from the water it sells to South Africa. However, in the context of "water trading", there appears to be very little shared understanding or agreement as to the value of water; it is usually treated as a "migrant" or "fugitive" resource with a variable value. This absence of an agreed system for valuing water also contributes to potential conflicts between neighbouring states. The value of water may also vary with its availability; for example, during floods, the unit value of abundant water supplies is considerably less than an equivalent unit of water that may be available during a drought (Ashton, 2000).

1.4.5 Strategies to avoid conflict or diminish conflict potential

The common-sense statement: "prevention is better than cure" provides a perfect outline of the goals and objectives that should direct our strategies and actions when we seek to deal with the complex issues of water-related conflicts. However, despite its apparent simplicity, this ideal often eludes us in practice (Ashton, 2000). A large part of the reason for this lies in the diverse, and often contradictory, ways in which we attach value to water, and the ways in which we strive to derive both individual and collective benefit from our use of water. Too often our objectives have a short-term, local focus aimed at meeting objectives and solving problems today, rather than a far longer-term focus on the sustainable and equitable use of our water resources on a regional or continental scale (Ashton, 2000, 2001; FAO, 2000b).

If our demands for water outstrip our ability to manage water as a focus for cooperation and the achievement of common goals, there is a very real risk that we will enter an ever-tightening spiral of poverty, whose social, economic and environmental consequences will threaten the fabric of society. In contrast, if we can attain an equitable balance between the demands we make for the services and goods that we derive from the use of water, and our ability to exercise our custodianship of water, we will be able to achieve a far more harmonious and sustainable situation. However, to achieve this, all our policies and strategies concerning water must be guided by the values of sustainability, equity, mutual cooperation, and the attainment of optimal benefit for society (Asmal, 1998).

Clearly, the countries concerned should not attempt to answer these questions in isolation from one another; a solution put forward by one country is likely to be rejected by the other states involved. Instead, the states should first agree to form an appropriate, formal institutional structure that will take responsibility for the judicious management of the shared water resource (Lundqvist, 1999). Several such institutional structures or river basin organizations already exist in Africa and elsewhere in the world; these provide ideal examples to be emulated. The formation of a suitable institutional structure should then be followed by agreement as to the most appropriate technical or investigative methods to use to answer the key questions, and, finally, agreement to abide by the results or findings produced.

The formation of a suitable institutional structure probably represents one of the greatest obstacles that river basin states need to overcome since this will formalize and legitimize the technical deliberations that take place. The question as to what fraction of the water can be allocated for society's use without jeopardizing or impairing the water resource will depend on the importance that each country attributes to the necessity to maintain essential ecosystem functions. This can be achieved by consensus-seeking approaches based on a thorough analysis of the structure, functioning and characteristics of the water resource and associated terrestrial systems in the catchment (Lundqvist, 1999; Ashton, 2000).

A final question: what constitutes a fair and equitable share of the water resource, is often viewed as the most difficult one to answer and one where participating states are most likely to disagree. Clearly, the basis of the answer will depend on the relative degree of importance that the participating states attach to the needs of their people for water, and the necessity to maintain essential ecosystem functions and services (Wolf, 1999; FAO, 2000b). The principle of "reasonable and equitable use" embodied in Article 5 of the United Nations Convention is somewhat vaguely worded, provides little guidance in this regard and is prone to subjective interpretations (van der Zaag *et al*., 2000).

Essentially, each of the participating states needs to agree on the fraction of water to be reserved for ecosystem functions, and the precise criteria that should be used to calculate the "fair and equitable share" that each country is then entitled to (Wolf, 1999; van der Zaag *et al*., 2000). Preliminary evaluations of a set of six tentative criteria have demonstrated that, if agreement can be reached on the precise nature of the criteria, then it is a relatively simple procedure to derive the respective shares of the available water (van der Zaag *et al*., 2000). Whilst this approach is not yet able to account for seasonal and year-to-year variations, it has an inherent simplicity that will make it attractive to decision-makers. However, because it is still incomplete, further development and testing are needed before it can be adopted.

1.5 Choice of catchments

An important principle of the MMSD SOUTHERN AFRICA project is the need to provide information on the mining and minerals processing sector that is both relevant and useful to all southern African countries. This principle required that the investigations carried out by the six Research Topics should be conducted at a wider scale than that of a single country. In addition, it would also be possible to enhance the value of the information and insights in each project by including researchers from different SADC countries in the research teams.

Against this background, and given that the most logical unit for water management is the river catchment or basin, it was entirely logical to focus attention in Research Topic 4 on specific river basins. A secondary consideration was the possibility of linking with work undertaken by the SADC Mining Sector Co-ordinating Unit (SADC-MSCU) on the Zambezi basin and thereby ensuring that the outputs from this study supported the SADC-MSCU activities.

Selection of the specific river basins for study was designed to achieve a balance between time and budget constraints, the availability and accessibility of relevant information, and the need to provide information of relevance to more than one SADC country. Ultimately, three river basins were selected for investigation, namely: the Zambezi, Limpopo and Olifants basins. Whilst the Olifants river basin is in fact a sub-catchment of the Limpopo system, its features are sufficiently distinct to warrant it being considered separately. The location and extent of the three river basins in relation to the SADC countries is shown in **Figure 1.4**, whilst a list of the different sub-catchments within each of these river basins is provided in **Table 1.5**. The impacts attributable to mining and minerals processing activities in each of the three river basins are described in subsequent sections of this report.

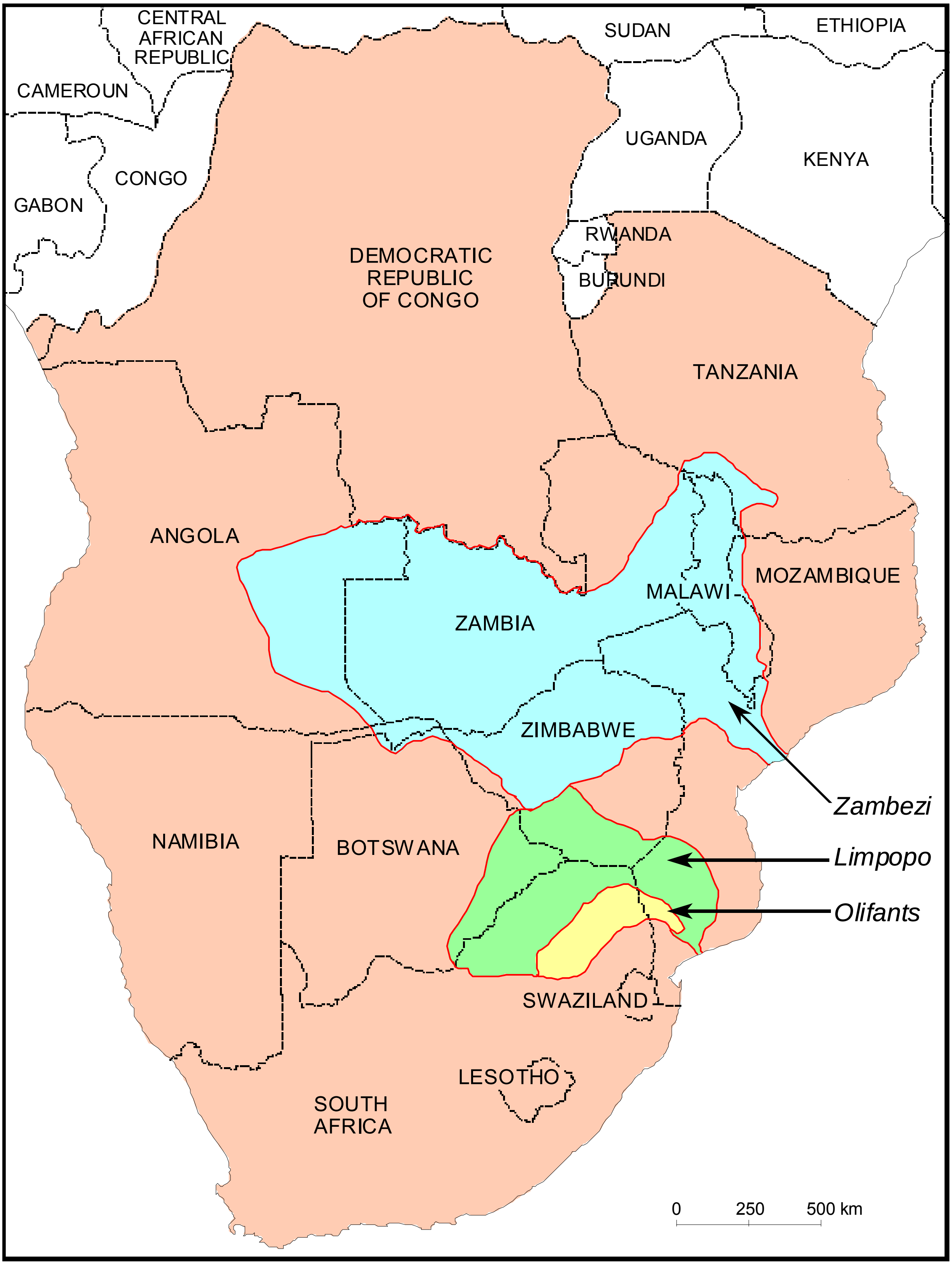

Figure 1.4: Sketch map of southern Africa, showing the twelve mainland African countries of the Southern African Development Community (SADC, shaded) and the location and extent of the Zambezi, Limpopo and Olifants basins.

Table 1.5: List of sub-catchments in the Zambezi, Limpopo and Olifants basins.

Zambezi	Limpopo	Olifants
Cuando-Luiana	Ngotwane – Bonwapitse	Wilge
Luanginga	Lotsane	Little Olifants – Reit
Lungue Bungo	Motloutse	Middle Olifants
Luena	Shashe-Tuli (Bots. + Zim.)	Steelpoort
Zambezi headwaters	Pazhi	Blyde
Kabompo	Mzingwane	Selati
Lunga	Diti	Middle and Great Letaba
Kafue (upper and lower)	Bubye	Shingwedzi
Mulungushi	Mwenezi	Timbavati – Klaserie
Luangwa	Mkgadikgadi	Lower Olifants (Mozamb.)
Shire (plus Lake Malawi)	L. Limpopo-Chagane (Moz.)	
Lower Zambezi (Cahora Bassa)	Marico	
Kariba	Crocodile–Elands-Pienaars	
Chamabonda	Matlabas – Mokolo	
Matetsi	Laphalala	
Deka	Theuniskloof	
Gwayi	Mogalakwena	
Sebungwe and Lwizilukulu	Setoka – Soutsloot	
Sengwa	Sand	
Ume	Nzhelele	
Sanyati – Munyati	Levuvhu	
Mupfure		
Charara and Nyaodza		
Rukomeshe and Chewore		
Angwa		
Manyame		
Musengezi		
Ruya		
Mazowe		
Ruenya		
Kayirezi		

1.6 Types of data presented in this report

In essence, four types of data are presented in this report. Due to difficulties in collecting appropriate data for each of the three river basins, the coverage of these basins is very uneven. In future work, this deficiency should be remedied by a programme of focussed data collection and compilation.

1.6.1 Data on the location, nature, size and scale of mining operations

Within South Africa, these data are available from the South African Minerals Database System curated by the Council for Geoscience and available for purchase in both digital form and as maps at a scale of 1:1,000,000. The price of the South African data set precluded its direct use in this study and the set of maps was used instead. In addition, a variety of publications and reports produced by the South African Geological Survey were also used.

For Angola, Botswana, Malawi, Mozambique, Namibia, Tanzania and Zambia, data were obtained from a variety of mapping sources and from publications and reports produced by different mining houses. These data consisted of site information only.

Data from Zimbabwe were obtained from a variety of publications of the Zimbabwe Geological Survey (ZGS), primarily the comprehensive Mineral Resources Series *by Bartholomew (1999a) and (1999b), though this data is somewhat old, being only continued up to 1984. These data were supplemented by data from the* ZGS Bulletin *on the Midlands Greenstone Belt (Campbell & Pitfield, 1994), other* ZGS Bulletins *(see for example, Baglow, 1998; Baldock, 1991; Garson, 1995), a gold database marketed by Zambezi Exploration Pty Ltd (Mikhailov* et al.*, 2000), as well as from various anecdotal data sources.*

*Data for mining operations located in Zimbabwe and South Africa were restricted to those mining operations that had achieved a minimum production specific to each commodity (**Table 1.6**). This process of selection was not possible for other basin states due to the scarcity of data; all mining operations identified for the Angola, Botswana, Malawi, Mozambique, Namibia and Tanzania sectors of the Zambezi and Limpopo basins were located on appropriate maps. Co-ordinates for the Zimbabwe mines, available from Bartholomew (1999a) and (1999b) were digitised during this project; Zimbabwe gold operation data were obtained from Mikhalov* et al. *(2000).*

Table 1.6: Minimum annual production limits (usually metric tonnes) for inclusion of mining operations in this study.

Commodity	**Production (Tonnes)**	**Commodity**	**Production (Tonnes**
Aventurine	100	Kaolin	2,000
Agate	10	Kyanite	10,000
Amazonite	10	Lead	100
Amethyst	10	Limestone	100,000
Andalusite	500	Lithium	500
Antimony	100	Magnesite	10,000
Arsenic	100	Manganese	1,000
Asbestos	1,000	Mercury	*All producing*
Baryte	500	Mica	200
Beryl	100	Mtorolite	1
Caesium	10	Nickel	1,000
Calcite	500	Ochre	1,000

Chromium	100,000	Palladium	0.01
Citrine	10	Phosphate	*All producing*
Clay	100,000	Platinum	0.01
Coal	**All producing**	Pyrite	1,000
Cobalt	50	Salt	500
Copper	10,000	Sapphire and Ruby	*All producing*
Cordierite	0.05	Selenium	1,000
Corundum	1,000	Silica	10,000
Diamond	*All producing*	Sillimanite	10,000
Dimension stone	*All producing*	Silver	1
Dolomite	10,000	Talc	1,000
Emerald	0.005	Tantalum	5
Feldspar	1,000	Tin	100
Fireclay	10,000	Titanium	100
Flintclay	1,000	Topaz	0.1
Fluorite	1,000	Tungsten	50
Garnet - gemstone	1	Uranium	*All producing*
Garnet – industrial	10	Vanadium	**All producing**
Gold	0.05	Vermiculite	1,000
Graphite	1,000	Zinc	100
Iron	100,000	Zirconium	50

For all three of the river basins, a very large number of mining operations have been closed, abandoned or have not proceeded beyond the initial prospecting and feasibility assessments. Unless these operations have had, or can be expected to have, a significant impact on water resources and water quality in their immediate vicinity, these operations are not dealt with in detail.

1.6.2 Water quality and flow data on rivers and lakes

For the South African sectors of the Limpopo and Olifants basins, river and lake water quality and flow data are available from the South African Department of Water Affairs and Forestry. Data are collected routinely and accessed into the Department's hydrological and water quality databases and a small selection of data were obtained for this study. Numerous studies have been conducted at different times and on different aspects of the water quality and flow characteristics of different portions of these two catchments (for example: Annandale *et al*., 1999; Boroto & Görgens, 1999; Brink *et al*., 1990; Brown, 1992, 1995; Cave, 1978; CSIR, 1993; CSIR & Wates Meiring and Barnard, 1993; Dallas & Day, 1993; Du Plessis & Reynders, 1992; Funke, 1990; Hodgson & Krantz, 1999; Holz, 1994; Pulles, 1992; Pulles *et al*., 1996a, b, c; Stimie *et al*., 2001; Thompson *et al*., 2001; Toerien *et al*., 1980; Vadeveer & Carter, 1993; van Niekerk, 1993, 1998; van Vuuren & Deacon, 1995; Vorster, 1997). In future studies, more attention needs to be directed towards a thorough and comprehensive analysis of the available water quality data so that a whole catchment assessment can be determined with more accuracy.

No water quality data could be obtained for portions of the Zambezi or Limpopo catchments located in Angola, Botswana, Malawi, Mozambique, Namibia or Tanzania. A few published water quality data were available for the upper Kafue River in Zambia, relating to specific studies undertaken on the Zambian Copperbelt (Chenje, 2000; Livingstone, 1999; Mwale, 1994; Mwase, 1994; Nkandu, 1996; Norrgren *et al*., 2000; Petterson & Ingri, 1993, 2000a, b; SADC-MSCU, 2001; SRK, 1998; Timberlake, 1998; Unrug, 1988).

In Zimbabwe, water quality data for selected rivers and lakes is available from the Zimbabwe National water Authority (ZINWA). However, the data available were restricted to those from sampling points within the Zambezi catchment that were readily available from the ZINWA Head Office in Harare. No water quality data were available for the Zimbabwe sector of the Limpopo basin.

1.6.3 Water quality data for certain individual mines

In South Africa, water quality data from individual mine properties is not openly available to the general public. These data are collected by the mines and are submitted to the Department of Water Affairs and Forestry as part of routine pollution control monitoring operations. These data are considered to be "*commercial in confidence*" and access is restricted.

A similar situation exists in Zimbabwe. However, a few data were made available to the Mineral Resources Centre by the Mine ventilation and Environmental Control Offices, Ministry of Mines, Gweru, on condition that the identity of the mines concerned was not revealed. Selection of these data was at the discretion of the Assistant Chief Mining Engineer, Mine Ventilation and Environmental Control Offices, and have been used simply to highlight some of the characteristic impacts of mining on certain water quality parameters.

No data on mine water quality could be obtained for Angola, Botswana, Malawi, Mozambique, Namibia and Tanzania. However, a few data for mine water quality on the Zambian Copperbelt were provided by the SADC Mining Sector Coordinating Unit in their report (SADC-MSCU, 2001).

1.6.4 Background spatially controlled data

All of the locality data reported for Zimbabwe has been spatially controlled, as well as the data pertaining to geology, land use, rivers and infrastructure. Spatially controlled data are also available for South African mining operations.

1.7 Purpose and structure of this document

This report provides an overview of the impacts that mining and mineral processing activities have had, or are likely to have, on the water resources (in particular, water quality aspects) of the Zambezi, Limpopo and Olifants river basins. The report is the output of a collaborative research process involving scientists from CSIR-Environmentek, South Africa, and the Mineral Resources Centre of the University of Zimbabwe, and forms part of the MMSD SOUTHERN AFRICA project.

The researchers from the Mineral Resources Centre in Harare have compiled an enormous quantity of information relating to the impacts of mining operations within Zimbabwe. Similarly, a considerable quantity of information is available for the South African sector of the Limpopo and Olifants basins. In contrast, the quantity of information available for mining operations in the other basin states (Angola, Botswana, Malawi, Mozambique, Tanzania and Zambia) is considered to be sparse. Nevertheless, despite obvious imbalances in the quantity and type of information available for inclusion in this report, the information presented here represents the most comprehensive compilation of this nature that has ever been undertaken for these river basins. As such, this document should guide future work on the issue and assist the SADC Mining Sector Coordinating Unit to assess the impacts of mining on water resources throughout the SADC countries of southern Africa.
The report has been structured into eight major sections to provide a logical framework for synthesis of the information and to facilitate transfer of insights, conclusions and recommendations to stakeholders. The content of each of the sections is described below.

Section 1 provides a brief background to this Research Topic and its relevance within the context of the MMSD SOUTHERN AFRICA project, followed by an overview of the Terms of Reference and an outline of the approach adopted during execution of the research programme. This section also includes an overview of the availability of water in southern Africa, as well as an analysis of the factors that contribute to potential conflicts over water in the region and strategies needed to prevent conflict.

Section 2 provides a short overview of the mining sector in southern Africa, followed by a description of the different types of mining and mineral processing operations that characterize this sector in southern Africa. This is followed by a concise summary of suitable methods used to distinguish between direct, indirect and cumulative impacts and a brief description of the importance of natural weathering processes in exacerbating environmental impacts from mining operations. The section concludes with an overview of the legislation that controls mining impacts on water resources in the SADC countries and briefly reviews the principal methods used to minimize and manage environmental impacts arising from mining operations.

Section 3 provides a brief overview of the water resources of the Zambezi basin and lists the available evidence related to impacts on water resources and water quality that can be attributed to mining and mineral processing activities the basin. This is supplemented with lists of all mining activities and maps showing the locations of these operations in each sub-catchment.

Section 4 contains a brief overview of the water resources of the Limpopo basin and describes the available evidence related to impacts on water resources and water quality that can be attributed to mining and mineral processing activities the basin. This is supplemented with lists of all mining activities and maps showing the locations of these operations in each sub-catchment.

Section 5 briefly reviews the water resources of the Olifants basin and records the available evidence related to impacts on water resources and water quality that can be attributed to mining and mineral processing activities the basin. This is supplemented with lists of all mining activities and maps showing the locations of these operations in each sub-catchment.

Section 6 synthesizes the information on impacts on water resources and water quality contained in Sections 3, 4 and 5 in the form of a series of conclusions that can be used by stakeholders.

Section 7 consists of a list of recommendations based on the findings of this study.

Section 8 lists all the reference materials consulted during the execution of this study, as well as the individuals who were consulted for their opinions and insights.

2. IMPACTS OF MINING AND MINERAL PROCESSING OPERATIONS ON THE BIOPHYSICAL ENVIRONMENT

2.1 The mining and minerals processing sector in southern Africa

Extensive archaeological evidence indicates that mining activities, particularly those aimed at the extraction of iron, gold and copper, have occurred in many of the SADC countries for at least a thousand years (Mendelsohn, 1961). These activities expanded spectacularly during the past century with the discovery of new mineral resources and the development of new mining and metallurgical technologies. Mineral exploration surveys also revealed that, collectively, southern African countries contain some of the most abundant reserves of strategic and economically important minerals, gemstones, oil and gas anywhere in the world (Anhaeusser & Maske, 1986; Wilson & Anhaeusser, 2000; SADC, 2000a). These mineral resources hold the promise of exceptional long-term social and economic benefits for the region and their exploitation has accelerated dramatically during the past century (Hounsome & Ashton, 2001). Today, despite recent adverse economic features and depressed commodity prices for many minerals and mineral products, mining and its associated industries continue to form the cornerstone for the economies of most southern African countries (**Table 2.1**).

Table 2.1: Summary data for the twelve mainland SADC states to show the relative importance of social and economic contributions made by the mining and minerals processing sector in each country (Adapted from Hounsome & Ashton, 2001).

SADC Country	2000 Population (Millions)	Population Growth Rate (%)	Mining Contribution To GDP (%) #1	Mining Employment (%) #2	Mining Share of Foreign Earnings (%) #3
Angola	10.145	2.15	52.3	9.0	90.0
Botswana	1.576	0.76	38.0	5.5	70.0
D. R. Congo	51.965	3.19	28.0	4.0	70.0
Lesotho	2.143	1.65	0.5	1.0	0.3
Malawi	10.386	1.61	0.9	0.4	0.5
Mozambique	19.105	1.47	2.0	1.3	2.0
Namibia	1.771	1.57	20.0	4.5	48.0
South Africa	43.421	0.50	8.0	9.0	28.6

Swaziland	1.083	2.02	2.0	3.5	2.0
Tanzania	35.306	2.57	2.8	2.7	22.0
Zambia	9.582	1.95	12.1	9.0	80.0
Zimbabwe	11.343	0.26	8.0	7.0	40.0

#1: Converted from gross (national) GDP in 1999, in US Dollars, divided by 1999 population; includes onshore and offshore oil and gas plus diamonds, plus all other formal land-based mining activities (www.sadcreview.com/countryprofiles; and www.mbendi.co.za/indy/ming).

#2: Expressed as a percentage of total available adult workforce; excludes linked industries and artisan miners (www.cia.gov/publications/factbook).

#3: Share of total foreign exchange earnings in 1999 that are directly attributable to sales of minerals and mineral products; excludes allied industries and artisan mining (www.mbendi.co.za/indy/ming).

In southern Africa, the mining industry has been pivotal in the development of infrastructure and in the establishment of manufacturing industries. Although the direct contribution of mining to the economies of SADC countries has varied during the past 30 years, the importance of manufacturing industries based on a wide variety of minerals as raw materials has grown substantially. Some of the social and economic contributions currently made by mining to the economies of mainland SADC countries are highlighted in **Table 2.1**. Importantly, these data exclude associated industries and beneficiation programmes, and therefore represent a conservative estimate of the current (1999-2000) direct contributions made by the formal mining sector.

The economic benefits attributable to the mining sector are reflected in the contribution to direct foreign exchange earnings in each country (**Table 2.1**). In particular, the economies of Angola, Botswana, Democratic Republic of Congo, Namibia, South Africa, Tanzania, Zambia and Zimbabwe obtain between 22% (Tanzania) and 90% (Angola) of their foreign exchange directly from mining and mineral exploitation activities. Overall, it is conservatively estimated that mining contributed an average of 40% to the direct foreign exchange earnings of SADC countries in 2000 (Mbendi, 2000; CIA, 2001; Hounsome & Ashton, 2001).

Importantly, the estimates of foreign exchange earnings exclude the economic contribution made by “informal” or “artisan” miners to the economies of several countries. The figures shown in **Table 2.1** also exclude “indirect” foreign exchange earned through the wages of migrant miners who, for example, work in South Africa and remit large portions of their earnings to their home country. These “indirect” foreign exchange earnings are estimated to contribute some 20% to Lesotho’s foreign exchange earnings (Mbendi, 2000; SADC, 2000a).

Despite the prevailing economic pressures on the mining industry, the mining sector in the twelve mainland SADC countries employs some 5.3% of the SADC regions’ total available workforce, estimated at approximately 68 Million (**Table 2.1**). Whilst these figures emphasize the importance of the mining sector as a source of employment, they ignore the large numbers of migrant mine workers and exclude “artisan” and “informal” miners. This last group is problematic in the sense that accurate estimates for the numbers of people engaged in these activities are not easy to obtain as the activities vary from year to year. For example, the available estimates for numbers of artisan miners in Mozambique range from 25,000 to 200,000 whilst those for Tanzania range from 5,000 to 100,000 and for Zimbabwe range from 5,000 to 40,000 (Mbendi, 2000; SADC, 2000b). In these countries, artisan miners are engaged in the production of gold, tantalum and tin, as well as gemstones and semi-precious stones, that are often sold on “informal” or “illegal” markets (SADC, 2000b).

The scale and importance of the diverse activities comprising the mining sector in the economies of all southern African countries have significant impacts on the social, economic and biophysical environment (Hounsome & Ashton, 2001). Depending on their size, type and location, the impacts of mining activities and mineral exploration programmes are often large enough to be regarded as drivers of environmental change, particularly on the biophysical environment. In order to appreciate the ways in which mining activities affect the biophysical environment, it is important to appreciate both the variety of mining activities and the different phases involved in a typical mining operation.

2.2 Types of mining activities and methods

Mining methods vary widely and depend on the location, type and size of mineral resources. Surface mining methods are most economical in situations where mineral deposits occur close to the surface (e.g. coal, salts and other evaporite deposits or road quarry material) or form part of surface deposits (e.g. alluvial gold and diamonds, and heavy mineral sands). Typical surface mining methods include: strip mining and open pit mining, as well as dredge, placer and hydraulic mining in riverbeds, terraces and beaches. These activities always disrupt the surface and this, in turn, affects soils, surface water and near-surface ground water, fauna, flora and all alternative types of land-use (Fuggle & Rabie, 1996; Ashton, 1999).

Shallow underground mining, up to about 50 metres below the surface, includes bord (room) and pillar mining (often used in coal mines), where pillars of the mineral seam are left to support overlying material. Many of the gold and copper mines in Zimbabwe, Zambia and the Democratic Republic of Congo are sited on historical workings that employed a variety of shallow underground mining techniques (Mendelsohn, 1961). In some of the older South African coalmines in the Witbank area, roof collapse has occurred after the mines were closed, allowing air to enter the old workings and promoting spontaneous combustion in the residual coal. Some of the abandoned workings in the Witbank area have continued to burn for many years and have resulted in unplanned surface collapse as well as ground and surface water contamination through acidification and salinization of local aquifers and streams (Wells *et al*., 1996; Fuggle & Rabie, 1996). Spontaneous combustion of exposed coal seams and stockpiles of coal fines is also experienced at the Hwange collieries in Zimbabwe and the Maamba Colliery in Zambia (SADC, 2001).

A variety of deep underground mining techniques are required to extract ores located deep beneath the earth's crust. Deep mining techniques include specialized ore extraction techniques, such as block caving and longwall mining, and require sophisticated infrastructure to ensure mine safety and maintain safe working environments. The principal environmental impacts associated with deep underground mining (for example, in gold, platinum, chrome and copper mines) are linked to the mine wastes and blasting residues brought to the surface by mine de-watering activities. These cause water pollution from leachates, as well as visual pollution, changes in land use, excessive dust, and surface subsidence as a result of mine dewatering activities.

Offshore (sub-marine) mineral deposits such as diamonds, oil and gas, heavy mineral sands, phosphorite, glauconite and manganese occur off the shores of southern Africa and some of these are already exploited in various ways. These offshore mining activities differs according to the specific locality and the effects of the mining operation on intertidal, sub tidal or deep-sea marine environments (Gurney *et al*., 1996). Many offshore mining operations are vulnerable to inclement weather conditions that pose added risks of fuel and material spills and loss of human life (Ashton, 1999).

Besides the rate and method of mining, the location, variety and scale of mine infrastructure also influences the nature and extent of impacts. Typical mine infrastructure includes: haul roads and ore dumps; ventilation shafts; surface facilities (e.g. offices, workshops, car parks and warehouses); tailings and waste rock disposal areas and methods; transport and service corridors (e.g. railway lines, roads, pipelines, conveyers, airstrips, port facilities, power, water and gas corridors); product stockpiles; ore processing facilities; chemicals and fuel storage and the locations of towns and housing facilities (Australian Environmental Protection Agency, 1995-1996; Fuggle & Rabie, 1996; Ashton, 1999; Weaver & Caldwell, 1999).

Each mineral ore reacts in distinct ways when brought to the surface and comes into contact with air and water, affecting or altering the type of impact that may be expected from the mining operation. Whilst many environmental impacts can be fairly severe, it is important to acknowledge that several sophisticated mitigation measures have been devised through the sharing of best practice approaches in the mining industry.

2.3 Phases of mining and mineral processing operations

The typical life cycle of a mining operation consists of a number of simultaneous or sequential phases and activities. For example: prospecting, development (including verification of the quantity and quality of ore and its amenability to various extraction and processing methods), construction, operation, staff housing and support, product stockpiling, mineral processing, waste management, rehabilitation and eventually, closure. The typical life span of a mine is in the region of 25 years although this can vary from less than 1 year to well over 100 years (Fuggle & Rabie, 1996).

Different environmental interactions and possible impacts are usually associated with each of the phases of a mine's life span. The impacts associated with each mining phase have the potential to drive environmental change in several different ways and at various scales. These range from local- to national-scale changes and may even give rise to international environmental changes (for example air pollution plumes over the Southern African region). **Table 2.2** outlines the stages of mine development from start-up to closure and lists the potential environmental impacts associated with each of these phases.

Table 2.2: Overview of the potential environmental impacts associated with different phases of mining activities. [Information adapted from Environment Canada (1969) and Australian Environmental Protection Agency (1995-1996)].

Mining Phase	**Activities**	**Potential Environmental Impacts**
Exploration and Surveying	• Geochemical, geophysical and airborne surveys • Drilling and trenching • Blasting of exploration adits • Exploration camp housing • Vehicle and machinery parks, fuel points and service bays • Access road construction • Waste disposal (garbage) • Camp sanitation systems	• Vegetation removal, damage and destruction • Habitat disturbance due to noise / vibration • Disturbance to wildlife and local residents • Soil erosion along trenches and transects • Dumping of drill cores and waste • Demand on local water resources • Discharge or spillage of contaminants • Contamination of local ground waters by drilling muds and exposed ores • Restricted public access
Mine development start-up; sourcing and stockpiling of raw materials Mine development start-up; sourcing and stockpiling of raw materials (Continued)	• Mine construction • Stripping / storing of soil “overburden” • Installation of power lines • Surveying and levelling of sites for buildings and plant • Installation of mine and surface water treatment plants • Construction of mine facilities, offices and roads • Construction of processing plant, smelter and refinery • Construction of storage facilities • Landscaping of site	• Fauna and flora habitat loss and disturbance • Reduction in biodiversity on site • Potential loss of heritage sites • Decreased aesthetic appeal of site • Altered landforms due to construction • Altered drainage patterns and runoff flows • Increased erosion of site area • Increased siltation of surface waters • Contamination of surface and ground waters by seepage and effluent discharges • Discharge of contaminants via mine de-watering activities • Methane emissions from mine contributes to greenhouse gases • Increased demand on local water resources • Seepage / discharge of acid rock drainage • Ground and surface water contamination from seepage and radionuclides

	site • Construction of staff housing, infrastructure and recreational facilities • Construction of railway lines and sidings	• Contamination from fuel spills and leakages • Increased demand for electrical power
Removal and storage of ores and waste materials	• Stripping / storing of soil "overburden" • Waste rock stockpiles • Low grade ore stockpiles • High grade ore stockpiles	• Land alienation from waste rock stockpiles and disposal areas • Disturbance from vehicle and machinery noise and site illumination • Acceleration of acid rock drainage through exposure of ores to air and water • Spontaneous combustion of coal fines • Increased erosion and siltation of nearby surface waterbodies (rivers and lakes) • Contamination of local ground waters
Blasting, milling and grinding	• Blasting of rock to release ores • Transport of ore to crusher • Extraction and preliminary crushing of ore • Milling and grinding of ore • Flotation and chemical concentration / leaching of ore and final product • Transport of ores to smelter	• Ground surface disturbance • Disturbance due to noise and vibrations • Dust and fumes from explosives, mine vehicles and transportation systems • Contamination from explosive residues • Discharge of contaminated water • Windborne dust and radionuclides • Sulphur dioxide emissions from roasters and acid plants • Metal vapour emissions from smelters
Smelting, refining and beneficiation	• Mineral processing through smelting, roasting and other methods for refining ore • Replenishment of refinery plant processes /solutions • Stockpiling of final product	• Discharge of contaminants to air, including heavy metals, organics and SO_2 • Leakages from electrolytic plant leading to site contamination • Spillage of corrosive liquids • Requirement for electrical power
Transport of final product to markets	• Packaging / loading of final product into transportation • Transport of final product via rail link	• Disturbance due to noise, vibration and site illumination • Dust and fumes from exposed product stockpiles
Mine closure and post-operational waste	• Decommissioning of roads • Dismantling buildings	• Subsidence, slumping and flooding of previously mined areas • Underground fires in abandoned coal

management	• Reseeding/planting of disturbed areas • Re-contouring pit walls/waste dumps • Water quality treatment • Fencing dangerous areas • Monitoring of seepage	mines • Acid rock drainage from exposed ores • Continuing discharge of contaminants to ground and surface water via seepage • Fauna and flora habitat loss and disturbance • Windborne dust, including radionuclides • Dangerous areas that pose health risks and possible loss of life (e.g. shafts, pits, etc.)

2.3.1 Exploration and surveying activities

Most of the potential environmental impacts associated with mining exploration and surveying activities occur at a very much smaller scale than those recorded during mine operational activities, and are mainly restricted to specific exploration areas and sites or slightly larger localities. However, the cumulative effects of exploration activities at multiple sites within an area have the potential to drive environmental change, particularly from a larger regional perspective (**Table 2.2**).

The more common and noticeable effects of these cumulative impacts include changes in aquatic and terrestrial ecosystem health. The general environmental impacts of mining exploration include the removal of vegetation for survey lines, vegetation damage and soil erosion from vehicle tracks, abandoned equipment and supplies, soil, vegetation and water resource pollution and contamination.

Mining exploration impacts include local spillage and leakage of fuels, oils and drilling fluids resulting in site and vegetation contamination. Potential surface water pollution may result from wastewater discharges, sewage disposal and waste rock dump heavy metal and sediment drainage. Habitat disturbance and soil erosion impacts are caused by vegetation clearing for access routes and drilling sites, and the use of bulldozers for stripping overburden to examine the underlying bedrock.

2.3.2 Mine development and start-up

The development and start-up of a mining operation covers the period of time when considerable changes take place as the mine infrastructure, plant and facilities are constructed, and when the ore body is first exposed (see **Table 2.2**). In practical terms, the scale and sequence of events varies from mine to mine, but always entails dramatic changes to most features of the local environment. Large areas of land are cleared of vegetation and leveled prior to construction, whilst testing of ore processing and refining facilities is finalized. The spatial scale of the mine site where impacts may be displayed can vary from a few tens of hectares to several square kilometres. The most immediate impacts are seen as disruptions and disturbances to plant and animal communities, accompanied by loss of aesthetic value and appeal.

During the development and start-up phase of mining, exposure of rocks, ores and soils to rainfall and winds leads to relatively high levels of atmospheric contamination by dusts and water contamination by eroded and oxidized materials, accompanied by increased erosion of the site and sedimentation of local water courses.

These effects are usually ameliorated by a variety of control measures, including: landscaping and re-vegetation; constructed, realigned and protected drainage systems; regular use of dust suppression measures; spoil capping with waste rock and stockpiled soil; collection and treatment of contaminated drainage water prior to discharge.

Oxidation of exposed and stockpiled ores (both sub-economic and economic) and waste rock leads to increased acid rock drainage as sulphide minerals are transformed. The resulting seepage has low pH values, as well as high concentrations of dissolved metals and total dissolved salts. This leads to extensive adverse effects of aquatic ecosystems and decreases the fitness of local water resources for use by other users.

2.3.3 Removal and storage of ores and waste material

The removal and storage (stockpiling) of ores prior to milling and extraction is usually the most intensive activity on any mine operation. The process involves large-scale exposure of ore bodies, followed by blasting, loading and transportation of various ore grades to the stockpile sites where the ores are separated on the basis of their ore grade (see **Table 2.2**). Waste material, including waste rock and soil overburden, are separated and stockpiled for possible later use during mine rehabilitation after closure. These activities are characterized by large-scale disturbance due to noise, vibration and wind-blown dusts. Rainfall is contaminated by eroded and oxidized materials, leading to varying degrees of sedimentation and pollution in local watercourses. Remediation techniques are very difficult to apply to ore stockpiles since these are “live” and undergo changes on a daily basis. Waste rock dumps can be rehabilitated as soon as they reach their planned extent.

2.3.4 Blasting, milling and grinding activities

The routine operational phases account for most of the environmental impacts associated with mining (see **Table 2.2**) and are considered to have the greatest potential to drive environmental change. The extent to which mining operational activities act as drivers of environmental change depends in part on the type, scale, duration and magnitude of the activities, and the sensitivity of the receiving environment. General overviews of the main types of impacts associated with the operational phases of mining are described briefly below.

2.3.4.1 Environmental changes associated with surface and underground mining methods

Surface mining methods, including strip mining, open pit mining, dredge, placer and hydraulic mining, may drive environmental change of the affected land surface in the following ways (Brink *et al*., 1990):

- Changes in topography and surface drainage with the potential for increased soil erosion, long-term compaction, subsidence and reduced agricultural capacity;
- Disturbance and disruption of the natural groundwater regime with the potential for both ground and surface water pollution; and

- Changes in topsoil characteristics with the potential for increased acidity and salt content, development of nutrient deficiencies or imbalances, surface crustiness or desiccation, changes in vegetation cover and land use with the potential for production of atmospheric dust and other pollution.

The surface effects of underground mining are mostly associated with localized subsidence, sinkholes, rock bursts and earth tremors, whilst roof collapse of shallow underground bord and pillar coal mine seams can promote spontaneous combustion in the residual coal. Some of the older coal workings in the Witbank area have continued to burn for many years and have resulted in unplanned surface collapse as well as ground and surface water contamination through acidification and salinization of local aquifers and streams (Wells *et al*., 1992). Further environmental effects associated with coal dump and fires in current Zambian and Zimbabwean coal workings include sulphur dioxide emissions and associated acid rain (Chenje, 2000).

2.3.4.2 Changes to the groundwater environment

Mining operational activities often have several adverse hydrogeological impacts, including changes to the local (and sometimes regional) groundwater dynamics, in terms of both the quality and quantity of water, and its flow direction.

The location of many southern African mining operations in or close to dolomite formations is often of particular concern to urban populations who rely on these dolomitic water resources for regular and emergency water supplies (Brink *et al*., 1990). Most of the changes in groundwater quantity that are attributed to mining are linked to dewatering activities, where the mines extract large volumes of good quality water to ensure safe and economical mining operations. The environmental effects of dewatering include lowering of water tables, the formation of sinkholes and localized subsidence.

Other hydrogeological impacts are often associated with the inappropriate placement of opencast and underground mining waste disposal facilities such as tailings dams and slurry ponds on surface or in open pits. These give rise to seepage mounds, decrease water quality and change the rate and direction of groundwater movement (Brink *et al*., 1990).

In general, mining and milling processes result in the release of environmental pollutants which were previously largely immobile. Probably the best-known example is that of acid rock drainage where the exposure of reactive ores to oxygen, water and bacteria leads to the formation of deleterious leachates that have significant environmental impacts. Sulphide minerals oxidize to acidic sulphate solutions with low pH values and high sulphate and total dissolved salt concentrations. Potential sources of acid mine drainage include surface runoff from open cast mining areas, seepage from leach ponds, runoff from residue dumps or ore stockpiles and drainage from underground workings (Brink *et al*., 1990).

2.3.4.3 Changes to the surface water environment

Water quality changes are widely considered to be the most significant consequence of mining activities. This is partly because of the wide variety of undesirable contaminants that are derived from mining operations, and partly due to the frequency and persistence of these problems. Historical records of mining activities in the sixteenth century clearly demonstrate the strongly antagonistic public opinion regarding the adverse effects of mining on water quality (Agricola, 1556, cited in Environment Canada, 1996). In many areas, varying degrees of adverse public opinion of mining activities continues to the present day (Viljoen & Reimold, 1999; Chenje, 2000).

Most mining operations share similar sets of activities or materials that generate contaminants and lead to pollution of surface water resources. The following mining sources generate a diversity of contaminants that have been shown to have adverse effects of varying intensity on surface waters, groundwater, aquatic plants, surface water biota and submerged sediments (Pulles *et al*., 1996):

- Underground stopes;
- Surface rock and sand dumps;
- Slimes dams and delivery pipelines;
- Coal discard dumps;
- Coal fines;
- Rehabilitated opencast pits;
- Plant areas; and
- Explosives residues

Chemical contaminants in mine water systems are very varied and complex in nature. Often, these contaminants have synergistic effects on a variety of different environmental components and these can seldom be reduced or ameliorated. Pulles et al*., (1996) indicate that South African coal and gold mines have been unable to cost-effectively eliminate the following sources of water pollution:*

- Acidic saline conditions with mobilized dissolved metals and nutrient enrichment caused by pyrite oxidation and blasting residues;
- Eutrophication, pH fluctuations and decreased oxygen content caused by sewerage discharges; and
- Cyanide and radionuclide contamination of gold mine seepage water.

These problems are not unique to South Africa and are shared by every SADC country, as well as most mining operations worldwide.

2.3.4.4 Landscape-scale ecological changes

The process of constructing, erecting and commissioning new mining infrastructure often results in large-scale alteration of the environment, particularly at landscape and ecosystem levels. Infrastructure associated with mine construction includes transport and service corridors (railway lines, roads, pipelines, conveyers, airstrips, port facilities, power, water and gas corridors) and surface facilities (e.g. offices, laboratories, workshops, vehicle parks and service bays, fuel storage and dispensing depots and warehouses), sinking of mine shafts and the removal of soil, vegetation and rock to access ore deposits and create sites for tailings and waste disposal areas. The landscape level environmental impacts are generally in the form of landscape alteration and fragmentation or dispersal of biological habitats, populations, communities and ecosystems. They also include altered patterns of stream flows, especially where mines have to be de-watered.

2.3.4.5 Air pollution effects

The coal mining industry is one of the major sources of the greenhouse gas methane emitted into the atmosphere every year. Mining processes release a variety of gases, metal vapours and dusts, as well as radioactive particles, into the broader environment through discharge from smelter stacks, washoff or leachate from unrehabilitated and revegetated mine dump and discard areas, or as constituents of mine dump dust. The environmental impacts of wind-borne dust, gases and particulates from mining activities are primarily related to human health and ecosystem damage. However, reports of copper toxicity to cattle and wildlife caused by emissions from copper mines have also been recorded (CSIR & Wates Meiring and Barnard, 1993; Pettersson & Ingri, 1993, 2000a, b).

2.3.4.6 Soil erosion and sedimentation

Mine construction results in widespread soil disturbance and is associated with accelerated soil erosion, particularly in areas receiving high rainfalls. Soil, sediments and any associated contaminants are transported into streams, rivers and other waterbodies, resulting in the loss or alteration of habitats for aquatic organisms, as well as changes in water quality. Soil erosion also promotes a variety of terrestrial ecological changes associated with disturbed areas, including the establishment of alien invasive plant species, altered plant community species composition and loss of habitat for indigenous fauna and flora.

2.3.4.7 Tailing dams and impoundment leaks, seepage and breaches

Tailings dams, as well as earth-wall water storage dams and berms, contribute to contamination of local and regional water supplies via seepage through or around the dam walls or via breaches and/or failures of the dams themselves. In the Vaal area of South Africa, it has been estimated that over 50,000 tonnes of salts seep out of tailings stockpiles into the Vaal barrage each year, resulting in extensive contamination of water, soil and riparian vegetation (Booth, 1994).

Under severe circumstances, dam wall failure may result in large-scale soil contamination and loss of viable land for agricultural and other forms of use, as well as potential loss of human life.

• 2.3.5 Smelting and refining activities

The primary environmental effects associated with smelting and refining processes include the contamination of soils, watercourses, and even entire food chains caused by leaching and transportation of pollutants from ore stockpiles and waste sites (**Table 2.2**).

All processes where ores are heated (to combust, melt or calcine specific minerals present in the ores) produce contaminated water, noxious gases and fine dust, and emit heavy metal vapours into the atmosphere (Booth, 1994). These substances settle out onto the surrounding landscape where they may have direct impacts on the area's fauna and flora, particularly if emissions contain acidic substances such as sulphur dioxide. In addition, *these substances are often mobilized during rainfall and transported by runoff into nearby watercourses where they have additional effects on components of the aquatic ecosystem as well as other water users.*

2.3.6 Stockpiling and transport of final product

In most mining operations, the stockpiling and eventual transport of final product to markets is seldom associated with significant impacts on the biophysical environment. However, the exception to this generalization concerns those mining operations where the ore is transported for beneficiation elsewhere (for example, coal, manganese and iron). In these cases, the primary impacts on the biophysical environment are linked to noise disturbance and the emission of dusts and fumes from both the stockpiles and the transportation system (Fuggle & Rabie, 1996).

2.3.7 Mine closure and post-operational waste management

Many mine-related environmental impacts often continue long after the mine has stopped production and has been closed (see **Table 2.2**). Amongst the more pronounced post-closure impacts on record are landscape scarring in the form of unrehabilitated waste rock dumps, mine tailings dams, discard dumps, old shafts and underground fires. In addition, continuing environmental damage from polluted waters (including acid rock drainage), wind-blown dusts and the dispersal of contaminated solid waste is a feature of mines throughout the world (Johnson *et al*., 1994). Environmental changes that result from these impacts include the following (Carl Duisberg Gesellschaft, 1999):

- Loss of productive land for alternative uses;
- Loss or degradation of groundwater quality;
- Pollution of surface water by sediments and/or salts, as well as lower pH values and increased metal concentrations;
- Alterations to river channels by erosion and slumping;
- Changes in river flow regimes with sharper flow peaks and reduced dry season flows;
- Air pollution from dusts, radionuclides and toxic gases; and
- Risks of falls into abandoned shafts and pits that are not adequately protected.

2.4 Specific impacts of mining on water resources

Five key areas of impact that mining may have on water systems are: acid mine drainage (AMD), release of metals, cyanide, siltation and water use. The set of impacts that any specific mining operation will have on the environment, and especially the aquatic environment, depends on:

- The type of rock and ore being mined;
- The type of mining operation and the scale of operations;
- The efficiency and effectiveness of any environmental management systems that are deployed by mine management; and
- The sensitivity of the receiving environment (including scarcity of water).

Clearly, any large mining operation is likely to have a proportionately greater impact on the environment than a smaller mining operation located in the same area. However, it is important to note that most large mining operations also tend to employ more effective and efficient environmental management programmes than their smaller counterparts. This feature tends to reduce the relative size and intensity of impacts associated with larger operations. Indeed, many small mining operations very often cannot afford to implement effective environmental management programmes and their impacts on the environment are sometimes disproportionately large. This is clearly evident in the case of small-scale and artisan mining operations, where little or no attention is directed towards minimizing impacts on the surrounding environment.

As a consequence, it is often extremely difficult to assign specific proportions of environmental impact to different scales of mining operations where these occur on close proximity to one another. The only way to separate the individual impacts in such a situation is through the application of a carefully structured monitoring programme that examines both water quantity and water quality aspects.

2.4.1 Acid mine drainage

The breakdown of pyrite and other sulphides by water or air releases acid, sulphate and metals into the environment. This is termed acid mine drainage (also referred to as acid rock drainage). The main reactions involved (Loos *et al*., 1990) are:

$$2FeS_2 + 2H_2O + 7O_2 \rightarrow 2FeSO_4 + 2H_2SO_4$$

$$4FeSO_4 + O_2 + 2H_2SO_4 \rightarrow 2Fe_2(SO_4)_3 + 2H_2O$$

$$Fe_2(SO_4)_3 + 6H_2O \rightarrow 2Fe(OH)_3 + 3H_2SO_4$$

$$4Fe^{2+} + O_2 + 4H^+ \rightarrow 4Fe^{3+} + 2H_2O \text{ (bacterial catalysis)}$$

$$FeS_2 + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 2SO_4^{2} + 16H^+$$

The system is autocatalytic: the earlier reactions catalyse the later ones. This makes it difficult to stop the reaction series once it has started (Mathesen *et al*., 1997).

It can be seen from these reactions that pyrite can remain in reduced form until exposed to air or water. Certain chemolithotrophic bacteria, notably *Thiobacillus ferrooxidans*, use pyrite as an energy source, catalysing pyritic decomposition. These bacteria have been found in water draining from various mine waste deposits, and in soil in the seepage zone below the same deposits (Loos *et al*., 1990). They are also often found in streams near mine dumps, where they aggregate in filamentous "streamers" of bacteria, coated in fibrillar polymers, which they secrete (Kelly, 1988). The bacteria can function in an anaerobic environment, such as in a flooded mine. According to comparisons of abiotic laboratory tests with field studies of sites with known *Thiobacillus* presence (Kirby & Elder Brady, 1998), the bacteria can increase oxidation rates by five to eight orders of magnitude.

The acidification of the water has immediate deleterious effects on aquatic ecosystems. A direct effect is the conversion below pH 4.2 of all carbonate and bicarbonate into carbonic acid, which dissociates into carbon dioxide and water. This destroys the bicarbonate buffer system in the water, which acts as a control on acidity. Secondly, since many photosynthetic organisms use bicarbonate as their inorganic carbon source, their ability to photosynthesise is limited or destroyed altogether as bicarbonate decomposes and becomes less available (Kelly, 1988). Thirdly, decomposition (and hence nutrient cycling) will be reduced and eventually cease, in water bodies severely affected by acid inflow (Dallas & Day, 1993). Fourthly, acid waters kill some organisms, by destroying ionic balances, or damaging cell components or carbonate exoskeletons (Kelly, 1988).

However, the most important effects of acidification of water are the changes that result in the speciation of metals. The solubility, mobility and bio-availability of metals are generally increased by acidification of water. This is probably the result of the combination of washout processes in rocks and soils in the catchment, enhancing the mobility of metals, and the active remobilisation of metals from aquatic sediments (Förstner & Salomons, 1991). Specifically:

1. At very low pH levels, aluminium is present as the toxic species Al^{3+}. Al^{3+} is complexed by SO_4^{2-} anions and since these are a major component of water subject to acid mine drainage, the affect on aluminium may be reduced somewhat by this process (Driscoll & Schecher, 1990).

2. The dissolution of feldspars and clay minerals becomes enhanced in acidic solution, and this results in the release of aluminium into the water (Kelly, 1988).
3. Beryllium, cadmium, copper, cobalt, chromium, mercury, manganese, nickel, lead, vanadium and zinc become more soluble in acidic solution (Dallas & Day, 1993; Edmunds & Smedley, 1996; Aström, 1998).
4. The formation of a sulphate-rich solution leads to the increasing solubility of arsenic, cobalt, iron, magnesium, nickel and uranium (Brink *et al*., 1990).

When acidic mine waters on the surface evaporate, they leave behind metal-bearing salts, such as chalcanthite, a complex hydrated copper sulphate. When the next pulse of water passes through the area, these salts re-dissolve, releasing acid and metals into solution, leading to sharp seasonal peaks in metal content in water systems (King, 1995).

Associated with acid mine drainage is the precipitation of iron (III) hydroxide and oxyhydroxide complexes, which give the water an orange colour. These are referred to frequently as "ochres" or "yellow boy". The hydroxides and sulphides are precipitated at moderately low pH (5-6), but once the pH drops below 4.3 they are soluble. This often means that iron (III) stays in solution near the source of contamination, but precipitates downstream, where the pH has been neutralized somewhat, and has risen above 4.3. These hydroxides form flocs, which can block light penetration, clog the bottom of the river and have abrasive affects on biota. Dissolved metals may re-precipitate when the iron (III) hydroxide flocs form at slightly raised pH (Kelly, 1988). The accumulation of nickel, manganese and aluminium in these precipitates has been demonstrated (Rose & Ghazi, 1998). Iron (III) flocs also precipitate in old, flooded mines, since once mining operations cease, no fresh pyrite is exposed, and the pH gradually rises (Mining Journal, 1996). Some of the iron may also be precipitated as iron phosphate, removing this nutrient from the water system (Kelly, 1998).

The release of sulphates and other sulphide breakdown products leads to increased suspended solids and dissolved solids, and thus to salinization. This is enhanced by the dissolving effect of acidic waters on country rock.

Acid mine drainage also leads to a reduction in dissolved oxygen concentration in the water system (Dallas & Day, 1993).

Organisms such as dragonflies, damselflies, mayflies, bivalves and gastropods are often destroyed in water systems subjected to acid mine drainage. Precipitation of iron hydroxides on aquatic plant leaves inhibits photosynthesis (Dallas & Day, 1993).

2.4.2 Release of metals

Another major problem associated with mining operations is the release of metals into rivers and lakes. Speciation refers to the proportion of the metal in different forms, such as ions, complex molecules or ion pairs and combinations, colloids and precipitates. The impact of metals on aquatic life within a water system is dependant on the specific complex that the metal is in, the ligands it is associated with, and the thermodynamic and kinetic stability of the complex (Fernando, 1995). Different metal species have different bio-availabilities, and some metal species are more toxic than others. For example, free Cu^{2+} ions are much more toxic than most forms of Cu(II) which have been complexed by organic ligands (Moffat, 1997).

Much of the metal present in a water system will be either adsorbed onto particulate matter or in suspension, rather than in solution as free ions (Kelly, 1988). Where metals are associated with a particulate phase, they can be transported long distances from the original source.

Where anaerobic and reducing conditions develop in a water system, metal sulphides may form, and be precipitated out of solution - although they can be re-dissolved when conditions change (Kelly, 1988). The superoxide radical (O^{2-}) is produced from photo-oxidation of coloured dissolved organic matter, and the radical reacts quickly with inorganic iron and copper species in water. This results in the formation of reduced species, and influences the overall speciation of metals such as iron and copper (Zafifiou & Voelker, 1997).

Increase in salt concentrations in the water increase solubility and mobility of sediment-bound metals, by competition for sorption sites, and formation of soluble complexes (Förstner & Salomons, 1991).

Metal speciation and concentration are also affected by changes in river flow regimes, leading to settling, re-suspension, sorption or co-precipitation. The drop in velocity that occurs when a river enters a lake results in deposition of suspended material, and diffusion and mechanical dispersion occur. Lake-bottom sediments may act as metal sinks. This is also affected by sediment or clay type, as dissolution, adsorption and precipitation are partly determined by factors such as surface area (Kelly, 1988). The presence of organic material in the sediments has been found to enhance the transfer of metals from water to sediments, taking them out (at least temporarily) of the water system (Nriagu *et al*., 1981). This process essentially buffers the availability of these metals, with high levels of carbon inhibiting mobility of some metals, such as copper (Hettler *et al*., 1997).

Seasonal variations in metal content (and pH) of water systems draining mining areas have been recorded. A suggested factor influencing this is the occurrence of soluble sulphate mineral phases (e.g. copiapite, chalcanthite) in the waste pile. During the rainy season, the increased precipitation leads to a greater amount of these minerals being dissolved.

2.4.3 Cyanide

Cyanide, a highly toxic substance, is indispensable in the refining of gold. Large quantities of cyanide are used to simultaneously oxidise gold and stabilize it in solution as a gold-cyanide complex (Marsden & House, 1993). The two main methods by which this takes place are agitation leaching, the aeration of mixed cyanide solution and ground ore, and heap leaching, where the cyanide solution slowly percolates through the finely ground ore (Channon, 1991; Love, *in preparation*). The gold is later recovered, but cyanide remains in the waste slurry, which ends up on the numerous tailings dams.

2.4.4 Siltation

Siltation is the process whereby fine solid particles build up on the bed of a river or lake and is the result of an excessive load of suspended solids in a river or rivers. Mining operations produce large quantities of dust and finely powdered rock, with much rock having been ground to particle sizes below 0.2 mm. Though the materials that are dumped after removal of the commodity being mined have fine particle size and reasonable physical characteristics that could permit plant growth and retain adequate amounts of water, these materials have been formed from hard unweathered material and so may not contain much of the finest clay material and lack organic or microbial activity. The result is that mine dumps may be very unstable, easily blown by wind when they are dry and eroded by heavy rain when wet. The action of rain and wind thus removes fine particles into nearby water systems, leading to a build up of suspended solids and ultimately siltation.

2.4.5 Water use

Mining operations are major users of water, most notably for:

1. Cooling;
2. Underground operations, such as hydraulic drills; and
3. Processing, such as flotation and leaching.

Larger mines also frequently use large quantities of water to supply nearby residential areas attached to the mines, such as mine housing units.

In arid and semi-arid areas, the quantity of water used by a mining operation places it in direct competition for water with other water users, especially domestic, agriculture and the aquatic environment. This “competition” becomes heightened when the mining operation is also responsible for any deterioration in water quality as a result of effluent discharges. Typically, however, the authority responsible for granting the mining permit will also work in collaboration with the authority responsible for granting permits for water abstraction and effluent treatment and discharge. When this collaboration is effective, it ensures that the quantity of water used by the mining operation is within the allowable limits posed by the available water within the catchment concerned. If insufficient water is available in the catchment, and the social and economic opportunities offered by the mining operation are sufficiently attractive, additional water may be brought in from a neighbouring catchment.

This process is carefully balanced to ensure that the prevailing principles of integrated water resource management (or integrated catchment management) are upheld.

In certain mining operations, (e.g. the Witwatersrand gold mines), the mines may be located in a dolomitic area that is characterized by large volumes of ground water. This ground water normally has to be removed and discharged into surface streams and rivers so that the underground mining operation may proceed. In such cases, this apparent “additional” water may provide a useful source of water for other surface water users in the catchment.

2.5 Small-scale mining

2.5.1 Alluvial gold mining

Alluvial gold mining has been carried out in many rivers across Mozambique, Tanzania, Zambia and Zimbabwe, mainly by small-scale operators using picks, shovels and panning dishes and sometimes sluice boxes. In Zimbabwe, mechanized mining was also applied in areas such as the Angwa River and the Ruenya River, both located in the Zambezi basin (Chiyanike, 1997). The numbers of small-scale gold miners fluctuate widely from year to year, often in response to the presence or absence of alternative employment.

Given the large numbers of small-scale miners, there is substantial physical impact due to the extensive diggings and workings, for example: the upper reaches of the Ruhuhu River in Tanzania and the Mazowe River in Zimbabwe. The normal gold recovery process in Zimbabwe is the stamp mill and amalgam plate (Holloway, 1993) and subsequent recovery of the gold from the amalgam using mercury (Love, *in preparation*). Mercury is frequently lost in this process, causing significant contamination of the water systems.

2.5.2 Small-scale chrome mining

Small-scale mining of chrome takes place along the length of the Great Dyke in Zimbabwe, especially in the Mutorashanga and Lalapansi areas, as well as southeast of the Mweza Range. The most important impact that these workings have is the stripping off of large quantities of soil, leading to enhanced erosion and increased sedimentation of nearby watercourses.

2.5.3 Gemstones and semi-precious stones

Small-scale mining of gemstones and semi-precious stones is widespread in almost all SADC countries, though the mining of gemstones (diamond, emerald, sapphire, garnet and ruby) is considered to be “illegal” by most SADC Governments because the small-scale mining operations are very often unlicensed.

The predominant semi-precious stones mined are: garnet, amethyst, aquamarine, citrine, topaz and beryl. Here again, the major problems associated with this activity are enhanced soil erosion and increased sedimentation of nearby watercourses, caused by inadequate control of surface spoil and waste rock heaps.

2.5.4 Tantalum and tin

There a re a few instances where small-scale miners work specific pegmatite deposits for tantalum and tin. These two metals are relatively valuable and can be sorted manually from the surrounding rock matrix. In view of the low numbers and small-scale of these operations, the associated impacts are negligible.

2.6 Differentiating between direct, indirect and cumulative impacts

Environmental factors (“impacts”) associated with, or caused by, mining, as distinct from those associated with the subsequent use of the extracted minerals, are largely confined to relatively restricted areas in the vicinity of the appropriate geological formation and downstream in the catchment where the deposit is located. These impacts would normally be considered to be “direct” impacts that can be linked directly to the mining and ore processing operations.

In contrast, there are many other types of impacts that are associated with mining activities, but do not occur as a direct consequence of the mining activity itself. These would be considered to be “indirect” impacts. A typical example would be the variety of impacts caused by the activities of individuals and organizations that take place in areas peripheral to a mining operation. An example of this is the discharge of effluent and wastes from households, businesses and factories in the towns that develop around or close to a particular mining operation. In several instances, these indirect impacts can exceed the total environmental impact of the original mining operation and thereby require a far greater degree of management attention.

The term “cumulative impacts” is generally applied to those situations where several impacts from different processes and activities combine to exert a greater set of (usually adverse) effects than those that would be predicted from the original activities. An example of this type of situation would be the combination of adverse effects that a community would experience if it were exposed simultaneously to atmospheric emissions of gases, wind blown dust and effluent discharged from a mining operation. A second example would be the situation where effluents and discharges from several mining operations or industries in a single catchment exerted a set of combined effects or impacts on the river system draining the basin.

In some circumstances, there may be synergistic effects, where the combined (cumulative) effect of two different activities is greater than would be expected from a simple combination of the two isolated activities. Similarly, there are also certain circumstances where the impacts from two different activities effectively neutralize each other – this situation is often referred to as an “antagonistic” or “counteractive” interaction. Three typical wastes provide a simple example of this type of situation, namely: acid rock drainage, raw sewage and power station ash. Individually, these wastes exert serious adverse impacts on aquatic environments; in combination, however, they neutralize and offset each other so that their combined effect on the aquatic environment is often innocuous.

In the context of this study, these examples of cumulative impacts are highly relevant as the three river basins evaluated in this study all contain very large numbers of mining operations as well as a wide variety of industries and other forms of land use. In combination, therefore, there is a large potential for the impacts of mining operations to add to, or possibly even counteract, some of the impacts from these other activities.

2.7 The role and importance of natural weathering processes

Natural weathering processes exert a marked influence on soil formation and also on the types and quantities of materials that enter aquatic systems from the surrounding landscape. Whilst climatic features as well as the parent rock material, degree of vegetation cover and prevailing landuse, control the specific type and extent of weathering processes that are active within a given area, weathering zones can be delineated on the basis of the degree to which chemical or mechanical weathering processes are dominant. A useful index of weathering processes is provided by a simple relationship between annual precipitation and evaporation (Weinert, 1964). This dimensionless index, the "Weinert N" value, is calculated as:

$$N = \frac{12 \times E_J}{P_A}$$

Where:

E_J = Mean evaporation (in millimetres) for the month of January, and

P_A = Mean annual precipitation (in millimetres).

Where specific monthly evaporation data are scarce, taking 10% of the total annual evaporation can approximate January evaporation values. The specific types of weathering processes that predominate in regions with different Weinert N values are shown in **Table 2.3**.

Table 2.3: Weathering characteristics associated with different Weinert N values.

Weinert Index Value	Weathering Characteristics
0.00 – 2.00	Predominantly chemical weathering
2.01 – 4.00	(Wet) Seasonal dominance of chemical weathering
4.01 – 5.00	Approximately equal chemical and physical weathering
> 5.00	Dominance of physical weathering processes

Mechanical weathering processes dominate in arid areas with low rainfall and high evaporation rates, causing the fragmentation of primary minerals such as quartz into smaller fragments and soils are predominantly sandy. Conversely, in warm, humid and wet landscapes chemical weathering processes dominate soil formation, giving rise to extensive deposits of secondary clay minerals. In zones where intermediate rainfall and evaporation values are recorded, both mechanical and chemical weathering processes are equally important. Mechanical weathering processes increase in importance as the rainfall declines and chemical weathering processes decrease in importance as determinants of soil formation.

Mines located in areas where Weinert N values are less than 2.00 usually show distinctive contributions to water quality and often require concerted management attention to prevent, minimize and/or remediate problems related to "water pollution". Conversely, mines located in areas where Weinert N values are substantially greater than 5.00 usually show little or no contribution to local water quality and often allow mine management considerable leeway in their "pollution control" efforts.

2.8 Legislative requirements for the control and management of impacts attributable to mining operations in southern Africa

In southern Africa, the respective Constitutions of the different SADC countries provide the foundation for legislation to control environmental impacts by promoting the rights of all people to a "safe and healthy environment". Despite minor differences between the legislation in the different countries, the basic intentions are very similar.

Currently, most countries still have several old and new sets of interlocking legislation that exert control over mining and related activities and their impacts on the environment. Many of these acts are now in the process of revision to reflect more clearly the principles embodied in their respective constitutions and the tenets of international treaties designed to minimize environmental degradation. Inevitably, the changes in existing legislative frameworks in each country are complicated by the fact that some pieces of legislation can be interpreted in ways which appear to conflict with the terms and conditions set out in other legislation. Similarly, there are situations where legislative requirements in neighbouring countries differ from each other, thereby complicating the process of managing impacts on shared resources (e.g. shared river basins). Nevertheless, despite these differences, the legislative framework in each country seeks to promote the economic benefits to be gained from mining whilst reducing to a minimum the risks to human safety and the adverse consequences of environmental degradation. From an environmental perspective, most attention is focused on minimization of waste products and associated sources of pollution or contamination, and the rehabilitation of land surfaces that have previously been mined or used for the disposal of waste products (Wells *et al*., 1996; Gurney *et al*., 1996; Chenje, 2000; SADC-MSCU, 2001).

Clearly, this attention to minimizing the adverse consequences of mining activities is a welcome development. In this context, it is also clear that many older mining operations started at a time when there was little or no explicit concern for the surrounding environment. Disposal of wastes was carried out in a manner designed solely to minimize costs, rather than to prevent pollution or facilitate rehabilitation. In many instances, old mines were simply abandoned and no attempt was required (or made) to rehabilitate the surface workings when the economic life of the ore body was exhausted. This situation now places enormous responsibility for rehabilitation on the respective governments, and is accompanied by a considerable economic burden (Fuggle & Rabie, 1996; Chenje, 2000).

In some SADC countries, however, certain pieces of legislation that cover air and water pollution are poorly enforced as a result of both weak institutional arrangements and inadequate or incomplete provisions in legislation. Chenje (2000) cites Zimbabwe's Atmospheric Pollution Act of 1971 as being a case in point, where industries that existed prior to promulgation of the legislation are allowed to continue using outdated equipment and need not upgrade their facilities.

In contrast, Zambia's Air Emission Control Regulation Statutory Instrument No. 141 of 1996 is stronger and sets out emission limits for sulphur dioxide, dust and heavy metals, but ignores the problems of greenhouse gases

(Chenje, 2000). Despite the recent improvements in atmospheric pollution legislation in many SADC countries, inadequate monitoring coupled to low penalties enable many companies to pay pollution fines and “continue operating as usual” (Chenje, 2000).

In South Africa, recent enabling legislation, particularly the Water Act and the Environmental Management Act provide specific guidelines that exert control on the ways in which mining and quarrying activities may be conducted (Ashton, 1999). In many instances, the provisions of these two Acts complement and enhance components of the existing (and soon to be upgraded) Mines and Minerals Act that are designed to control mining activities. In terms of current legislation in virtually all SADC countries, an environmental impact assessment (EIA) must be carried out before a mining licence can be granted for all new terrestrial and offshore mining activities. As part of this process, mining companies are legally required to consult widely with the affected public during the EIA and also to ensure that all the necessary licences and permissions will be forthcoming from the relevant local, provincial or national authorities (Weaver & Caldwell, 1999).

The South African situation is similar to that in most countries with established EIA legislation where virtually all mining activities are classified as "likely to significantly affect the environment" and require that a full-scale EIA be conducted before taking the decision to proceed (Donnelly *et al*., 1999). In some countries, this requirement relates to the size of a proposed mining or quarrying operation. In Canada, for example, a full EIA is required for all proposed construction, expansion, decommissioning or abandonment of any mining project with a "footprint" greater than 25 hectares or where the production capacity exceeds specific limits (Weaver & Caldwell, 1999).

Whilst the "size limit" requirement for an EIA may be a useful and pragmatic approach, considerable caution is required in those cases where several "small" operations may be located in close proximity to one another and whose combined impacts may be very large. In such situations, it is useful to adopt a more "strategic" approach to the problem and thereby ensure that appropriate attention is paid to the likely cumulative impacts of several small operations (Buckley, 1998). This process will also help to eliminate instances of poor or inadequate planning, and reduce the potential risks associated with future rehabilitation costs.

A case in point relates to the complicated situation which surrounds many small-scale, often "illegal" mining operations, particularly the situation of so-called "artisan miners" who are a common feature of the mining scene in several parts of southern Africa. In such cases, each individual operation is not only well below the minimum size limit that would require an EIA, but many of the operations are not registered or the claims are worked illegally. Furthermore, many of the so-called beneficiation techniques used not only pose potential environmental risks, but they also have the potential to cause significant human health problems (e.g. the use of mercury to concentrate gold). Perhaps more important than the absence of formal government control, however, is the fact that there appears to be very little effort made to ensure that these operations cause the least possible risk to human health and minimize the potential for environmental damage (Ashton, 1999).

One of the most important objectives that the SADC countries should seek to attain in the short-term is a harmonization and rationalization of their respective pieces of legislation that relate to mining activities and to the control of environmental impacts, particularly those that relate to water. This would help to eliminate inconsistencies between countries and would also help to enhance a sense of shared or common purpose between the states. A partial listing of the relevant legislation for the different SADC states is given in **Table 2.4**. In recent years, SADC member states have succeeded in drawing up and ratifying several treaties and protocols designed to improve inter-country relations and complement the approaches adopted in each country. A notable example in this regard is the SADC Protocol on Shared Water Course Systems that seeks to harmonize relations between states in terms of their use and management of shared river basins and rivers in the region.

The Mineral Resources Centre at the University of Zimbabwe have drawn up a comprehensive document that describes the history of mining in Zimbabwe, as well as the policy and statutory framework that governs mining and mineral processing, water resource management, environmental conservation and impacts on the environment. This document has been reproduced in full in **Section 2.9** of this report and can serve as an example that should be emulated for each of the SADC countries. This would allow a comprehensive overview to be made of all policies and legislation related to mining impacts on the environment and would help harmonization between countries.

Table 2.4: Partial listing of relevant legislation relating to mining activities and the control of environmental impacts in some of the SADC states.

Country	Sector / Area	Laws or Regulations
Angola	Water Resources and	• Decree of 1 December 1992

	Pollution Fisheries and Wildlife Land and Water Resources	• Decree Law No. 39193 of 1953 • Decree Law No. 40040 of 1955 • Decree Law No. 46186 of 1965 • Legislative Edict No. 3574 of 1965
Botswana	Water Resources Environment Atmosphere Heath Mines, Quarries, Works	• Water Act, 1968 • Boat Regulations • Declaration of Infested Waters • National Conservation Strategy • Atmospheric Pollution (Prevention) Act, No. 18 of 1971 • Declaration of Controlled Areas Order, No 109 of 1979 • Factories Act • Sanitary Accommodation Regulations • Public Health Act • Mines, Quarries, Works and Machinery Act
Lesotho	Water	• Water Resources Act No. 22 of 1978
Malawi	Environmental Management Land Use Management Fisheries Water	• Environmental Management Act, No. 23 of 1996 • National Parks and Wildlife Act, 1992 • Land Act of 1965 • Fisheries Management & Conservation Act of 1997 • Water Resources Act of 1969, and its Amendment of 1978
Mozambique	Land Water Resources Mining Health / Pollution Environment	• Land Act, 1979 • Water Act No. 16 of 1991 • Mining Act, 1986 • Pesticides Regulations, 1987 • General Environment Act, No. 20 of 1997
Namibia	Land / Water Mines and Minerals Pollution Health	• Water Act No. 54 of 1956 • Water Amendment Act, No. 22 of 1985 • Minerals (Prospecting & Mining) Act, 1992 • Soil Conservation Act, 1969 • Agriculture (Commercial) Land Reform Act, 1995 • Mines Regulations of 1993 • Prospecting and Mining Act, No. 33 of 1992 • Agricultural Pests Act, 1973 • Atmospheric Pollution Prevention Ordinance, No. 11 of 1976 • Hazardous Substances Ordinance, Act No. 14 of 1974 • Machinery and Occupational Safety Act, No. 11 of 1992 • Labour Act of 1992 • Public Health Act, No. 36 of 1919
South Africa	Environment Water Health Minerals and Mining Miners Health	• Environment Conservation Act No. 73 of 1989 • National Environmental Management Act (NEMA) No. 107 of 1998 • Environmental Laws Rationalization Act, No. 51 of 1997 • National Water Act, No. 36 of 1998 • Water Services Act, No. 108 of 1997 • Atmospheric Pollution Prevention Act, No 45 of 1965 • Occupational Health and Safety Act, No. 85 of 1993 • National Health Act, No. 63 of 1977 • Labour Relations Act No. 66 of 1995 • Minerals Act No. 50 of 1991 • Mine Health and Safety Act No. 29 of 1996 • Mines and Works Act No. 27 of 1956 • Mineral and Energy laws Amendment Act, No. 47 of 1994

		• Nuclear Energy Act, No. 46 of 1999
Swaziland	Water Environment	• Water Act of 1967 • Protection of Fresh Water Fish Act, 1938 • Swaziland Environment Authority Act, No. 15 of 1992
Tanzania	Fisheries Water Resources Mining Environment Petroleum Health	• Fisheries Act, 1970 • Water Utilization (Control & Regulation) Act, 1974 and Amendment, 1981 • Mining Act, 1979 • National Environment Management Act, 1983 • Petroleum Act, 1980 • Public Health Ordinance CAP 336 • Protection from Radiation Act, 1983
Zambia	Water Resources Health Land / Water Resources and Environment Mines and Minerals	• Water Act, Chapter 312 • Water Pollution (Effluent and Wastewater) Regulations, 1993 • Zambezi River Authority Act, 1986 • Public Health Act, 1930 • Factories Act, 1967 • Action for Smoke Damage Act, 1959 • Air Pollution Control Regulations, 1996 • Environmental Protection and Pollution Control Act No. 12 of 1990 • Environmental Protection Control (Environmental Impact Assessment) Regulations, 1997 • Natural Resources Conservation Act, 1970 • Petroleum Act, 1985 • Explosives Act, 1974 • Mines and Minerals Act, 1995 • Mining (Dumps) Regulations, Act 31 of 1995 • Mines and Minerals (Environmental) Regulations, 1997 • Mines and Minerals (Environmental Protection Fund), 1998
Zimbabwe	Natural Resources Mines Pollution / Health / Atmosphere Land / Water Resources	• Natural Resources Act, 1996 • Parks and Wildlife Act, 1998 • Mines and Minerals Act, 1996 • Explosives Act, 1972 • Atmospheric Pollution Prevention Act, 1971 • Water Act of 1977 and its Amendment of 1998 • Hazardous Substances and Articles Act, 1961

2.9 Legal and policy frameworks that influence or control mining and minerals processing activities in Zimbabwe

2.9.1 Introduction

Zimbabwe has a long history of mining, dating from at least the twelfth century. The early twentieth century colonial economy was primarily a settler mining economy. This dated back to the occupation of the country in the late nineteenth century. Indeed, Cecil Rhodes' expectations of discovering a "Second Witwatersrand" in Mashonaland were a major motivating factor behind the occupation. This attitude towards mining has translated into a bias in national legislation in favour of mining that is still current today. Mines and minerals legislation tends to override all other legislation, including parts of the recent Water Act[1].

The mining industry is a major water user: both in terms of consumption, and in terms of disposal of wastewater. The management of water quality in mining operations relates mainly to two areas: disposal of wastewater, and contamination of water from mining operations (Love & Hallbauer, 1999). Mines are also required to comply with a variety of environmental impact assessment protocols and guidelines.

There are a number of other Acts with the power to regulate mining activities in Zimbabwe. Although Zimbabwean water and environmental legislation has been revised in the last few years, the legislation remains somewhat fragmented. Indeed, the existing legal basis for environmental protection is inadequate to address conventional air and water pollution issues, let alone more recent environmental concerns such as hazardous waste, emission of "greenhouse" gases, leaking underground storage tanks, or environmental emergency "preparedness" plans. One reason for this inadequacy is the fact that amendments to the original statutes, adopted from British laws in the 1960s and 1970s, have not kept pace with scientific advances or regulatory improvements.

In recent years an increasing number of developers, trans-national firms and international donors have undertaken environmental impact assessments (EIAs) for large and environmentally significant projects in Zimbabwe as global awareness of the importance of environmental protection has accelerated. Furthermore, following recent revisions of the Mines and Minerals Act, new mining operations involving investments in excess of US$ 100 Million, are now required to submit an environmental report with their application for a special mining lease. In this regard, the mining industry has made significant advances in environmental management of mining operations, and the industry has implemented a number of initiatives to increase awareness of environmental matters.

In recognition of the shortcomings and gaps in its environmental laws and regulations, in 1992, the Ministry of Environment and Tourism, through the Department of Natural Resources, initiated a programme to upgrade the existing legislation. The programme intends to develop new laws, where needed, and integrate the nation's overall approach to environmental protection. A key component of this effort is to develop regulations and procedures to guide the preparation of EIAs for all environmentally significant projects undertaken in Zimbabwe. In 1995 the Ministry published an "Interim EIA Policy" and guidelines for the preparation of EIAs.

The following discussion revolves around the legislation and how it regulates mining with respect to the environment. It is not meant to be an exhaustive description of each Act. **Tables 2.5** and **2.6** list the current legislation, together with its controlling Ministry, which has a bearing on the issue of mining impacts of water resources in Zimbabwe, and the series of activities that are subject to such legislation.

Table 2.5: Summary of relevant legislation in Zimbabwe.

Legislation	Type	CAP.	Date	Ministry
Environmental Impact Assessment Policy	Policy		1997	Environment and Tourism

[1] Section 5 of Act 31 of 1998

Draft Environmental Management Bill	Draft Bill		1998	Environment and Tourism
Mines and Minerals Act	Act	21:05	1996	Mines and Energy
Natural Resources Act	Act	20:13	1996	Environment and Tourism
The Parks and Wildlife Act	Act	20:14	1998	Environment and Tourism
Forest Act	Act	19:05	1996	Environment and Tourism
Explosives Act	Act	307	1972	Mines and Energy
Communal Land Forest Produce Act	Act	20 of 87	1987	Environment and Tourism
Water Act	Act	20:24	1998	Rural Resources and Water Development
Public Health Act	Act	15:09	1996	Health and Child Welfare
Hazardous Substances and Articles Act	Act	322	1961	Health and Child Welfare

Table 2.6: Activities and relevant legislation in Zimbabwe.

Activity	Responsible Authority	Relevant Act
Prospecting in protected areas	Parks and Wildlife Board	Parks and Wildlife Act
Environmental impact assessment	Ministry of Mines and Energy	Mines and Minerals Act
Allocation of water to mine	Ministry of Mines and Energy	Mines and Minerals Act
Water extraction	Zimbabwe National Water Authority (ZINWA)	Water Act
Health of workforce	Ministry of Mines and Energy	Mining (Health and Sanitation) Regulations
Use of timber on private or state land	Mining Timber Permit Board	Forest Act
Manufacture, storage and use of toxic material	Ministry of Health and Child Welfare	Hazardous Substances Act
Manufacture, storage and use of explosives	Ministry of Mines and Energy	Explosives Act
Waste disposal into water; disposal of wastewater	ZINWA	Water (Waste and Effluent Disposal) Regulations
Pollution of water	Ministry of Rural Resources and	Water (Waste and Effluent

	Water Development	Disposal) Regulations
Rehabilitation and closure of mine	Ministry of Mines and Energy	Mines and Minerals Act
Alluvial mining	Rural District Councils	Mining (Alluvial Gold) (Public Streams) Regulations
Consultation on water matters	ZINWA	National Water Authority Act

2.9.2 Mines and minerals legislation and policy

The Mines and Minerals Act was promulgated in 1961. Subsidiary legislation issued under the Mines and Minerals Act includes General Regulations, Management and Safety Regulations and Alluvial Gold Regulations. The relevance of these is discussed below.

2.9.2.1 Mines and Minerals Act (Chapter 21:05, Revised 1996)

The Mines and Minerals Act is continually under criticism from environmental groups, because it appears to override all other legislation in Zimbabwe. Prospectors and miners are allowed access to almost all land within the country, including National Parks (Section 26). However, there are some restrictions that include written consent from the "owner" (Section 31). Prospectors and miners are allowed access to water (Section 29) and timber (Section 36) with certain restrictions. Landowners may apply to the mining commissioner for a reservation against the cutting of indigenous timber, but the miners may take up to 50% of the timber on the land.

Section 159 (Special Mining Leases, 1994 Amendment) defines controls applicable to mines where the investment will be either wholly or mainly in foreign currency and will exceed US$ 100 million, and where the mines output is principally for export. An environmental impact report is required before these Special Mining Leases are issued and requires the developers to adhere to the following.

(vii) a report on the anticipated impact of mining operations on the environment and any measures to be taken to assess, prevent or minimise such impact, including proposals for:
   - A. the prevention or treatment of pollution; and
   - B. the treatment and disposal of waste;
   - C. the protection of rivers and other sources of water; and
   - D. the reclamation and rehabilitation of land disturbed by mining operations; and
   - E. monitoring the effect of mining operations on the environment;

Perhaps the closest reference to any form of environmental control on standard mining leases mentioned in the Mines and Minerals Act is seen in sections 234 to 241 (Appendix 2.1). In these sections a miner must submit a siting of works plan for approval to the mining commissioner. This plan should also show rivers, hills and other natural features. Section 236 allows for the lodging of objections within 21 days of their notification by the mining commissioner. It should be noted that the miner may carry out certain works before the plan is submitted. These works can include residential accommodation, roads and dumps.

There are several other sections within the Act that could be construed as rehabilitation regulations, but these were largely developed with safety in mind (Table 2.7).

Table 2.7: Sections of the Mines And Minerals Act (1996) relevant to environmental protection in Zimbabwe.

Section	Comment
267	The miner may remove buildings and machinery from an abandoned, forfeited or cancelled mining location.
269	The miner is required to fill in all shafts, open surface workings and excavations or to deal with them otherwise to ensure the safety of people and livestock. This should be done within 30 days of abandonment.
311	Timber on “Town Lands” cannot be cut without permission of the Mining Commissioner.
312	Water from mining operations on “Town Lands” shall not pollute surface water with mine water – but it must be disposed of in the nearest natural water channel.
370	Prospectors are required to fence or enclose the mouths of all shafts and other open surface workings for the protection of people and livestock. He should maintain these during the period that prospecting is continuing.
403	The minister can make regulations as deemed expedient regarding safety, sanitation, housing and feeding of employees, welfare etc; amongst other administrative matters.

The Act also recognises the powers of the Water Court, especially if it affects public water or irrigation projects.

2.9.2.2 Mining (Alluvial Gold) (Public Streams) Regulations, 1991 (SI 275/1991)

This statutory Instrument contains some environmental safeguards and is aimed at controlling the activities of small scale panning locations. These include the distance of workings from the stream bank (3 metres), the depth of unsupported workings (1.5 metres) and the use of machinery - which must be authorised by an inspector of mines in consultation with the provincial natural resources officer.

2.9.2.3 Mining (Health and Sanitation) Regulations, 1990 (S1 156/1977)

There are several sections of these regulations that deal with environmental concerns (Table 2.8). It should be noted that the responsibility for policing the regulations falls to an "Environmental Health Officer" who has to be registered with the health professions council (Medical, Dental and Allied Professions Act). However, the regulations fall under the Minister of Mines.

Table 2.8: Mining (Health And Sanitation) regulations with environmental control facets.

Section	Comment
5	All mines and dwelling places thereon shall be kept in a sanitary condition and adequately drained
6	Rubbish (other than mineral refuse) must be deposited on a site approved by an environmental health officer.
7	Disposal of carcasses
8	Burial sites
9, 10, 11 12, 13	Latrines (1 per family dwelling or 1 per 15 single men) to be approved by an environmental health officer. Regulation and use of underground latrines. Night soil removal and disposal.
22	Piped water system to the satisfaction of the environmental health officer. No polluted water to be used for domestic purposes. Adequate ablution facilities (to the satisfaction of the environmental health officer).
23	Protection of the water supply for domestic use (due care).
24	Sites for washing clothes to be approved.

2.9.2.4 Environmental Management Policy for the Mining Industry – 1995

The Ministry of Mines issued a second draft of an Environmental Management Policy for the mining industry in early 1995. The document was in four parts with Part 1 being a brief summary of the existing situation, a mission statement and some statements on environmental impact assessment, environmental management plans and guidelines. The mission statement is as follows:

> "The Department of Mining Engineering is committed to the safe and efficient extraction of the mineral resources of Zimbabwe and the promotion of responsible environmental management practices, consistent with the national policy of sustainable development of Zimbabwe's valuable natural resource base."

The draft policy encourages developers to consult with the Department of Mining Engineering before conducting an EIA. It also provides guidelines for the preparation of EIA reports on mining projects.

It is suggested that new small workings need only complete a brief "Statement of Environmental Effects" rather than a full EIA. This statement should include a description of the project and a works plan. The possible environmental hazards resulting from the mining operations and the mitigatory measures necessary for these hazards should be identified2.

Annexure C of the document is the one in which environmental management guidelines for mining and exploration in Zimbabwe are detailed. It covers tailings dams, waste rock dumps, shafts, open cast mines, quarries, alluvial mining, processing plants and both mineral and oil/gas exploration (Appendix 2.2).

2.9.3 Water and environmental legislation and policy

2.9.3.1 Introduction

There are many aspects of water issues in mining, which are subject to legal controls and protections. The concern about the pollution of water systems by mining was already being reflected in European legislation in the middle of the last century, e.g. the UK 1861 Land Drainage Act and 1876 Rivers Pollution Prevention Act (Fitzgerald 1902).

2.9.3.2 Water Act (20:24, No 31 of 1998)

The Water Act is to provide for the planning of the optimum development and utilisation of water resources. The Act establishes Catchment Councils3, under the Zimbabwe National Water Authority (ZINWA), and confers wide-ranging powers on them. Although this devolutionary reform process was designed to improve stakeholder participation and to empower local water users, especially rural communities, it has been shown that this is has not necessarily occurred. Problems include differential access to resources, the lack of a level playing field, financial costs of consultation and the veto held by the government on most issues (Sithole, 2000). In fact the Minister of Rural Resources and Water Development has extensive powers to override ZINWA and the Catchment Councils, as well as to issue directives to them.

[2] A major mine or quarry is defined as one in which more than 10 000 tons of ore or rock are mined or milled or one in which a surface area of more than two hectares is disturbed each year.

[3] Sections 20 - 22

The Act, like its South African equivalent4, provides for national ownership of water and licenses for use of water. However, unlike the South African law which vests ownership of water in the state, the Zimbabwean act vests all ownership of water in the President5. Regulation and supervision of water use and issuing of water permits is carried out by the Catchment Councils6.

Mining and mineral exploration operations retain rights granted to them by the Mines and Minerals Act with respect to surface water for domestic and brick making purposes and to groundwater7. However, to abstract water for purposes other than these, a mining operation must apply to the Mining Commissioner of the relevant mining district for a permit8. The Mining Commissioner shall "transmit the application, together with a report thereon by a government mining engineer, to the appropriate catchment council"9. This is presumably to provide for expert recommendations on the mining operation's needs. Records of the amount of water abstracted must be maintained10. The abstraction of water in the absence of a permit is an offence punishable by fine or imprisonment or both11.

The Act also addresses pollution of water. Many mines dispose of large quantities of wastewater: water from processing, water in slimes and also groundwater pumped out of the mine (Love & Hallbauer, 1999). The Act requires persons wishing to discharge waste to apply for a permit12. The Water (Waste and Effluent Disposal) Regulations (SI 274/2000; Appendix 2.3) were promulgated to give effect to this provision, and to replace regulations from the 1970s13. The 2000 regulations govern disposal of wastewater and disposal of waste into water and fall under the jurisdiction of Pollution Control Unit (PCU) of the Zimbabwe National Water Authority (ZINWA). These regulations require yearly permits for effluent and wastewater that is discharged or disposed of into any surface water or groundwater14, excepting septic tanks, municipal dumps and agricultural application of animal manure15. The PCU considers application for permits and may reject the application or award a permit, specifying effluent standards16. An "environmental fee" is charged per Megalitre of liquid waste disposed or for solid waste, and is increased for disposal of waste that constitutes a "high environmental hazard"17.

Permit holders are required to notify the PCU and downstream water users of "any accidental disposal or discharge of waste or effluent"18. What constitutes "accidental disposal or discharge" is not defined. However, defining accidents or emergency incidents is very difficult: for example, the relevant South African legislation

[4] National Water Act (Act No 36 of 1998), Republic of South Africa
[5] Section 3
[6] Sections 21 and 22
[7] Section 5
[8] Section 34(3)
[9] Section 34(4)
[10] Section 43
[11] Section 118(1)(b)
[12] Section 69
[13] RGN 687/1977
[14] Section 5(1)
[15] Section 11(1)
[16] Section 6 and 4th Schedule
[17] Section 9(6) and (7)
[18] Section 13

provides a definition but one which is extremely broad19. There are many occurrences in mining which could apply, such as overflowing of discharge canals, flooding of tailings dams or settling ponds, overloading of treatment works and the dumping of wastes (Love & Hallbauer, 1999). The Act also provides that pollution in the absence of an appropriate permit is an offence that may be punishable by fine or imprisonment or both20.

The regulations also provide for sampling procedures21 and for public access to information on permits current, applied for and rejected22. The attached schedules define river zones and the permissible levels of contamination.

Alluvial mining or other mining operations that may affect the banks, bed or course of a river or stream of springs or natural wetlands is subject to permission of the Catchment Council[23]. To carry out such activities without a permit is an offence punishable by fine or imprisonment or both[24].

The Minister of Rural Resources and Water Development may declare any area to be a water shortage area. In these areas permits for the abstraction and use of underground water are required[25].

2.9.3.3 Parks and Wildlife Act (20:14 – Revised 1996)

The Parks and Wildlife Act establishes a Parks and Wildlife Board and provides for the establishment of national parks, botanical reserves, botanical gardens, sanctuaries, safari areas and recreational parks. It also makes provision for the preservation, conservation, propagation, or control of wildlife, fish and plants of Zimbabwe and the protection of her natural landscape and scenery. Permits are required for prospecting and mining within the Parks and Wildlife Estate.

2.9.3.4 Forest Act (19:05 – Revised 1996)

The Forest Act establishes a commission for the administration, control and management of state forests as well as a Mining Timber Permit Board. Other functions include the control of burning, regulation of trade of forest produce and to provide for the conservation of timber resources. The Act has some regulations pertaining to the use of timber by miners and prospectors that seems at odds with those stipulated in the Mines and Minerals Act. Firstly no miner shall cut, injure or destroy any indigenous trees or timber from any State or private land unless

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[19] "Any incident or accident in which a substance (a) pollutes or has the potential to pollute a water resource; or (b) has a detrimental effect or is likely to have a detrimental effect on a water resource" Section 20(1) of the [South African] National Water Act (Act 36 of 1998)
[20] Section 68
[21] Section 8
[22] Section 10
[23] Section 46
[24] Section 118(1)(g)

he/she is in possession of a permit issued by the Mining Timber Permit Board (Section 45). The Minister of Mines and Energy may also require that certain measures be taken by the owner or occupier of private land to prevent environmental damage resulting from tree felling or cutting methods (Section 56).

2.9.3.5 Natural Resources Act (20:13 – Revised 1996)

The Natural Resources Act provides for the conservation and improvement of natural resources both inside and outside Communal Lands. It also allows for establishment of the Natural Resources Board, Intensive Conservation Areas, and soil and water use restrictions. It does not provide legislative authority for the establishment of a Natural Resources Ministry and Department to manage natural resources, control pollution or carry out environmental assessments.

2.9.3.6 Hazardous Substances Act (Chapter 322 - 1972)

The Hazardous Substances and Articles Act assigns substances to one of three groups for regulation and control and is administered by the Ministry of Health and Child Welfare. The Act can apply to any substance or mixture of substances which may endanger the health of human beings, domestic or wild animals, birds or fishes as a result of its toxic, corrosive, irritant, sensitory, inflammable or radio active nature.

2.9.3.7 Explosives Act (Chapter 307 - 1961)

The Explosives Act deals with the manufacture, purchase, possession, delivery, storage, use and conveyance of explosives. Licences and/or permits are required for these activities. There are no sections within the regulations or the Act that could be interpreted as being related to environmental protection.

2.9.3.8 Public Health Act (15:09 – Revised 1996)

The Public Health Act makes provisions to safeguard public health. In environmental terms it can prohibit or regulate activities likely to pollute streams, which, in time, can become a nuisance or danger to health (Section 68).

In addition, nuisances are prohibited. Nuisance, as defined by the Act, covers a wide variety of health, safety and hygiene aspects. The powers of this Act could be broad ranging if required.

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[25] Sections 61 - 66

2.9.3.9 Zimbabwe Environmental Impact Assessment Policy, 1994

The Interim Policy issued by the Ministry of Environment and Tourism is based on seven principles that serve as guidelines for decision-making on policy implementation. These principles are:

1). The EIA must enhance and not inhibit development, by contributing to environmental sustainability.

2). EIA is a means for project planning, and not just evaluation

3). Identifying means for managing project impacts is an essential component of the EIA Policy

4). The EIA Policy depends on the normal regulatory functions of permitting authorities to implement the EIA results.

5). The EIA Policy involves the participation of all government agencies with a mandated interest in the benefits and costs of a project.

6). The EIA Policy pays particular attention to the distribution of project costs and benefits

7). Public consultation is an essential part of EIA Policy[26].

Compliance with the Policy is currently voluntary, but it is expected to be legislated soon. The Interim Policy is administered by the Ministry of Environment and Tourism and applies to both private and public sector developments. The document has a list of prescribed activities for which EIAs are required (Table 2.4). In addition the Minister is empowered to prescribe other activities, which he/she feels may have significant environmental impacts, or cause community disruption.

All submissions under the Interim Policy are made to the Minister, who will maintain a register of all activities being appraised. Three levels of reports are possible[27].

1) A **Prospectus** is a short (1 or 2 page) document informing the Minister that a prescribed activity is being considered. Based on the prospectus the Minister has 21 days to decide if the second level of report - a Preliminary EIA - is needed[28].

2) The **Preliminary EIA** is a comprehensive initial assessment of the environmental impacts of a project. Detailed Terms of Reference need to be approved by the Ministry, who may require that a joint scoping exercise between the proponent and the Ministry be carried out before the Terms of Reference are written. The Natural Resources Board, who may call in outside advisors, reviews the draft report. The Ministry has 60 days in which to review the first draft and 30 days to review subsequent drafts. The final document is either approved and the activity is allowed to proceed, subject to, if necessary, environmental terms and conditions, or it is not granted and a detailed EIA is requested on the significant impacts[29].

[26] Section 3
[27] Section 4
[28] Section 4.1
[29] Section 4.2

3) The **Detailed EIA** is not a comprehensive document, but rather focuses on the issues of primary concern. It should be undertaken in close liaison with engineering, financial and other project planners. The Detailed EIA is subject to a similar review process as the preliminary EIA[30].

Public consultation is regarded as being a very important part of the EIA process. The project proponents are expected to ensure that public consultation does take place during the EIA. The general public must also have access to all documentation on the project written during the EIA process[31].

The Interim EIA Policy is backed by a draft "General Environmental Impact Assessment Guidelines". This detailed document covers the general format that should be used when preparing an EIA. Again, public consultation is considered to be a vital part of the process. The proponents are also required to draw up an environmental management plan. It should be noted that the Ministry is in the process of drawing up the Environmental Management Act, which seeks to combine the disjointed legislation controlling use and abuse of the environment into a single Act.

***Table 2.9**: Prescribed Activities For Which EIAs Are Required.*

Sector	**Activity**
Agriculture	°New agricultural land development °Land subdivision °Feedlots
Dams	
Drainage and Irrigation	°Wetland or wildlife habitat drainage °Irrigation Schemes
Forestry	°Conversion of forest land to other use °Conversion of natural woodland to other use within important catchment areas (e.g. adjacent to National Parks or supplying reservoirs and irrigation projects).
Housing	Housing Developments

30 Section 4.3
31 Section 5

Sector	Activity
Industry	°Chemical and Petrochemical plants °Lime plants °Iron and Steel smelters and plants °Cement plants °Smelters other than iron and steel °Tanneries °Pulp and paper mills °Breweries °Agro-industries °Industries involving the use manufacture, handling, storage, transport or disposal of hazardous or toxic materials
Infrastructure	°New towns or townships °Highways °Airports and airport facilities °New rail lines °Industrial sites for medium and heavy industries
Mining and Quarrying	°Mineral prospecting and mining °Ore processing and concentrating °Quarrying
Petroleum	°Oil and gas exploration and development °Oil and gas separation, processing, handling and storage °Oil refineries °Pipelines
Power Generation and Transmission	°Thermal power stations °Hydro-power schemes °High voltage transmission lines
Tourist, Resort and Recreational Development	°Resort facilities and hotels °Marinas °Safari operations
Waste Treatment and Disposal	°Toxic and hazardous waste, incineration plants, recovery plants, wastewater treatment plants, landfill facilities and storage facilities. °Municipal solid waste and sewage schemes
Water Supply	°Groundwater development for industrial, agricultural or urban water supplies. °Water withdrawals from rivers or reservoirs °Major pipelines or canals °Cross-drainage water transfers

2.9.4 Chamber of Mines Environmental Management Guidelines, 1994

The Chamber of Mines prepared and released a set of Guidelines in response to developing government environmental impact management policy (COM, 1994). It should be noted that this predates the Zimbabwe Environmental Impact Assessment Policy, 1994. The Guidelines cover rehabilitation32, effluent disposal33, re-vegetation and prevention of erosion34, river diversions35, dumps and tailings dams36 and exploration activities37. However, the Guidelines are generally vague and without detail. It is to be hoped that more detailed guidelines will be prepared by the Chamber subsequent to the promulgation of proposed new environmental management legislation.

2.9.5 Concluding Remarks

Much of the legislation governing environmental and water affairs applied to mining is still in its infancy, and much remains to be done to work out how the many different laws and regulations interconnect and how the spheres of activity and control of the various different government agencies interact. In the meantime, there is little clarity on exactly where a mining operations legal responsibility towards water systems begins and ends. There is no simple answer to what legally constitutes impact as such. However, the best guide is that provided by the standards contained in the Water (Waste and Effluent Disposal) Regulations, see **Appendix 2.3** and also **Table 2.10** below.

Table 2.10: Comparison of Various Standards. Values in ppm unless specified

Parameter	Maximum level	
	Zimbabwe	South Africa
Aluminium	*	0.15
Ammonia (NH3)	0.50	1.00
Arsenic (As)	0.05	0.01
Barium (Ba)	0.50	*
Biological Oxygen Demand	30.00	*
Boron (B)	1.00	*
Cadmium (Cd)	0.01	5.00
Chloride (Cl-)	250.00	100.00
Chlorine residual (free Chlorine)	0.10	*
Chromium (Cr (hex))	0.05	0.50
Chromium total (Cr)	1.00	*
Cobalt (Co)	*	*
Chemical Oxygen Demand	50.00	*
Colour (TCU)	15.00	*
Conductivity (µS/cm)	1000.00	*
Copper (Cu)	1.00	1.00

[32] Sections 2 – 4, 23, 24, 27, 28, 30, 32, 33
[33] Sections 5 – 6, 35
[34] Sections 11 - 13
[35] Section 14
[36] Sections 19 – 21, 29, 34
[37] Sections 36 - 42

Cyanides and related compounds (CN)	0.07	*
Free Cyanide (CN^-)	0.07	*
Detergents	1.00	*
Faecal coliforms (No./100ml)	1000.00	0.00
Fluoride (F)	1.00	1.00
Grease & Oil	2.50	*
Helminth eggs (No/100ml)	1000.00	*
Iron (Fe)	1.00	0.10
Lead (Pb)	0.05	0.01
Manganese (Mn)	0.10	0.05
Mercury (Hg)	0.10	0.00
Nickel (Ni)	0.30	*
Nitrite Nitrogen (NO_2)	3.00	6.00
Nitrogen total (N)	10.00	*
Oxygen absorbed	10.00	*
Phenolic compounds (phenol)	0.01	0.00
Phosphates Total (P)	0.50	*
Selenium (Se)	0.05	0.02
Sodium (Na)	200.00	100.00
Parameter	**Maximum level**	
	Zimbabwe	**South Africa**
Sulphate (SO_4)	250.00	200.00
Sulphide (S)	0.20	*
Total dissolved solids	500.00	450.00
Temperature deg. C	35.00	*
Total heavy metals	2.00	*
Total suspended solids	25.00	*
Turbidity (NTU)	5.00	1.00
Zinc (Zn)	0.50	3.00
Dissolved Oxygen % Saturation	**Minimum** 60%	*
pH (pH units)	**Range**: 6 - 9	**Range**: 6 - 9

- * Means that no limit is specified
- Values in parts per million (ppm) unless specified
- Zimbabwean limits: "blue normal" limits specified by 4th Schedule of Water (Waste and Effluent Disposal) Regulations
- South African limits: limits for domestic use (DWAF, 1996)

2.10 Principal approaches adopted to minimize and manage environmental impacts arising from mining operations

Minimizing and managing the range of environmental impacts associated with mining and mineral processing operations in the SADC countries poses several challenges to national, regional and local authorities, as well as the companies responsible for operating the mines. Several different strategies are employed to meet these challenges in each country and a brief overview is presented here.

In general terms, the SADC countries have responded to the threat of environmental degradation in their respective countries by developing National Conservation Strategies (NCSs) and National Environmental Action Plans (NEAPs), many of which have been decentralized to district level (e.g. Zambia and Zimbabwe; Chenje, 2000). These developments continue to be supported by international development and aid organizations such as the United Nations Development Programme (UNDP), the World Conservation Union (IUCN) and the Global Environment Facility (GEF).

Further programmes such as those directed towards cleaner production technologies and the Biodiversity Strategic Action Plan (BSAP) deal with biodiversity and pollution prevention issues. These are implemented at national and regional levels through support from both private sector and international development aid agencies.

Every SADC country has an array of legislation, regulations and environmental standards that seek to regulate developments that impact on the environment, monitor human impacts and help enforce environmental laws. However, whilst these laws are in place, the regulation, monitoring and enforcement of these well-intentioned pieces of legislation are hampered by a lack of resources, inadequate technical capacity and poor national and regional co-ordination (Chenje, 2000).

Part of the reason for this situation is due to the fact that many government ministries in each country share responsibility and accountability for different aspects of the environment, or activities that impact on the environment, thereby complicating enforcement procedures and processes. As a result, companies that own or operate mining undertakings are subject to several different pieces of legislation, each of which is often administered by a different government department or authority. In the absence of proper co-ordination and clear allocation of responsibility, it becomes difficult to develop and implement cost-effective management strategies to minimize and control environmental impacts (Ashton, 1999; Chenje, 2000).

The uncertainties caused by inconsistent legislation and inadequate enforcement have inevitably led to reservations in the minds of mine operators regarding the best approaches to prevent, minimize and remediate the impacts that may be attributable to their mining operations. Growing international requirements for improved environmental management systems in mining and mineral processing operations further complicates this situation. Many marginal mines also face the prospect of closure as mineral commodity prices decline worldwide; to these mines, environmental management and impact reduction activities represent an unwelcome financial burden.

More recently, attention has been focussed on ensuring that environmental management actions are integrated throughout the mine's life cycle so that, on closure, the mine site is regarded as an "environmental asset" (Smithen *et al*., 1997). A number of agencies worldwide promote this integrative approach to environmental management in mining, for example, the Australian Environmental Protection Agency, the Canadian Department of Natural Resources and the South African Department of Mineral and Energy Affairs (Australian Environmental Protection Agency, 1995-1996; Weaver & Caldwell, 1999). The approach to integrating environmental management into the full mine life cycle has also been adopted in South Africa (Freer, 1993).

Typical mining impact management and mitigation measures include the adherence to the Best Practice Guidelines that have been developed for a range of mining activities (for example, water quality management), investigating alternative locations for infrastructure and waste disposal sites, the adoption of different mining and beneficiation technologies, the use of cleaner production technologies, recycling of water and specific materials, pollution control measures, rehabilitation and landscaping, and the acquisition of additional property to compensate for habitat loss (Ashton, 1999).

An important development in the improvement of environmental management practices in mining operations is the growing awareness of, and acceptance of, formal management systems such as those developed by the International Standards Organization (the ISO series of management guidelines). Increasing numbers of mining operations are implementing the ISO 14000 series of environmental management plans, both in an attempt to reduce and manage their environmental impacts, and to comply with growing international market requirements for "certificates of environmental responsibility" by providers of goods and services. The ISO series of guidelines is internationally accepted and provides mining companies with the necessary certification if an environmental audit demonstrates that they comply with the conditions of their environmental management plans.

In South Africa, mining environmental management practices are currently guided by the 1992 Aide Mémoire for the preparation of Environmental Management Programme Reports for Prospecting and Mining (Department of Minerals and Energy, 1992) and enforced by both the Minerals Act, No. 50 of 1991, and the National Environmental Management Act, No. 107 of 1998. Recent developments aimed at improving environmental management practices in the mining sector include the first draft of the new Minerals Development Bill, released for comment by the Department of Minerals and Energy in December 2000, while the Aide Mémoire is currently being revised and expanded.

By the very nature of its activities, the mining sector will continue to drive environmental change, despite the plethora of environmental guidelines, legislation and substantial impact mitigation and management measures developed to address many of the adverse environmental affects. Perhaps the most important challenge facing the mining sector today is the need to embrace the concept of sustainable development and, in doing so, to improve public perceptions, particularly with regards to social and environmental issues of concern.

3. THE ZAMBEZI BASIN

In order to provide a suitable background for subsequent descriptions of the impacts of mining on water resources in the Zambezi basin, this section starts with a brief overview of the catchment characteristics. This is then followed by condensed descriptions of the information relating to mining activities and their impacts in each sub-catchment.

3.1 Introduction

The Zambezi River is recognized as one of the largest and most important rivers in southern Africa and its basin comprises portions of eight SADC states (Angola, Botswana, Malawi, Mozambique, Namibia, Tanzania, Zambia and Zimbabwe; **Table 3.1**; **Figure 1.1**). The basin is located between 8 ° and 20 ° South latitude and between 16.5 ° and 36 ° East longitude, with a total area of some 1,281,800 km^2, comprising approximately 23 % of the total area of the basin states. The area contributed to the basin by each state varies between 1.9 % (Namibia) and 42.1 % (Zambia), with four of the eights states (Angola, Mozambique Zambia and Zimbabwe) contributing a combined total of 83.9 % of the entire basin area (**Table 3.1**).

Table 3.1: Area statistics for the eight SADC states comprising the Zambezi basin. [Data obtained from Chenje (2000) and Ashton & Ramasar (2001)].

Country	Total Area of Country (km^2)	Country Area in Basin (km^2)	Proportion of Country Area (%)	Proportion of Basin Area (%)
Angola	1,246,700	145,000	11.6	11.3
Botswana	600,370	34,000	5.7	2.7
Malawi	118,484	110,390	93.2	8.6
Mozambique	801,590	140,000	17.5	10.9
Namibia	825,418	24,000	2.9	1.9
Tanzania	945,087	37,000	3.9	2.9
Zambia	752,614	540,000	71.7	42.1
Zimbabwe	390,759	251,410	64.4	19.6
Totals:	5,680,843	1,281,800	22.6	100.0

The Zambezi River and its dense network of tributaries and associated ecosystems constitute one of southern Africa's most important natural resource systems. The basin is considered to be a regional centre of endemism due to the extraordinary diversity of ecosystem components and the flora of the Zambezian unit is reported to be one of the richest in Africa with over 6,000 species of flowering plants, as well as 650 species of birds and over 200 species of mammals (Chenje, 2000). The basin also has some of the most important National Parks in southern Africa, including Chobe in Botswana, Liwonde in Malawi, Gorongoza-Marromeu in Mozambique, Kafue and Luangwa in Zambia and Hwange in Zimbabwe. In addition, several other protected areas and Game Reserves are also located in the basin.

The Zambezi basin's river systems provide most of the SADC region's hydropower generation, support some of the region's poorest subsistence communities and represent a series of critical assets in terms of the region's tourism and recreational opportunities (Chenje, 2000).

3.1.1 Geology, topography and soils

The Zambezi basin is located between the three Archaean Cratons: the Central African Craton to the northwest, the Tanzanian Craton to the northeast and the Zimbabwe lobe of the Kalahari Craton to the south. The Archaean Craton rocks comprise mainly granitic terrain, intruded by various Greenstone belts and dolerite dykes and sills. Karoo System rocks overlie large areas of the central portion of the basin and these are intruded by younger (Cretaceous) crystalline rocks, consisting predominantly of shales, sandstones and conglomerates. Recent sedimentary deposits line most of the river valleys (SADC-MSCU, 1998; Chenje, 2000).

In the east, the southern extension of the east African Rift Valley, containing Lake Malawi, forms the eastern rim of the basin. A second rifting structure, the Luangwa and Lunsemfwa Rift Valleys in Zambia lie almost parallel to the Lake Malawi basin. The zones between the three Archaean Cratons are marked by several mobile belts where considerable seismic activity has taken place and mineralization has occurred along fault and shear planes (SADC-MSCU, 1998).

The crystalline rocks underlying the central region of the Zambezi basin have been formed through metamorphosis of sedimentary deposits. These rocks have complex structures and contain most of the mineralization recorded in the basin.

The topography of the Zambezi basin is very varied. The elevation of the catchment rim ranges from some 1,000 metres in the west (in Angola), to over 3,000 metres in the east at points along the eastern rim of the Lake Malawi Rift Valley (e.g. the Zomba and Mulanje Mountains in Malawi), to sea level at the Zambezi mouth at Chinde in Mozambique.

The terrain separating the Lake Malawi and Luangwa River rifts is also marked by several points of high elevation, notably the Nyika and Viphya plateaux marking the border between Zambia and Malawi, as well as the Livingstone Mountains along the northern border with Tanzania (Chenje, 2000). On its western flank, the Luangwa Rift Valley is marked by the high Muchinga escarpment. The central portion of the Zambezi basin is marked by undulating terrain with low hills and escarpments formed by outcrops of quartzites, granites, schists and gneisses. In the north, the region of the Zambian Copperbelt, quartzitic sandstones outcrop at surface. Many of these rocks are stained green by oxides and carbonates of copper (Mendelsohn, 1961).

In its upper reaches, the Zambezi River flows along a relatively broad, moderate-gradient valley, until reaching the Victoria Falls. At this point, the river has incised through some 60 metres of Karoo Supergroup basalts and flows in a deep, narrow gorge until reaching Lake Kariba. The river gradient in these middle reaches is relatively low, and the river flows within a deep valley flanked on the Zambian and Zimbabwean banks by steep terrain. At Cahora Bassa, the river gradient steepens slightly, flowing through a second set of narrow gorges before emerging into the lower reaches within a broad shallow valley. Downstream of the town of Tete in Mozambique, the Zambezi River meanders along a broad, flat-bottomed valley and is joined by the Shire River from the north before reaching the delta at the coast. Features of the Zambezi delta (increased salinity, tidal movements) are recognizable some 120 kilometres inland from the coast, and the riverbanks are marked by noticeable flood levees along most of its length (Chenje, 2000).

Soil formations across the Zambezi basin reflect the influence of parent rock material, climatic features and biological activity. The dominant soil types in the basin are acidic, leached out tropical soils of low fertility known as tropical red soils (ferrasols) that are derived from geologically old or ancient rock types.

More fertile soils are located in areas where younger geological strata form the underlying parent rock or where humic materials are found. In general, the average fertility of the basin soils is considered to be low (Chenje, 2000). However, several areas of high quality vertisols (such as the type known as "black cotton soils") are found in the basin. These form important areas of agricultural activity wherever sufficient water is available and appropriate fertilizer added.

Deep layers of wind-blown Kalahari sands cover large areas of the southwestern, western, and northwestern portion of the Zambezi basin. Whilst agricultural production is severely limited in these areas and small-scale subsistence agriculture seems the only option, these areas are often well timbered with economically important hardwoods.

The valley-bottom soils of the middle Zambezi region are generally alluvial or colluvial in origin and support extensive agriculture. This contrasts with those soils on slopes and river valleys immediately to the south and north of Lakes Kariba and Cahora Bassa; these are fragile, shallow, stony soils with little agricultural potential. The soils of the lower Zambezi basin are variable and predominantly sandy of sandy loams, overlying weathered red ferralitic soils, and are considered to be amongst the most fertile in the basin. In the Malawi sector of the basin, (the Lake Malawi and Shire River drainage system), the soils are deep sandy loams and extremely fertile (Chenje, 2000).

Large areas of vertisols occur on the floodplains of the Kafue Flats and are usually associated with underlying basalt and mudstone or shale formations. Similar soils are found on the Zambezi floodplain in Barotseland.

Hydromorphic soils with a high clay content, blocky nature and marked propensity to swell and shrink with wetting and drying are found in areas subject to seasonal waterlogging. These are the characteristic "dambo soils" of Angola, Zambia, Malawi, and parts of Zimbabwe. During the rainy season, the water table is located at or close to the soil surface and these soils are intensively used for subsistence agriculture throughout the basin.

Small areas of dispersive sodic soils are found in areas where the parent rocks have a high sodium content and are subject to intensive mechanical weathering.

3.1.2 Climatic features

Because of its geographic position, the climate of Zambezi basin is influenced by prevailing wind systems, including tropical cyclones from the Indian Ocean. One of the most important rain-bearing systems is the Inter-Tropical Convergence Zone (ITCZ) that moves seasonally along a north-south axis. In the southern portion of the basin, south-easterly wind systems bring rainfalls from the Indian Ocean (Chenje, 2000).

Air temperatures across the Zambezi basin show a marked seasonal cycle, with hottest temperatures recorded during the early Austral Summer months and lowest temperatures during the cool, dry winter months. Rainfalls are also highly seasonal, falling predominantly as intense convective thunderstorms during the warmer summer months (Chenje, 2000). Rainfalls vary from as little as 450 mm per annum in parts of the lower Zambezi valley to over 2,000 mm per annum on the Mulanje Plateau and the Livingstone Mountains to the north of Malawi. The "average" position of the ITCZ is located across the central and northern portions of Zambia; these areas regularly receive rainfalls in excess of 1,500 mm each year. A sketch map showing the distribution of mean annual rainfall over the Zambezi basin is shown in **Figure 3.1**. This figure also shows the main tributaries of the Zambezi.

Evaporation rates across the Zambezi basin are both high and variable, ranging from some 2.4 metres per annum in the south-western areas of Botswana, Namibia and Zimbabwe, to some 1.65 metres in the cooler, mountainous regions to the north of Lake Malawi. In view of these evaporation rates, and the quantity of rainfall received each year, several areas of the Zambezi show clear evidence of the dominance of physical weathering processes (Weinert N values greater than 5.0). These areas are located in the southwestern portion of the basin and along the middle Zambezi valley. Virtually all of the rest of the Zambezi basin is subject to chemical weathering processes, either seasonally (Weinert N values below 4.0) or continually (Weinert N values below 2.0) (Weinert, 1964).

3.1.3 Population and land use patterns

The total population of the Zambezi basin is approximately 30.8 Million, with Malawi, Mozambique, Zambia and Zimbabwe having the highest proportion of the basin population (**Table 3.2**). The Zambezi basin covers over half of the area of Malawi, Zambia and Zimbabwe, containing the breadbasket districts of these three countries, most of the largest cities and towns and most of the largest mines. As such, the basin includes the economic heartland of these three countries.

All Zambezi basin states have skewed population distributions, and experience large-scale migration from rural areas to urban settlements. In addition to this pattern of urbanization, several countries (especially Malawi and Zambia) also house several million refugees who have escaped from various civil wars in Angola, Burundi, Democratic Republic of Congo, Mozambique and Rwanda. These unfortunate people place a heavy additional burden on the economies and fragile natural resources available in these two countries.

Table 3.2: Population statistics for the eight SADC states comprising the Zambezi basin. [Data obtained from Chenje (2000) and Ashton & Ramasar (2001)].

Country	**Total Population of Country (Millions)**	**Country Population in Basin (Millions)**	**Proportion of Country Population (%)**	**Proportion of Basin Population (%)**
Angola	12.903	0.477	3.7	1.5
Botswana	1.639	0.013	0.8	0.04
Malawi	10.778	9.280	86.1	30.1
Mozambique	19.980	3.836	19.2	12.4
Namibia	1.739	0.050	2.9	0.2
Tanzania	33.744	1.282	3.8	4.2
Zambia	9.191	6.452	70.2	20.9
Zimbabwe	13.109	9.452	72.1	30.6
Totals:	103.083	30.842	29.9	100.0

Land is a critically important resource throughout the Zambezi basin upon which the livelihoods of residents and the national economies of all basin states depend (Chenje, 2000). However, the specific types of land use that are practiced are controlled by climatic factors, water availability and, importantly, by land tenure arrangements. A large proportion of the land in all the Zambezi basin states is under communal or customary forms of tenure, and land ownership is considered to be one of the major constraints to proper land use and conservation (Chenje, 2000).

Overcrowding and insecure ownership in the smaller communal farming areas is a primary source of land degradation in the basin. This feature is a critically important driver of poverty within the Zambezi basin and is associated closely with declining indices of per capita agricultural production (Dalal-Clayton, 1997; Chenje, 2000).

Within the Zambezi basin, some 15.4 % of the total land surface is under some form of formal (commercial irrigated and rain-fed, as well as small-scale) agriculture, whilst approximately 71 % is “open land” (usually savannah, grassland or woodland) that is subjected to *chitemene* use (shifting agriculture). A further 5.6 % of the basin is comprised of different forest types, whilst a total of some 7.7% is made up of river, lakes, marshes, swamps or other forms of wetlands, and constructed reservoirs such as lakes Kariba and Cahora Bassa (Pallett, 1997; Chenje, 2000).

In many parts of the basin, progressive urbanization and the development of peripheral “informal” settlements has been accompanied by the removal of large areas of natural vegetation for cultivation as well as for charcoal or fuelwood production. Similar patterns are also associated with the development of mining operations and satellite towns in remote regions of the basin (Chenje, 2000).

3.1.4 Hydrological characteristics, water availability and patterns of water use

The quantity and timing of rainfall received in the Zambezi basin controls the quantity, timing and duration of flows in the different tributary rivers. The uneven distribution of rainfall in the basin is reflected in the very uneven distribution of water resources in the basin states. In turn, these influence the types of economic activities undertaken by the residents in each country. The uneven distribution of water across the basin has led to tensions and occasional disputes between some of the basin states regarding what can be constituted as a “fair and equitable share” of the available water resources (Ashton, 2000).

The Zambezi and its larger tributaries are all perennial with seasonal cyclical patterns of high and low flows. The Luangwa River in Zambia shows a very marked seasonality, and in dry years, flows cease altogether. The western and southwestern parts of the basin that receive the lowest rainfalls have mainly seasonal or episodic rivers that have no surface flow during the dry winter months (Chenje, 2000).

The available information on flows in the Zambezi River show the presence of a distinct long-term cycle, with a period estimated at some 70-80 years. At Victoria Falls, flow measurements show that high flows average some 3,500 Million m^3/second, whilst low flows are some 60% below this level. In recent years (1985-1999), however, dry season flows at Victoria Falls have been exceptionally low and parts of the Victoria Falls have dried out completely for periods of several weeks.

The demand for water in the Zambezi basin is both high and unevenly spread. In particular, water demands by industry, mining and the agricultural sector account for over 75% of all water used. Coupled with high evaporation losses from Lakes Kariba and Cahora Bassa, flows in the lower reaches of the Zambezi River are usually relatively small, unless they have been “boosted” by the arrival of a tropical cyclone (e.g. the cyclone that arrived in 2000 and flooded large areas of Mozambique).

Flows in the lower Shire River are fed by outflows from Lake Malawi. Recent declines in the level of Lake Malawi have resulted in significantly decreased outflows and, as a result, the Shire River has contributed relatively little water to flows in the lower Zambezi River.

Large areas of important wetlands are found in several areas of the Zambezi basin (Timberlake, 1998). These wetlands absorb and attenuate flows from upstream catchment areas, releasing this “trapped” water slowly over a period of several months and maintaining flows during the dry winter months. The most important wetland areas in the Zambezi basin are the Zambezi Floodplains in Barotseland, the Chobe-Linyanti Swamps in northeastern Namibia and Botswana, the Busanga Swamps on the Lunga River (a tributary of the Kafue River), and the Lukanga Swamps and the Kafue Floodplain on the Kafue River. Smaller wetland areas are located on the lower reaches of the Luangwa River, as well as the Elephant Marsh near the town of Chiromo on the lower Shire River in Malawi and Mozambique (Timberlake, 1998).

The growing water shortages in Botswana and Zimbabwe have prompted several investigations of the feasibility of transferring water from the Zambezi River to urban demand centres in these countries. South Africa (not a Zambezi basin state) has also considered the feasibility of entering into an agreement with the Zambezi basin states to withdraw water from the Zambezi and transfer it via pipeline to the Witwatersrand in South Africa (Ashton, 2000). Whilst none of these water transfers have taken place, they do indicate the growing tension in southern Africa around looming water shortages driven by population growth and development. The picture is made somewhat more uncertain by the very real possibility that global climate changes will also have an adverse effect on water availability in southern Africa (Ashton, 2000).

Throughout the length of the Zambezi River, water quality is generally very good and the water is entirely fit for all designated uses. However, several communities continue to discharge untreated or partially treated domestic effluent into the river (e.g. the towns of Livingstone in Zambia and Victoria Falls in Zimbabwe). Whilst sufficient dilution remains and the river flows are turbulent, this practice is unlikely to have long-term or large-scale detrimental effects. However, as effluent quantities increase and river flows decline, whilst demands for water increase, it is inevitable that water quality problems will occur. This problem is likely to become more acute further downstream, where several more towns (e.g. Siavonga, Kariba, Chirundu and Tete) rely on water abstracted directly from the Zambezi River and who also discharge their effluent (treated and untreated) directly into the Zambezi River.

In addition to water abstracted for domestic use, large volumes of water are also withdrawn for irrigation; for example: the Gwembi Irrigation Project on Lake Kariba, The Chaiwa Irrigation Project downstream of the Kafue-Zambezi confluence and the Sena Sugar Estate on the lower Zambezi in Mozambique. Similar irrigation schemes for sugar cane also operate on the Shire River in Malawi (e.g. Sucoma Sugar Estate) and the Kafue River in Zambia (e.g. the Nakambala Sugar Estate). In addition, large citrus estates such as the Mazowe Citrus Estate in Zimbabwe also withdraw substantial volumes of water (Chenje, 2000). Most small-scale farmers rely either on red-fed agriculture or on water drawn from shallow wells or nearby watercourse (Chenje, 2000).

3.1.5 Water management systems and institutions

Each of the basin states has their own water management systems and segments their respective territories into Water Management Units. These divisions are normally in the form of sub-catchments, though some of the larger sub-catchments are further sub-divided (e.g. the Kafue and Luangwa in Zambia; the Shire in Malawi). The formal constitution of catchment councils or catchment management agencies has only taken place in Zimbabwe. In the other basin states, water management is undertaken by central Government or is delegated to Provincial Departments.

In Zimbabwe, the Zimbabwe National water Authority (ZINWA) segments the Zimbabwean sector of the Zambezi Catchment into three Catchment Councils: Gwayi, Sanyati and Mazowe. These correspond to Hydrological Zones A, C and D, respectively (ZSG, 1984). The Zimbabwe portion of the catchment is divided into a series of sub-catchments for the purposes of this study, as shown in **Figure 3.2**. Water quality data is available from a number of ZINWA sampling points in Zimbabwe (**Figure 3.3**). The only information that could be obtained for the other basin states consisted of a few water quality data for the Kafue sub-catchment in

Zambia. Clearly, some water quality information must be available for the other basin states and concerted attempts should be made to secure this information and synthesize it to provide a better overview of the Zambezi basin.

The SADC Protocol on Shared Watercourse Systems is an important legislative instrument that promotes regional co-operation and collaboration amongst all SADC states. However, inadequate and unequal institutional and professional capacity within the member states hampers full expression of this protocol.

Zambia and Zimbabwe have jointly passed the Zambezi River Authority legislation in 1987 to form the Zambezi River Authority (Pallett, 1997; Chenje, 2000). Whilst this move will certainly help to improve collaborative management of the Zambezi basin, the fact that the other six basin states (Angola, Botswana, Malawi, Mozambique, Namibia and Tanzania) are not included is seen as an impediment to the optimal functioning of this authority. To date, the Zambezi River Authority (ZRA) has focused its activities on the section of the Zambezi River shared by Zambia and Zimbabwe, with particular attention being paid to setting up an efficient monitoring system and database (Chenje, 2000). Under the auspices of the ZRA, Zambia and Zimbabwe have agreed to collaborate closely on the utilization, operation and maintenance of all existing infrastructure and installations (e.g. dams, reservoirs, telemetry stations), as well as any future installations that may be constructed in their spheres of influence.

Each basin state maintains its own system of meteorological and hydrological data collection, primarily for use at the national level. Whilst these systems are at very different levels of coverage in the different states, all data is fed into regional data systems such as the Drought Monitoring Centre in Harare, Zimbabwe, where the data provides important information for national and regional agricultural planning systems. Recent improvements include weather radar systems and satellite monitoring systems that are intended to expand the regional coverage.

3.1.6 Mining and mineral processing operations in the Zambezi basin

There are a large number and wide variety of mining and minerals processing operations in the Zambezi catchment; the locations of these are shown in **Figures 3.4 and 3.7 to 3.14**, whilst details of land use and geology in Zimbabwe are given in **Figures 3.5 and 3.6**.

Data on the type of mine, size, operational status and location of mining operations in the Zambezi basin are presented, along with inferences on their potential impacts. The inference for potential impact was arrived at using the criteria in **Table 1.3** and is summarized for each sub-catchment in the following sections. A summarizing overview of the potential impacts on water resources and water quality in each sub-catchment of the Zambezi basin is given in **Section 3.40**.

In the following portions of this section of the report that contain descriptions of the mining and mineral processing activities in each sub-catchment, it is important to refer to **Figure 3.2** and **Figure 3.4** for the positions of the different sub-catchments within the Zambezi basin.

3.2 The Kazungula sub-catchment

3.2.1 General description

3.2.1.1 Hydrology

The catchment zone comprises the so-called “headwater zone” of the Chamabonda Stream, a series of small, ephemeral streams with episodic flows that flow into Zimbabwe and enter the Zambezi River both above and below the Victoria Falls. In the northern part of this small sub-catchment, a few small ephemeral streams flow into the Zambezi River at Kazungula.

3.2.1.2 Geology and geomorphology

The Upper Karoo Batoka Basalt Formation, covered in a few areas by recent alluvial material and large expanses of Kalahari Sands, underlies this small sub-catchment.

3.2.1.3 Pedology, agriculture and land use

The soils can be separated into two groups, namely: the Kalahari Sands and very shallow, gravelly soils overlying the basalts. The area lies within an are of low rainfall (approximately 650 mm) in northeastern Botswana. The predominance of Kalahari Sands makes the area generally unsuitable for agriculture, except for small areas of subsistence agriculture along the richer soils on river terraces. Land use is largely given over to forestry, with a minor emphasis on tourism. The area is traversed by the Kazangula – Nata – Francistown road linking Zambia and Botswana, with a small road to the border post at Mpandamatenga on the Zimbabwe border.

3.2.1.4 Surface water users

The only settlements of any size are the Botswana border post of Kazangula. A few small boreholes at veterinary fences along the Kazungula – Nata road provide the only source of surface water away from the Zambezi River. A borehole serves the Mpandamatenga border post.

3.2.1.5 Water management systems

This area falls under the management of the Botswana Department of Minerals, Energy and Water.

3.2.1.6 Human impacts on water resources (excluding mining)

The following could be expected to have an impact on water resources:

- Minor non-point impact from sparse, subsistence agriculture located close to Kazungula and the veterinary fence control points;
- Disposal of domestic and commercial solid waste at Kazangula;
- Minor non-point impact from subsistence agriculture and garbage disposal at the Mpandamatenga border post; and
- Minor non-point impact from garbage along the Kazungula – Nata road.

3.2.2 Mining and mineral processing operations

One coal mining operation is located in this sub-catchment (**Figure 3.4**; **Table 3.3**). No information is available regarding current prospecting in the area. There are no known minerals processing operations in the sub-catchment.

Table 3.3: Mining operations in the Kazungula sub-catchment.

Code Number	Name of Mine	Commodity (ies) Mined	Status	Relative Size	Probable Impact
B-1	Pandamatenga	Coal	Operating	Small	Very low

3.2.3 Alluvial mining

None recorded and none anticipated.

3.2.4 Monitoring systems

None.

3.2.5 Water quality data

None.

3.2.6 Implications for water quality and quantity management

None.

3.3 The Chobe - Linyanti sub-catchment

3.3.1 General description

3.3.1.1 Hydrology

The Linyanti – Chobe River system joins the Zambezi River at the base of this sub-catchment. Flows are distinctly seasonal, with extensive flooding of eastern Caprivi. If the Zambezi floodwaters arrive earlier than the floodwaters of the Chobe River, the Zambezi water may push upstream into the Chobe River as far as Lake Liambezi.

3.3.1.2 Geology and geomorphology

The Upper Karoo Batoka Basalt Formation underlies the eastern portion of the catchment, outcropping at surface along the Zambezi River.

3.3.1.3 Pedology, agriculture and land use

A deep layer of Kalahari Sands covers most of the sub-catchment, with rich alluvial soils on the river terraces along the Chobe, Linyanti and Zambezi rivers. Much of the eastern Caprivi is flooded during the rainy season and the soils support an extensive wetland area.

Land use is predominantly subsistence agriculture with livestock rearing, as well as tourism along the Chobe and Zambezi rivers. A new sugar cane project (10,000 hectares in extent) is planned for the Namibian sector of the Caprivi. This will draw water from the Chobe – Linyanti system.

3.3.1.4 Surface water users

The only settlements of any size in Botswana are border post at Ngoma Bridge and the small town of Kasane in Botswana. In Namibia, the Provincial Capital of Caprivi Province, the town of Katima Mulilo is important, with several smaller villages along the Namibian bank of the Chobe and Linyanti rivers.

Water for Katima Mulilo is drawn from the Zambezi River whilst Ngoma Bridge and Kasane take water from the Chobe River. Other smaller villages also draw water from the Chobe and Linyanti rivers. If the planned sugar cane project proceeds, this will become the largest water user in the sub-catchment.

3.3.1.5 Water management systems

The Botswana segment of this area falls under the management of the Botswana Department of Mineral, Energy and Water. The Namibian segment falls under the jurisdiction of the Namibian Department of Water Affairs who operates a regional office at the town of Katima Mulilo on the Zambezi River.

3.3.1.6 Human impacts on water resources (excluding mining)

Impacts on water resources consist of the following:

- Disposal of domestic and minor commercial solid waste at Katima Mulilo;
- Disposal of domestic and minor commercial solid waste at Kasane;
- Minor non-point impact from sparse, subsistence agriculture located close to Katima Mulilo and along the Chobe River;
- Minor non-point source pollution from septic tank drainage systems at Kasane, Katima Mulilo and Chobe River Lodge in the Chobe National Park;
- Minor non-point impact from subsistence agriculture and garbage disposal at the Ngoma Bridge border post; and
- Minor non-point impact from garbage along the Kasane – Ngoma Bridge road.

3.3.2 Mining and mineral processing operations

None known.

3.3.3 Alluvial (small-scale) mining

None known and none anticipated.

3.3.4 Water management systems

Both the Botswanan and Namibian Governments operate controls on water abstraction from rivers and over the quality of water supplied for domestic consumption.

3.3.5 Monitoring systems

Both the Botswanan and Namibian Governments collect water samples from time to time and both also collaborate on biological control programmes against the invasive waterweed *Salvinia molesta* (Kariba weed).

3.3.6 Water quality data

None available.

3.3.7 Implications for water quality and water resources management

The impacts of seepage into the Chobe and Zambezi rivers are likely to be small. There are no impacts of mining or mineral processing on water resources or water quality in this sub-catchment.

3.4 The Luiana sub-catchment

3.4.1 General description

3.4.1.1 Hydrology

The Luiana River is a major tributary of the Cuando River in Angola. Flows are seasonal though there is no information as to the size of the flows.

3.4.1.2 Geology

The Upper Karoo Batoka Basalt Formation underlies the lower reaches of the sub-catchment, covered by Kalahari Sands. Archaean rocks of the Central African Craton underlie the headwaters of the sub-catchment.

3.4.1.3 Pedology, agriculture and land use

The soils are in two groups: the deeper ferralitic soils of the upper headwaters of the catchment, and Kalahari Sands over most of the lower reaches of the sub-catchment. The predominance of Kalahari Sands makes the area generally unsuitable for commercial agriculture, though subsistence agriculture occurs on floodplain levees along the rivers.

3.4.1.4 Surface water users

The only settlements are small villages scattered throughout the sub-catchment, as well as anecdotal evidence for the presence of UNITA army camps in the headwaters region of the sub-catchment.

3.4.1.5 Water management systems

This area falls under the management of the Angolan Department of Water Affairs.

3.4.1.6 Human impacts on water resources (excluding mining)

The following could be expected to have an impact on water resources:

- Disposal of domestic and solid waste and UNITA army camps in the headwaters; and
- Minor non-point impact from sparse, subsistence agriculture throughout the sub-catchment.

3.4.2 Mining and mineral processing operations

None known.

3.4.3 Alluvial mining

Neither known nor likely, except possibly for diamonds in the headwaters region.

3.4.4 Monitoring systems

None.

3.4.5 Water quality data

None.

3.4.6 Implications for water quality and quantity management

None.

3.5 The Cuando sub-catchment

3.5.1 General description

3.5.1.1 Hydrology

The Cuando River drains the southeastern portion of the Bié Highlands in central Angola. Flows are seasonal though there is no information as to the size of the flows.

3.5.1.2 Geology

The Upper Karoo Batoka Basalt Formation underlies the lower reaches of the sub-catchment, covered by Kalahari Sands. Archaean rocks of the Central African Craton underlie the headwaters of the sub-catchment.

3.5.1.3 Pedology, agriculture and land use

The soils are in two groups: the deeper ferralitic soils of the upper headwaters of the catchment, and Kalahari Sands over most of the lower reaches of the sub-catchment. The predominance of Kalahari Sands makes the area generally unsuitable for commercial agriculture, though subsistence agriculture occurs on floodplain levees along the rivers.

3.5.1.4 Surface water users

The only settlements are small villages scattered throughout the sub-catchment, as well as anecdotal evidence for the presence of UNITA army camps in the headwaters region of the sub-catchment. Prospecting teams in the sub-catchment uses small volumes of water.

3.5.1.5 Water management systems

This area falls under the management of the Angolan Department of Water Affairs.

3.5.1.6 Human impacts on water resources (excluding mining)

The following could be expected to have an impact on water resources:

- Disposal of domestic and solid waste and UNITA army camps in the headwaters; and
- Minor non-point impact from sparse, subsistence agriculture throughout the sub-catchment.

3.5.2 Mining and mineral processing operations

One good diamond prospect is under investigation (**Table 3.4; Figure 3.4**).

Table 3.4: Mining operations in the Cuando sub-catchment.

Code Number	Name of Mine	Commodity (ies) Mined	Status	Relative Size	Probable Impact
A-3	Lumbala Nguimbo	Diamond – kimberlite	Prospecting	Small	Very low

3.5.3 Alluvial mining

Neither known nor likely, except possibly for diamonds in the headwaters region.

3.5.4 Monitoring systems

None.

3.5.5 Water quality data

None.

3.5.6 Implications for water quality and quantity management

None.

3.6 The Luanginga sub-catchment

3.6.1 General description

3.6.1.1 Hydrology

The Luanginga River drains the southeastern portion of the Bié Highlands in central Angola. Flows are seasonal though there is no information as to the size of the flows.

3.6.1.2 Geology

The sub-catchment is underlain predominantly by sandstones and conglomerates of the middle Zambezi basin; these are covered by deep Kalahari Sands. Archaean rocks of the Central African Craton underlie the headwaters of the sub-catchment.

3.6.1.3 Pedology, agriculture and land use

The soils are in two groups: the deeper ferralitic soils of the upper headwaters of the catchment, and Kalahari Sands over most of the lower reaches of the sub-catchment. The predominance of Kalahari Sands makes the area generally unsuitable for commercial agriculture, though subsistence agriculture occurs on floodplain levees along the rivers.

3.6.1.4 Surface water users

The only settlements are small villages scattered throughout the sub-catchment. Prospecting teams in the sub-catchment uses small volumes of water.

3.6.1.5 Water management systems

Most of this area falls under the management of the Angolan Department of Water Affairs, with the lower portions of the catchment falling within the jurisdiction of the Zambian Department of Water Affairs (Barotseland) office at Mongu.

3.6.1.6 Human impacts on water resources (excluding mining)

The following could be expected to have an impact on water resources:

- Disposal of domestic and solid waste from small communities; and
- Minor non-point impact from sparse, subsistence agriculture throughout the sub-catchment.

3.6.2 Mining and mineral processing operations

None known.

3.6.3 Alluvial mining

Neither known nor likely, except possibly for diamonds in the headwaters region.

3.6.4 Monitoring systems

None.

3.6.5 Water quality data

None.

3.6.6 Implications for water quality and quantity management

None.

3.7 The Lungue Bungo sub-catchment

3.7.1 General description

3.7.1.1 Hydrology

The Lungue Bungo River drains the astern portion of the Bié Highlands in central Angola. Flows are seasonal though there is no information as to the size of the flows.

3.7.1.2 Geology

The sub-catchment is underlain predominantly by sandstones and conglomerates of the middle Zambezi basin; these are covered by deep Kalahari Sands. Archaean rocks of the Central African Craton underlie the headwaters of the sub-catchment.

3.7.1.3 Pedology, agriculture and land use

The soils are in two groups: the deeper ferralitic soils of the upper headwaters of the catchment, and Kalahari Sands over most of the lower reaches of the sub-catchment. The predominance of Kalahari Sands makes the area generally unsuitable for commercial agriculture, though subsistence agriculture occurs on floodplain levees along the rivers.

3.7.1.4 Surface water users

The only settlements are small villages scattered throughout the sub-catchment. Prospecting teams in the sub-catchment uses small volumes of water. Small administrative centres are located near the town of Kalabo in Zambia.

3.7.1.5 Water management systems

Most of this area falls under the management of the Angolan Department of Water Affairs, with the lower portions of the catchment falling within the jurisdiction of the Zambian Department of Water Affairs (Barotseland) office at Kalabo.

3.7.1.6 Human impacts on water resources (excluding mining)

The following could be expected to have an impact on water resources:

- Disposal of domestic and solid waste from small communities; and
- Minor non-point impact from sparse, subsistence agriculture throughout the sub-catchment.

3.7.2 Mining and mineral processing operations

One small coal deposit is being utilized (**Table 3.5; Figure 3.4**).

Table 3.5: Mining operations in the Lungue Bungo sub-catchment.

Code Number	Name of Mine	Commodity (ies) Mined	Status	Relative Size	Probable Impact
A-4	Muangai	Coal	Operating	Small	Very low

Most of the lower reaches of the catchment area are under prospecting permits for diamonds.

3.7.3 Alluvial mining

Neither known nor likely, except possibly for diamonds in the headwaters region.

3.7.4 Monitoring systems

None.

3.7.5 Water quality data

None.

3.7.6 Implications for water quality and quantity management

None.

3.8 The Luena and Zambezi Headwaters sub-catchments

3.8.1 General description

3.8.1.1 Hydrology

The Luena River drains the eastern portion of the Bié Highlands in central Angola and joins the Zambezi River in its headwater zone. Flows are seasonal though there is no information as to the size of the flows.

3.8.1.2 Geology

These two sub-catchments are underlain predominantly by sandstones and conglomerates of the middle Zambezi basin; these are covered by deep Kalahari Sands. Archaean rocks of the Central African Craton underlie the headwaters of the sub-catchments.

3.8.1.3 Pedology, agriculture and land use

The soils consist almost entirely of deep, well-leached ferralitic soils, with subsistence agriculture on the richer soils located on floodplain levees along the riverbanks.

3.8.1.4 Surface water users

The only settlements are small villages scattered throughout the sub-catchment. Prospecting teams in the sub-catchments uses small volumes of water. Small administrative centres are located near the town of Luena in Angola. Prospecting teams active in the area will also use water.

3.8.1.5 *Water management systems*

This area falls under the management of the Angolan Department of Water Affairs.

3.8.1.6 *Human impacts on water resources (excluding mining)*

The following could be expected to have an impact on water resources:

- Disposal of domestic and solid waste from small communities; and
- Minor non-point impact from sparse, subsistence agriculture throughout the sub-catchment.

3.8.2 *Mining and mineral processing operations*

See **Figure 3.4** and **Table 3.6**. The Macondo Copper Mine was abandoned several years ago as a result of the Angolan Civil War. The Alto Zambezi kimberlites show good prospects for diamonds.

Table 3.6: Mining operations in the Luena sub-catchment.

Code Number	Name of Mine	Commodity (ies) Mined	Status	Relative Size	Probable Impact
A-1	Alto Zambezi	Diamond – kimberlite	Prospecting	Small	Very low
A-2	Macondo	Copper	Abandoned	Small	Unknown
A-5	Macondo – A	Iron	Prospecting	Medium	Very low
A-6	Macondo - B	Fluorite	Prospecting	Medium	Very low

3.8.3 *Alluvial mining*

Anecdotal evidence for alluvial diamond mining in the headwaters of the Luena River.

3.8.4 Monitoring systems

None.

3.8.5 Water quality data

None.

3.8.6 Implications for water quality and quantity management

None.

3.9 The Kabompo sub-catchment

3.9.1 General description

3.9.1.1 Hydrology

The Kabompo River drains the northwestern portion of the watershed between Northern Zambia and the Democratic republic of Congo (**Figure 3.2**) and joins the Zambezi River after it flows out of Angola. Flows are seasonal though there is no information as to the size of the flows.

3.9.1.2 Geology

This sub-catchment is underlain predominantly by copper-rich sandstones, quartzites, arenites and conglomerates of the Copperbelt region.

3.9.1.3 Pedology, agriculture and land use

The soils consist almost entirely of deep, well-leached ferralitic soils. Subsistence agriculture occurs on the richer soils located on floodplain levees along the riverbanks.

3.9.1.4 Surface water users

The only settlements are small villages scattered throughout the sub-catchment. Prospecting teams in the sub-catchment uses small volumes of water. Prospecting teams active in the area will also use water.

3.9.1.5 Water management systems

This area falls under the management of the Zambian Department of Water Affairs.

3.9.1.6 Human impacts on water resources (excluding mining)

The following could be expected to have an impact on water resources:

- Disposal of domestic and solid waste from small communities;
- Disposal of domestic and solid waste from prospecting camps; and
- Minor non-point impact from sparse, subsistence agriculture throughout the sub-catchment.

3.9.2 Mining and mineral processing operations

See **Figure 3.4** and **Table 3.7**. Major new copper, cobalt, zinc and uranium deposits have been found at Lumwana and Kalumbila; a mine has started operating at Lumwana. The Kalengwa Copper Mine has closed down and there are good prospects for iron and nickel.

Table 3.7: Mining operations in the Kabompo sub-catchment.

Code Number	Name of Mine	Commodity (ies) Mined	Status	Relative Size	Probable Impact
A-7	Macondo-C	Iron	Prospecting	Medium	Very low
A-8	Macondo-D	Iron	Prospecting	Medium	Very low
Z-40	Kalengwa	Copper, Silver	Closed	Medium	Low-Medium
Z-41	Kalumbila	Copper, Cobalt, Zinc	Operating	Small-Med	Low-Medium
Z-54	Kabompo	Iron	Prospecting	Medium	Low
Z-55	Kalumbila-Nickel	Nickel, Copper	Prospecting	Medium	Low
Z-71	Lumwana	Copper, Cobalt, U	Operating	Medium	Medium
Z-72	Mwinilunga	Copper	Prospecting	Small	Very low
Z-73	Luamata	Copper	Prospecting	Small	Very low
Z-74	Kawanga	Uranium	Prospecting	Small	Low
Z-77	Mufumbwe	Copper	Start-up	Medium	Low
Z-78	Lalafuta	Copper	Prospecting	Small	Very low
Z-86	Balovale	Amethyst	Prospecting	Small	Very low

3.9.3 Alluvial mining

None known.

3.9.4 Monitoring systems

Sporadic water quality monitoring is carried out at Kalabo.

3.9.5 Water quality data

None available.

3.9.6 Implications for water quality and quantity management

None, bar minor adverse effects of increased soil erosion around new mining operations and close to prospecting trenches.

3.10 The Middle Zambezi sub-catchment

3.10.1 General description

3.10.1.1 Hydrology

This sub-catchment covers the Zambezi Floodplain in Barotseland. During the seasonal floods, the Zambezi spills its banks, often reaching 48-50 kilometres in width. Several large tributaries arising in the Angolan sector of the basin join the Zambezi in this sub-catchment.

3.10.1.2 Geology

This sub-catchment is underlain predominantly by the Karoo Supergroup basalts and sandstones overlain by deposits of Kalahari Sands.

3.10.1.3 Pedology, agriculture and land use

The soils consist almost entirely of alluvial soils and hydromorphic vertisols. Smaller tributaries in the eastern portion of this catchment have sandy-loam soils. Some of the soils in the northern (higher rainfall) section of the sub-catchment have deep, well-leached ferralitic soils. Subsistence agriculture occurs on the richer soils located on floodplain levees along the riverbanks.

3.10.1.4 Surface water users

The only settlements are small towns and villages scattered throughout the sub-catchment. The Provincial capital, Mongu, is located on the banks of the Zambezi River and the smaller town of Sesheke is also located on the banks of the Zambezi River, opposite the town of Katima Mulilo in Caprivi. Prospecting teams also use water from the river.

3.10.1.5 Water management systems

This area falls under the management of the Zambian Department of Water Affairs.

3.10.1.6 Human impacts on water resources (excluding mining)

The following could be expected to have an impact on water resources:

- Disposal of domestic and solid waste from small towns and communities;
- Disposal of domestic and solid waste from prospecting camps; and
- Minor non-point impact from sparse, subsistence agriculture throughout the sub-catchment.

3.10.2 Mining and mineral processing operations

See **Figure 3.4** and **Table 3.8**. The only mining operations in this segment of the Zambezi basin are three small amethyst mines.

Table 3.8: Mining operations in the Middle Zambezi sub-catchment.

Code Number	Name of Mine	Commodity (ies) Mined	Status	Relative Size	Probable Impact

Z-87	Mulobezi	Amethyst	Operating	Very small	Very low
Z-88	Njoko	Amethyst	Operating	Very small	Very low
Z-89	Loazamba	Amethyst	Operating	Very small	Very low

3.10.3 Alluvial mining

None known.

3.10.4 Monitoring systems

Sporadic water quality monitoring is carried out at Mongu and Sesheke.

3.10.5 Water quality data

None available.

3.10.6 Implications for water quality and quantity management

None.

3.11 The Lunga sub-catchment

3.11.1 General description

3.11.1.1 Hydrology

The Lunga River is the most important tributary of the Kafue River and drains the central portion of the watershed between Northern Zambia and the Democratic Republic of Congo (**Figure 3.4**). Flows are seasonal though there is no information as to the size of the flows.

3.11.1.2 Geology

This sub-catchment is underlain predominantly by copper-rich sandstones, quartzites, arenites and conglomerates of the Copperbelt region.

3.11.1.3 Pedology, agriculture and land use

The soils consist almost entirely of deep, well-leached ferralitic soils. Subsistence agriculture occurs on the richer soils located on floodplain levees along the riverbanks. Considerable numbers of people have flocked to the town of Solwezi near the headwaters of this river, attracted by the increase in mining activity. Large areas of Miombo woodland have been cleared for the layout of mining infrastructure and housing, as well as for the provision of fuelwood. Large areas of subsistence agriculture occur around Solwezi.

3.11.1.4 Surface water users

The major settlement is the town of Solwezi, though there are several small villages scattered throughout the sub-catchment. Prospecting teams in the sub-catchment uses small volumes of water.

3.11.1.5 Water management systems

This area falls under the management of the Zambian Department of Water Affairs, Copperbelt office.

3.11.1.6 *Human impacts on water resources (excluding mining)*

The following could be expected to have an impact on water resources:

- Disposal of domestic and solid waste from towns and small communities;
- Disposal of domestic and solid waste from prospecting camps;
- Increased quantities of suspended solids washed into the rivers from cleared and eroded areas; and
- Minor non-point impact from sparse, subsistence agriculture throughout the sub-catchment.

3.11.2 *Mining and mineral processing operations*

See **Figure 3.4** and **Table 3.9**. Major deposits of copper, cobalt and gold at Kansanshi are being evaluated for their economic potential. Additional prospecting for copper and zinc is ongoing close to the junction of the Lunga River with the Kafue River, shortly after the Busanga Swamps.

Table 3.9: Mining operations in the Lunga sub-catchment.

Code Number	Name of Mine	Commodity (ies) Mined	Status	Relative Size	Probable Impact
Z-39	Lunga Basin	Copper, Zinc	Prospecting	Small	Low
Z-42a	Solwezi	Copper	Prospecting	Closed	Medium
Z-42b	Solwezi – Claims	Copper	Abandoned	Small	Low-Medium
Z-43a	Kansanshi – old	Copper, Cobalt, Gold	Closed/Rehab	Large	Medium
Z-43b	Kansanshi - new	Copper, Cobalt, Gold	Prospecting	Large	Low-Medium
Z-75	Dumbwa	Uranium, Copper	Prospecting	Small	Very low
Z-76	Lunga	Gold, Copper	Prospecting	Small	Very low

3.11.3 *Alluvial mining*

None known, though possible alluvial gold exploration downstream from Kansanshi.

3.11.4 Monitoring systems

Sporadic water quality monitoring is carried out at Solwezi.

3.11.5 Water quality data

None available.

3.11.6 Implications for water quality and quantity management

None, bar minor adverse effects of increased soil erosion around new mining operations and close to prospecting trenches. If mines become operational, acid mine drainage is also possible.

3.12 The Upper Kafue sub-catchment

3.12.1 General description

3.12.1.1 Hydrology

The Upper Kafue River is the probably the most important river in Zambia as it drains the mineral and economic heartland of the country. The river flows south-westwards, draining the eastern portion of the watershed between Northern Zambia and the Democratic Republic of Congo (**Figure 3.4**), before swinging southwards to join the Lunga River and enter the Kafue Floodplain. Flows are highly seasonal though there is no information available as to the size of the flows.

3.12.1.2 Geology

This sub-catchment is underlain predominantly by copper-rich sandstones, quartzites, arenites and conglomerates of the Copperbelt region. The region hosts substantial deposits of copper and cobalt, and has several emerald-bearing pegmatites. Large deposits of high-grade limestone are found at Ndola, the site of a very large cement works. Very large numbers of pegmatite deposits and intrusions of Greenstone formations in the eastern portion of this sub-catchment hold good prospects for gemstones and gold. Zinc and lead are found in the south near the well-known Broken Hill deposit at the town of Kabwe.

3.12.1.3 Pedology, agriculture and land use

The soils consist almost entirely of deep, well-leached ferralitic soils. Subsistence agriculture occurs on the richer soils located on floodplain levees along the riverbanks. Considerable numbers of people have flocked to the Copperbelt towns of Ndola, Kitwe, Luanshya, Mufulira, Chingola, Chililabombwe, Kalulushi and Chambishi in search of work or to join their families. Each of the Copperbelt towns now has enormous numbers of informal settlements around its periphery, accompanied by extensive areas of subsistence agriculture. Large-scale de-vegetation takes place as people use the Miombo (*Brachystegia*) woodlands for fuelwood. These peripheral impacts can be considered as both “indirect” and “cumulative” impacts linked to mining operations. A Landsat TM image (**Figure 3.15**) provides an overview of the extent of the impacted area associated with the different Copperbelt mining towns.

3.12.1.4 Surface water users

All of the towns use substantial quantities of water for domestic and industrial purposes and the mining operations also use considerable volumes of water. The numerous small “informal” settlements and communities around the periphery of the Copperbelt towns rely on shallow hand-dug wells in nearby dambos, or draw water directly from nearby rivers and streams.

3.12.1.5 Water management systems

This area falls under the management of the Zambian Department of Water Affairs, Copperbelt office.

3.12.1.6 Human impacts on water resources (excluding mining)

The following could be expected to have an impact on water resources:

- Disposal of domestic and solid waste from towns, industries and small communities;
- Disposal of domestic and solid waste from peripheral industries (e.g. cement factories);

- Increased quantities of suspended solids washed into the rivers from cleared, cultivated and eroded areas;
- Seepage of oils, fuels and industrial chemicals from roadways and industrial sites into the local ground water and nearby streams; and
- Minor non-point impact from sparse, subsistence agriculture throughout the rest of the sub-catchment.

3.12.2 Mining and mineral processing operations

See **Figure 3.4** and **Table 3.10**. Major deposits of copper and cobalt have been exploited for several years by both open pit and underground mining methods. There is a large copper smelter at the Nkana Operation in Kitwe – this facility is in serious need of upgrading as it has an extremely poor performance in terms of sulphur capture. The Chambishi cobalt Refinery processes ores from other mines as well as the spent slag from the Nkana Mine in Kitwe. Most of the mines are large to very large. Open pit emerald mining takes place at several pegmatites in the southern part of the Copperbelt.

Table 3.10: Mining operations in the Upper Kafue sub-catchment.

Code Number	Name of Mine	Commodity (ies) Mined	Status	Relative Size	Probable Impact
Z-44	Konkola	Copper, Cobalt	Operating	Very Large	High
Z-45a	Nchanga-open pit	Copper, Cobalt	Closed	Very Large	High (residual)
Z-45b	Nchanga-deep	Copper, Cobalt	Operating	Very large	High
Z-46a	Chambishi	Copper, Cobalt	Re-opening	Large	Medium-High
Z-46b	Chambishi-COSAC	Cobalt (smelter) + Cu	Operating	Large	Medium-High
Z-47a	Chibuluma	Copper	Closed/Rehab	Large	High
Z-47b	Chibuluma South	Copper	Startup	Large	Medium
Z-48a	Mufulira – Main	Copper, Cobalt	Operating	Large	High
Z-48b	Mufulira – Mokambo	Copper	Closed	Medium	Medium
Z-49a	Nkana	Copper, Cobalt	Operating	Very Large	High
Z-49b	Nkana – Slag pile	Cobalt, Copper	Operating	Large	Medium – High
Z-50a	Luanshya	Copper	Operating	Large	High
Z-50b	Baluba	Copper	Operating	Large	Medium-High
Z-51	Bwana Mkubwa	Copper	Dump reclaim	Medium	Low
Z-52	Ndola Lime	Limestone	Operating	Large	Medium
Z-53a	Ndola Rural	Emerald	Operating	Small	Low-Medium
Z-53b	Ndola Rural Claims	Emerald	Abandoned	Artisan (few)	Very low - Low
Z-56	Mwekera	Copper	Prospecting	Medium	Low
Z-57	Bob Zinc	Zinc	Prospecting	Medium	Low
Z-62	Kabwe Division	Zinc, Lead, Silver	Prospecting	Medium	Low
Z-65	Pirala	Emerald	Operating	Small	Low

Z-79	Sakania	Gold, Copper	Abandoned	Small	Very low
Z-80	Hippo	Copper	Prospecting	Small	Very low
Z-81	Silver King	Copper, Silver	Prospecting	Medium	Very low
Z-82	Sable Antelope	Copper, Gold	Prospecting	Medium	Very low

3.12.3 Alluvial mining

None known.

3.12.4 Monitoring systems

Regular water quality monitoring is carried out at points both upstream and downstream of major tailings dams and effluent discharge points on the Kafue River. Zambian and Swedish researchers have undertaken extremely detailed investigations of tailings geochemistry and water quality associated with the mines near Kitwe and Chingola (Petterson & Ingri, 1993; 2000a, 2000b; Mwale, 1994; Mwase, 1994; Nkandu, 1996; Norrgren *et al*., 2000).

3.12.5 Water quality data

Some published water quality data is available from the publications of Petterson & Ingri (1993, 2000a, 2000b; **Table 3.11**). These workers have shown that the acid mine drainage emanating from the Copperbelt mines is largely neutralized by the carbonate-rich rocks and sediments of local geological formations. As a result, the concentrations of dissolved copper and cobalt in the Kafue River are extremely low, though larger quantities are present as suspended (adsorbed) material. In the past, this suspended copper has been implicated in the death of cattle that drank from the Mwambashi River (**Figure 3.15**; Mwale, 1994; Petterson & Ingri, 2000a, 2000b).

Table 3.11: Analyses of water quality (dissolved substances) at three sites in the Kafue River, from upstream of Chingola (Fischer's Farm), 20 km downstream of Kitwe (Raglan's Farm) and 100 km downstream of the Zambian Copperbelt (Machiya Ferry). Data provided are averages of monthly samples collected between March 1995 and April 1996; all data units are given in microgrammes per litre (µg/litre) (Pettersson & Ingri, 2000a, 2000b).

Determinant	Fischer's Farm	Raglan's Farm	Machiya Ferry
Silica (Si)	3,395	18,932	4,755
Aluminium (Al)	1,687	12,674	1,594
Calcium (Ca)	442	1,261	653
Magnesium (Mg)	223	1,106	252
Potassium (K)	270	2,481	522
Sodium (Na)	189	223	159
Iron (Fe)	2,076	5,936	1,444
Manganese (Mn)	106	363	671
Phosphorus (P)	77	234	160
Titanium (Ti)	79	451	58
Barium (Ba)	12	90	20
Strontium (Sr)	1.92	11	5
Cobalt (Co)	1.27	115	16
Copper (Cu)	4.7	662	79
Chrome (Cr)	1.37	4.87	0.96
Nickel (Ni)	0.72	4.97	1.15
Lead (Pb)	0.46	37	1.33
Zinc (Zn)	14	117	29

The concerted sampling programme conducted by Pettersson and Ingri (2000a, 2000b) showed very clearly that the concentrations of every determinant examined increased dramatically as a result of mining activities on the Zambian Copperbelt. In addition to the dissolved fraction, these authors also found very large concentrations of particulate material in the Kafue River, and that the concentrations of most heavy metals (Cobalt, Copper, Chrome, Lead, Zinc) were occasionally up to ten time higher (than the dissolved concentrations) as adsorbed ions onto the particulate material. These authors also found even higher concentrations of metals in sediment samples collected from the bed of the Kafue River.

Overall, Pettersson and Ingri (2000a, 2000b) have concluded that the background geology and soils of the Zambian Copperbelt are able to neutralize most of the dissolved seepage and effluent discharge from the copper-cobalt mining operations, but that the process of neutralization results in most of the material entering the particulate phase that is then sedimented out of the water column. Wetland areas located downstream of the Zambian Copperbelt are able to trap large quantities of this particulate material so that very little reaches the lower Kafue River or the Zambezi River.

Whilst the predominance of heavy metals as (suspended) particulate material or as components within the river sediments suggests that they are likely to have very little effect on aquatic biota and other water users, these metals will become available as soon as the sediments and particulate material are oxidized. This could pose several important water quality problems for water resource managers in the area.

3.12.6 Implications for water quality and quantity management

The very large population that is now resident in this sub-catchment has considerable implications for overall water resource and water quality management. The sheer volume of treated sewage effluent and industrial effluent that is discharged into the Kafue River suggests very strongly that water quality problems will continue to worsen in the future. The situation is exacerbated by seepage of acid mine drainage from mining operations, as well as the erosion of particulate material in the form of fines from poorly-sited and badly protected tailings dams close to the Kafue River.

3.13 The Lower Kafue sub-catchment

3.13.1 General description

3.13.1.1 Hydrology

This sub-catchment covers the Kafue River Floodplain in the Central province of Zambia. During seasonal floods, the Kafue spills its banks, often reaching 15-20 kilometres in width across the floodplain. Several small tributaries join the Kafue in this sub-catchment. The Kafue River is dammed at the Itezhitezhi gap and at the Kafue Gorge; both dams are designed for hydroelectric power generation and supplement the power gained from the Kariba North hydroelectric power station at the Kariba Dam.

3.13.1.2 Geology

This sub-catchment is underlain predominantly by the Karoo basalts and sandstones overlain by sedimentary and alluvial deposits.

3.13.1.3 Pedology, agriculture and land use

The soils consist almost entirely of alluvial soils and hydromorphic vertisols, with some well-leached ferralitic soils in the northern portion of this sub-catchment. The Kafue Floodplain supports the Kafue National Park as well as two smaller National Parks (Lochinvar and Blue Lagoon). Extensive cultivation of rice and sugar cane occurs on the floodplains, whilst subsistence agriculture occurs on the richer soils located on floodplain levees along the riverbanks. The southern portion of this catchment supports a thriving livestock rearing area.

3.13.1.4 Surface water users

There are several small towns and villages scattered throughout the sub-catchment. The Provincial capital, Mumbwa, is located north of the Kafue River, whilst the smaller towns of Chilanga and Kafue are located near to the downstream end of this sub-catchment. Considerable quantities of water are used for sugar cane irrigation as well as for livestock rearing.

3.13.1.5 Water management systems

This area falls under the management of the Zambian Department of Water Affairs.

3.13.1.6 Human impacts on water resources (excluding mining)

The following could be expected to have an impact on water resources:

- Disposal of domestic and solid waste from small towns and communities;
- Salinized return flows from extensive irrigation schemes;
- Discharge and seepage of water from livestock farms; and
- Minor non-point impact from sparse, subsistence agriculture throughout the sub-catchment.

3.13.2 Mining and mineral processing operations

A variety of small to medium mining operations are located in this sub-catchment (**Table 3.12; Figure 3.4**). Several areas are also under prospecting licence for gemstones, copper, nickel and gold.

Table 3.12: Mining operations in the Lower Kafue sub-catchment.

Code Number	Name of Mine	Commodity (ies) Mined	Status	Relative Size	Probable Impact
Z-25	Chilanga	Limestone	Operating	Large	Low-Medium
Z-26	Nampundwe	Iron Pyrites, Copper	Operating	Medium	Medium

Z-27	Matala	Gold, Silver	Operating	Small	Low-Medium
Z-28	Munali	Nickel	Prospecting	Small	Low
Z-29	Luwana	Copper	Operating	Small	Low
Z-30	Luiri- Dunrobin	Gold, Silver, Copper	Operating	Medium	Medium
Z-31	Shimwyoka	Iron	Operating	Medium	Low
Z-37	Itezhitezhi	Aquamarine	Operating	Small	Low
Z-38	Kaindu	Amethyst	Operating	Small	Low
Z-58	Argosy	Copper	Prospecting	Medium	Low
Z-59	Chongwe	Copper	Prospecting	Medium	Low
Z-83	Kamiyobo	Copper, iron	Prospecting	Small	Very low
Z-84	Nambala	Iron	Operating	Small	Very low
Z-85	Lochinvar	Gypsum	Prospecting	Small	Very low

3.13.3 Alluvial mining

None known.

3.13.4 Monitoring systems

Regular water quality monitoring is carried out at Kafue and at the two hydroelectric dam sites.

3.13.5 Water quality data

None available.

3.13.6 Implications for water quality and quantity management

The Nampundwe pyrite mine poses a risk of contamination from acid mine drainage, as do the Dunrobin and Luiri gold mines. The Chilanga Cement Works poses a potential problem from alkaline dust.

3.14 The Kariba (Zambia) sub-catchment

3.14.1 General description

3.14.1.1 Hydrology

This area comprises a series of small sub-catchments, whose rivers flow from the surrounding plateau down steeply inclined riverbeds into Lake Kariba. None of these rivers are perennial, though continual seepage from Maamba Colliery gives the appearance of perennial flow in a nearby stream.

3.14.1.2 Geology

The plateau is composed of quartzites and associated rocks, underlain by Karoo Supergroup sedimentary rocks and basalt. These rock formations are deeply incised by the numerous streams flowing from the plateau to Lake Kariba.

3.14.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into three groups:

- Very shallow, gravely soils derived from Upper Karoo sediments and basalts;
- Moderately deep sandy soils derived from Lower Karoo sediments;
- Moderately deep kaolin tic sandy to loamy sand soils derived from quartzites and associated rocks.

The sub-catchment experiences low and erratic rainfall; usually below 650 mm per year; the exception being the higher elevation plateau that receives slightly more.

Land use comprises the sparsely populated communal lands with subsistence agriculture, commercial stock farming (beef cattle and goats) on the plateau and some cash cropping of tobacco. Several small towns are located along the watershed marking the plateau, Zimba, Monze, Choma and Kalomo being the most important centres. A small urban centre has developed close to the Maamba Colliery to house the colliery staff.

3.14.1.4 *Surface water users*

There is some consumption of water for small-scale agriculture in the communal lands along the escarpment, whilst most of the water used for domestic purposes in the towns is obtained either from the Kafue River or from local boreholes. Some water is used at the Maamba Colliery.

3.14.1.5 *Water management systems*

The area falls under the jurisdiction of the Zambian Department of Water Affairs.

3.14.1.6 *Human impacts on water resources (excluding mining)*

The following could be expected to have an impact on water resources:

- Disposal of solid waste at Maamba Colliery and local towns;
- Disposal of liquid effluent at local towns;
- Urban run off from towns;
- Non-point sources of domestic effluent in the rural areas; and
- Litter and garbage on the main road between Livingstone and Lusaka.

3.14.2 Mining and mineral processing operations

The Maamba Colliery is the largest mining operation in this sub-catchment; the other operations are all small or very small (**Table 3.13**; **Figure 3.4**). There are several identified coal resources and a few pegmatites with semi-precious stones located in this sub-catchment.

Table 3.13: Mining operations in the Kariba (Zambia) sub-catchment.

Code Number	Name of Mine	Commodity (ies) Mined	Status	Relative Size	Probable Impact
Z-32	Chipepo	Coal	Prospecting	Small	Low
Z-33	Maamba	Coal	Operating	Large	High – Very high
Z-34	Simani	Amethyst	Operating	Very small	Very low – Low
Z-35a	Kabanga	Tin	Operating	Very small	Very low – Low
Z-35b	Kalomo Claims	Amethyst	Abandoned	Very small	Very low
Z-36	Senkobo	Amethyst	Operating	Very small	Very low – Low

Z-90	Chisuki	Mica, Tin, Tantalite	Operating	Very small	Very low
Z-91	Phoenix	Coal	Operating	Small	Low
Z-92	Namakande	Uranium	Prospecting	Small	Very low
Z-93	Nkandabwe	Coal	Operating	Medium	Low – Medium
Z-94	Siavonga	Uranium	Prospecting	Small	Very low

Maamba and Nakandabwe Collieries experience relatively frequent occurrences of spontaneous combustion in their coal discards and coal fines stockpiles, as well as occasional spontaneous combustion of newly exposed coal measures. Seepage from the collieries is acidic and contains high levels of total dissolved salts.

There has been considerable exploration in the area for semi-precious stones (amethyst and aquamarine) as well as gold, coal and uranium. Minor prospecting has been carried out for diamonds.

3.14.3 Alluvial mining

None known or anticipated.

3.14.4 Monitoring systems

The Zambian Department of Water Affairs carries out occasional sampling of water near the mamba Colliery to check the extent of acid mine drainage.

3.14.5 Water quality data

None available.

3.14.6 Implications for water quality and quantity management

There is evidence to suggest that coal mining operations have had a slight influence on local water resources close to the colliery concerned.

3.15 The Chirundu sub-catchment

3.15.1 General description

3.15.1.1 Hydrology

This area comprises a series of small sub-catchments, whose rivers flow south-eastwards towards the Zambezi Valley, incising relatively deep channels through the edge of the escarpment from the surrounding plateau. None of these rivers are perennial and only contain appreciable flow after rainstorms.

The plateau inland of the Zambezi Escarpment comprises relatively undulating terrain with several small wetland areas and seeps, as well as small sinkholes in areas underlain by limestone deposits.

3.15.1.2 Geology

The plateau is composed of quartzites and associated rocks, underlain by Karoo Supergroup sedimentary rocks and basalt. These rock formations are deeply incised by the numerous streams flowing from the plateau to the Zambezi River. High quality limestone deposits are found at a few places on the plateau, testifying to the marine origin of these rocks. The Zambezi Mobile Belt contains several occurrences of gold.

3.15.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into four groups:

- Very shallow, gravely soils derived from Upper Karoo sediments and basalts;
- Moderately deep sandy soils derived from Lower Karoo sediments;
- Moderately deep kaolinitic sandy to loamy sand soils derived from quartzites and associated rocks;
- Moderately deep, sandy loams on areas underlain by limestone deposits.

The sub-catchment experiences moderate rainfalls of around 800-850 mm on the higher-lying plateau, grading down to some 650 mm per year in the Zambezi Valley.

Land use comprises a mixture of sparsely populated communal lands with subsistence agriculture, densely populated urban areas of Lusaka and Chilanga, with commercial stock farming (beef cattle and goats) on the plateau and some cash cropping and commercial farming of maize. Several small communities are located along the major roads between Chirundu and Lusaka. Large-scale irrigated sugar cane farming is located at the junction of the Kafue and Zambezi rivers.

3.15.1.4 Surface water users

There is some consumption of water for small-scale agriculture in the communal lands along the escarpment, whilst most of the water used for domestic purposes in the larger towns and cities is obtained either from the Kafue River or from local boreholes and dolomite aquifers. Large volumes of water are used by commercial farmers, including large-scale irrigation of sugar cane at the junction of the Kafue and Zambezi rivers.

3.15.1.5 Water management systems

The area falls under the jurisdiction of the Zambian Department of Water Affairs.

3.15.1.6 Human impacts on water resources (excluding mining)

The following could be expected to have an impact on water resources:

- Disposal of solid and liquid wastes at Lusaka, Chilanga, Kafue and Chirundu;
- Urban run off from towns and cities;
- Non-point sources of domestic effluent in the urban and rural areas;
- Contaminated (fertilizers and pesticides) return flows from irrigated agriculture and commercial farming enterprises; and
- Litter and garbage on the main road between Chirundu and Lusaka.

3.15.2 Mining and mineral processing operations

There are several small gold mines in the area and new copper prospects seem to be commercially viable (**Table 3.14**; **Figure 3.4**). A small zinc and lead mine is starting operations to the north of Lusaka. There are several prospecting attempts to locate workable gold and semi-precious stones.

Table 3.14: Mining operations in the Chirundu sub-catchment.

Code Number	Name of Mine	Commodity (ies) Mined	Status	Relative Size	Probable Impact

Z-18	Chumbwe	Gold	Operating	Small	Low – Very low
Z-19	Chakwenga	Gold	Operating	Small	Low – Very low
Z-24	Star	Zinc, Lead	Startup	Small	Low
Z-60	Chongwe East	Copper	Prospecting	Medium	Low
Z-61	Cheowa	Copper	Prospecting	Medium	Low
Z-95	Chakwenga	Gold, Copper	Prospecting	Small	Very low
Z-98	Pamba	Iron	Prospecting	Small	Very low

Minor seepage of cyanide is associated with the gold mining operations, especially from tailings dumps. The zinc deposit is a sulphide ore so acid mine drainage is a potential problem.

3.15.3 Alluvial mining

None known, but can be anticipated if additional gold deposits are found.

3.15.4 Monitoring systems

The Zambian Department of Water Affairs carries out occasional sampling of water to test the quality of water supplied to towns.

3.15.5 Water quality data

None available.

3.15.6 Implications for water quality and quantity management

There is no evidence to suggest that mining operations have had any effect on local water resources.

3.16 The Mulungushi sub-catchment

3.16.1 General description

3.16.1.1 Hydrology

This area comprises a series of small sub-catchments, whose rivers flow in a southerly direction towards the Luano Rift valley, where they swing westwards to join the Luangwa River. The two main rivers, the Mulungushi and the Lusemfwa, are both perennial and have incised relatively deep channels through the edge of the escarpment where they drop into the Luano Rift Valley. Both of these rivers have been dammed for hydroelectric power, at the Mulungushi and Mita Hills dams, respectively. Smaller, non-perennial and perennial tributaries that drain the higher rainfall region to the north of the sub-catchment feed both of these rivers. There are several small wetland areas and seeps in the upper reaches of the rivers.

3.16.1.2 Geology

The plateau is composed of quartzites, sandstones, arenites and associated rocks, underlain by sedimentary rocks and some basalt to the south. These rock formations are intruded by small Greenstone formations that are normally associated with gold and copper mineralization. The Kabwe lead-zinc-vanadium deposit is associated with a dolomite and limestone outcrop. The mobile belt marking the rim of the Luano Rift Valley hosts several pegmatite deposits with high quality mica and other pegmatite minerals, as well as small quantities of gold.

3.16.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into four groups:

- Moderately deep, well-leached ferralitic soils in the wetter northern parts;
- Moderately deep sandy soils derived from quartzites and sandstones associated with the Luano Rift Valley;
- Moderately deep kaolinitic sandy to loamy sand soils derived from quartzites and associated rocks along the floor of the rift valley;
- Moderately deep, sandy loams on areas underlain by limestone deposits.

Much of the sub-catchment experiences annual rainfalls in excess of 1,000 mm, whilst areas in the Luano Rift Valley receive lower rainfalls of around 850 mm.

Land use comprises a mixture of sparsely populated communal lands with subsistence agriculture, densely populated urban areas of Kabwe and Kapiri Mposhi, with commercial stock farming (beef cattle and goats) and commercial maize and tobacco growing on the plateau. Several small communities are located along the major roads between Kabwe and Ndola, as well as the great North Road from Kapiri Mposhi through Mkushi to Mpika.

3.16.1.4 Surface water users

There is some consumption of water for small-scale agriculture in the communal lands along the Luano escarpment, whilst most of the water used for domestic purposes in the larger towns and cities is obtained either from the Mulungushi River or from local boreholes and dolomite aquifers.

3.16.1.5 Water management systems

The area falls under the jurisdiction of the Zambian Department of Water Affairs.

3.16.1.6 Human impacts on water resources (excluding mining)

The following could be expected to have an impact on water resources:

- Disposal of solid and liquid wastes at Kabwe, Kapiri Mposhi and Mkushi;
- Urban run off from towns and cities;
- Non-point sources of domestic effluent in the urban and rural areas;
- Contaminated (fertilizers and pesticides) return flows from large-scale farming enterprises; and
- Litter and garbage on the main road between Lusaka and Ndola.

3.16.2 Mining and mineral processing operations

There are several small gold mines in the area, whilst the Mkushi gold and copper mines have closed. There are good prospects for commercial monazite and strontium deposits at Mbolwe Hill, whilst several promising new copper prospects are located in the north of this sub-catchment (**Table 3.15**; **Figure 3.4**). The old lead-zinc-vanadium deposit at Kabwe is being re-examined with a view to re-working the tailings dumps with improved extraction technologies.

Table 3.15: Mining operations in the Mulungushi sub-catchment.

Code Number	Name of Mine	Commodity (ies) Mined	Status	Relative Size	Probable Impact
Z-15	Lusemfwa	Gold	Abandoned	Very Small	Low

Z-17	Jessie	Gold	Starting	Very Small	Low-Medium
Z-20a	Mkushi	Copper, Silver	Closed	Small	Low-Medium
Z-20b	Mkushi Claims	Copper, Silver	Abandoned	Very small	Very low
Z-21	Mita Hills	Pegmatite-Muscovite	Closed	Very Small	Very low
Z-22	Mulungushi	Pegmatite-Muscovite	Operating	Very Small	Very low
Z-23	Kabwe	Lead, Zinc, Vanadium	Exhausted	Large	Medium-High
Z-66	Mbolwe Hills	Monazite, Strontium	Prospecting	Small	Very low
Z-67	Munshiwemba	Copper	Closed	Medium	Low
Z-69	Sebembere	Copper	Prospecting	Medium	Low
Z-70	Mufukushi	Copper	Prospecting	Medium	Low
Z-96	Green Hills	Copper	Prospecting	Small	Very low
Z-97	Kampumba	Iron, Manganese	Prospecting	Medium	Low
Z-99	Serenje - A	Gold	Prospecting	Small	Very low
Z-100	Lonshi	Copper	Prospecting	Small	Very low
Z-101	Mtuga	Copper	Prospecting	Small	Very low
Z-103	Muchinga	Zinc	Prospecting	Small	Very low

Minor seepage of cyanide is associated with the abandoned gold mining operations at the Lusemfwa Mine, especially from tailings dumps. The lead-zinc-vanadium deposit at Kabwe is a sulphide ore and acid mine drainage as well as sulphuric acid fumes from the old smelter are a management problem. This mine was the first mine to operate in the country, starting in 1906. New copper and gold prospects in the Mkushi District show great promise.

3.16.3 Alluvial mining

None known, but can be anticipated if additional gold deposits are found near Mkushi or in the Luano Rift Valley.

3.16.4 Monitoring systems

The Zambian Department of Water Affairs carries out occasional sampling of water to test the quality of water supplied to towns.

3.16.5 Water quality data

None available.

3.166 Implications for water quality and quantity management

There is some evidence to suggest that the mining operations at Kabwe have had adverse effects on the local environment. Large (but localized) areas are denuded of vegetation as a result of atmospheric pollution from the smelter and seepage from the waste dumps.

3.17 The Luangwa sub-catchment

3.17.1 General description

3.17.1.1 Hydrology

This area comprises one large sub-catchment containing the Luangwa River, with a series of smaller streams and rivers that drain into the Luangwa. The Luangwa River flows in a south-southwesterly direction, draining the Luangwa Rift Valley and also receiving flows from the Mulungushi sub-catchment before swinging southwards to join the Zambezi River at the town of Feira on the Mozambique border.

The Luangwa River is perennial, though dry season flows are barely discernable. The Luangwa Rift Valley lies in a rain shadow that reduces rainfall from the southeasterly winds, and annual rainfalls average some 750 mm. The Luangwa River meanders across a broad floodplain, leaving many isolated oxbow lakes and lagoons. The central portion of the Luangwa Valley contains the Luangwa North and Luangwa South National parks.

The smaller, perennial and non-perennial streams that drain the Muchinga Escarpment to the west and the Nyika and Viphya Plateaux to the east have steep gradients and have incised deeply into the country rock.

3.17.1.2 Geology

The plateaux on both sides of the Luangwa Rift Valley are composed of quartzites, sandstones, granites and gneisses, underlain by sedimentary rocks with coal measures to the east. These rock formations are intruded by numerous small pegmatites that are host to a variety of high-quality semi-precious stone deposits (amethyst, garnet, aquamarine).

Small intrusions of Greenstone formations occur along the mobile belt and these host deposits of gold. A single occurrence of diamond-bearing kimberlite has been located on the Muchinga Escarpment. The mobile belt rocks along the lower reaches of the Luangwa River host gold, lead and zinc deposits.

3.17.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into three groups:

- Moderately deep, well-leached ferralitic soils in the wetter northern, western and southeastern parts of the sub-catchment;
- Moderately deep sandy soils derived from quartzites and sandstones and associated alluvial material along the floor of the Luangwa Rift Valley;
- Moderately deep, sandy loams on areas underlain by limestone deposits.

Land use comprises a mixture of sparsely populated communal lands with subsistence agriculture, densely populated urban areas of Chipata and Lundazi, with commercial stock farming (beef cattle and goats) and commercial maize and tobacco growing on the wetter southern portions of the sub-catchment. Tourism is important in the two National Parks. Several small communities are located along the major roads between Chipata and Lundazi, and north to Songwe, as well as the Great East Road from Lusaka through Chipata to Lilongwe in Malawi.

3.17.1.4 Surface water users

There is some consumption of water for small-scale agriculture in the communal lands along the Luangwa escarpment, whilst most of the water used for domestic purposes in the larger towns is obtained from nearby streams or boreholes. Water used for tourist camps in the national parks is drawn directly from the Luangwa River.

3.17.1.5 Water management systems

The area falls under the jurisdiction of the Zambian Department of Water Affairs.

3.17.1.6 Human impacts on water resources (excluding mining)

The following could be expected to have an impact on water resources:

- Disposal of solid and liquid wastes at Chipata and Lundazi;

- Urban run off from towns and villages;
- Non-point sources of domestic effluent in the urban and rural areas;
- Contaminated (fertilizers and pesticides) return flows from larger farms; and
- Litter and garbage on the main road between Lusaka and Chipata.

3.17.2 Mining and mineral processing operations

There are several small alluvial gold operations in the area, with many artisan miners managing to eke out a living. In addition, numerous artisan miners also extract semiprecious stones (especially garnet and aquamarine) from pegmatites in the Lundazi District. The Tazara diamond kimberlite appears to be promising (**Table 3.16**; **Figure 3.4**). The old asbestos mine at Lukusuzi has been abandoned.

Table 3.16: Mining operations in the Luangwa sub-catchment.

Code Number	Name of Mine	Commodity (ies) Mined	Status	Relative Size	Probable Impact
Z-1	Mbeya	Aquamarine	Operating	Very Small	Very low – Low
Z-2	Chama-A	Garnet	Operating	Very Small	Very low
Z-3	Chama-B	Aquamarine, Garnet	Operating	Small	Low
Z-4	Lundazi-A	Aquamarine	Operating	Artisan (many)	Very low
Z-5	Lundazi	Coal	Operating	Small	Low
Z-6	Lundazi-B	Aquamarine	Operating	Very Small	Very low
Z-7	Lukusuzi	Chrysotile asbestos	Abandoned	Small	Very low
Z-8a	Lundazi-C	Aquamarine	Operating	Small	Very low – Low
Z-8b	Lundazi Claims	Aquamarine	Abandoned	Artisan (many)	Very low
Z-9	Tazara	Diamond – kimberlite	Prospecting	Very small	Very low
Z-10	Sasore	Gold – alluvial	Operating	Small	Low
Z-12	Nyimba-A	Aquamarine	Operating	Small	Very low
Z-13	Nyimba-B	Aquamarine	Operating	Small	Very low
Z-14	Luangwa	Gold – alluvial	Prospecting	Small	Low
Z-16	Hillcrest	Gold – alluvial	Prospecting	Small	Low
Z-63	Mpongo	Lead, Zinc	Prospecting	Medium	Low
Z-64	Chipirinyuma	Lead, Zinc	Prospecting	Medium	Low
Z-68	Chipata claims	Gold - alluvial	Operating	Artisan (many)	Low - Medium

3.17.3 Alluvial mining

Several stretches of streams and rivers near Chipata are worked by artisan miners for gold. Further prospecting may reveal additional gold deposits along the Luangwa Mobile Belt and its associated Greenstone formations.

3.17.4 Monitoring systems

The Zambian Department of Water Affairs carries out occasional sampling of water to test the quality of water supplied to towns.

3.17.5 Water quality data

None available.

3.17.6 Implications for water quality and quantity management

There is some evidence to suggest that the artisan mining operations near Lundazi have contributed small amounts of suspended material to nearby rivers. There appears to be no evidence of any other impact due to mining activities in this sub-catchment, possibly due to the dominance of physical weathering processes in the southern portion where most of the mines are located.

3.18 The Cahora Bassa (Mozambique) sub-catchment

3.18.1 General description

3.18.1.1 Hydrology

This area comprises the Zambezi River zone that stretches from the town of Feira on the Zimbabwe-Zambia border down to the junction with the Mazowe River. A large number of seasonal and a few perennial streams drain northwards from Zimbabwe into this zone, as well as southwards from the Zambian and Malawi border. The very large Cahora Bassa dam is located here, upstream of the town of Tete.

This portion of the Zambezi Valley lies in a relatively dry zone with annual rainfalls averaging between 650 and 750 mm. Below the Cahora Bassa dam, the Zambezi River flows through the deeply incised Cebrasbassa Gorge before emerging onto a broad, flat-bottomed river valley where the river meanders between high flood levees.

The smaller, perennial and non-perennial streams that drain the escarpments from the north and south all have steep gradients and only contain significant quantities of water after rainfalls.

3.18.1.2 Geology

The plateaux on both sides of the Luangwa Rift Valley are composed of quartzites, sandstones, granites and gneisses, underlain by Karoo Supergroup sedimentary rocks with extensive coal measures running from west to east. These rock formations are intruded by numerous small pegmatites and Greenstone formations that are host to a variety of semi-precious stone deposits and gold.

The intrusions of Greenstone formations and the coal measures mark the position of the Zambezi Mobile Belt and its associated mineralization. A significant deposit of uranium is also located in this zone.

3.18.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into two main groups:

- Moderately deep, well-leached soils in the wetter northern and eastern parts of the sub-catchment; and
- Moderately deep sandy soils derived from quartzites and sandstones and associated alluvial material along the floor of the Zambezi Valley.

Land use comprises a mixture of sparsely populated communal lands with subsistence agriculture, the densely populated urban area of Tete, and the small communities associated with the various mining ventures in this sub-catchment. Livestock consists almost entirely of goats and most families rely on fish caught from the Zambezi River. Several small communities are located along the major roads between Zimbabwe and Blantyre in Malawi and between Tete and the Cahora Bassa Dam. Large areas of vegetation have been removed to make charcoal for fuel.

3.18.1.4 Surface water users

There is some consumption of water for small-scale agriculture, whilst water used for domestic purposes in the larger towns is obtained from the Zambezi River.

3.18.1.5 Water management systems

The area falls under the jurisdiction of the Mozambican Ministerio De Aguas.

3.18.1.6 Human impacts on water resources (excluding mining)

The following could be expected to have an impact on water resources:

- Minor disposal of solid and liquid wastes at Cahora Bassa and Tete;
- Non-point sources of domestic effluent in the urban and rural areas;
- Litter and garbage on the main road between Zimbabwe and Blantyre in Malawi.

3.18.2 Mining and mineral processing operations

This sub-catchment hosts several small alluvial gold operations in the area immediately downstream of the Cahora Bassa Dam and the gorge, with many artisan miners managing to eke out a living. In addition, numerous artisan miners also extract semiprecious stones (especially aquamarine) from pegmatites close to the border with Zambia. The Moatize Coal Mine is the largest mine in the area (**Table 3.17**; **Figure 3.4**).

Table 3.17: Mining operations in the Cahora Bassa (Mozambique) sub-catchment.

Code Number	Name of Mine	Commodity (ies) Mined	Status	Relative Size	Probable Impact
Z-11	Capoche	Aquamarine	Prospecting	Small	Very low
Z-102	Gambito	Gold	Abandoned	Small	Very low
M-1	Missale	Gold - alluvial	Operating	Artisan (many)	Low
M-2	Fingoè	Coal	Prospecting	Small	Very low
M-3	Furancungo	Coal	Operating	Very small	Very low
M-4	Tsangano	Coal	Operating	Very small	Very low
M-5	Zambezi diggings	Gold - alluvial	Operating	Artisan (many)	Low – Medium
M-6	Zambezi	Coal	Abandoned	Small	Very low
M-7	Mphende	Coal	Prospecting	Small	Very low
M-8	Songo – Coal	Coal	Operating	Very small	Low
M-9	Matangua	Uranium, Thorium	Operating	Very small	Medium
M-10	Moatize	Coal	Operating	Medium	Medium
M-22	Moatize – Iron A	Iron	Prospecting	Small	Very low

M-23	Moatize – Iron B	Iron	Prospecting	Small	Very low
M-24	Tete	Coal	Prospecting	Medium	Low
M-25	Tete North – A	Fluorite	Abandoned	Small	Very low
M-26	Tete North – B	Iron	Prospecting	Medium	Very low
M-27	Tete North – C	Iron	Prospecting	Small	Very low
M-28	Cassoca – Iron	Iron	Prospecting	Small	Very low
M-29	Cassoca Alluvial	Gold – Alluvial	Operating	Artisan (many)	High
M-30	Ulongue	Iron	Prospecting	Small	Very low
M-31	Ulongue – A	Fluorite	Prospecting	Small	Very low
M-32	Ulongue – B	Fluorite	Prospecting	Small	Very low
M-33	Cahora Bassa-A	Iron	Prospecting	Small	Very low
M-34	Cahora Bassa-B	Iron	Prospecting	Small	Very low
M-35	Fingoè – Iron	Iron	Abandoned	Small	Very low
M-36	Zumbo – East	Nickel	Prospecting	Small	Very low
M-37	Zumbo	Iron	Abandoned	Small	Very low
M-39	Songo	Copper	Prospecting	Small	Very low

3.18.3 Alluvial mining

Several stretches of streams and rivers near Cahora Bassa are worked by artisan miners for gold. Further prospecting may reveal additional gold deposits along the Zambezi Mobile Belt and its associated Greenstone formations.

3.18.4 Monitoring systems

The Mozambican Departimento De Aguas carries out sporadic sampling of water to test the quality of water supplied to towns.

3.18.5 Water quality data

None available.

3.18.6 Implications for water quality and quantity management

There is some evidence to suggest that the Moatize Coal Mine may have had a minor-medium impact on local water quality whilst other mining operations are likely to have had small, localized impacts at most. The artisan gold diggings have contributed to a considerable increase in the suspended sediment load of the Zambezi River during periods of low flow. The Matangua uranium and thorium deposit holds the risk of contaminating local water supplies.

3.19 The Shire (Malawi) sub-catchment (including Tanzania)

3.19.1 General description

3.19.1.1 Hydrology

This area comprises one large sub-catchment containing the Lake Malawi and its outflow, the Shire River, with a series of smaller streams and rivers that drain into Lake Malawi from the Malawi and Tanzanian portions of the rift valley.

In the Tanzanian sector, the most import inflow is the Ruhuhu River, with smaller rivers draining the Livingstone Mountains and entering Lake Malawi at Songwe. All of these rivers are short, with steep gradients and carry large volumes of water since they drain areas that receive annual rainfalls in excess of 2,000 mm.

Lake Malawi also receives inflows from several smaller perennial streams and rivers that drain the Rift Valley and flow into the lake. Outflows from Lake Malawi flow down the Shire River to the Zambezi River.

The Shire River is perennial, though flows have declined in recent years due to a drop in the water level of Lake Malawi. The lower portion of the Lake Malawi Rift Valley lies in a partial rain shadow that reduces rainfall from the southeasterly winds, and annual rainfalls average some 850 mm. Slightly further south, the Mulanje Plateau receives over 2,500 mm of rainfall and provides strong inflows into the Shire River.

All of the smaller, perennial and non-perennial streams that drain the Rift Valley into Lake Malawi have steep gradients and have incised deeply into the country rock.

3.19.1.2 Geology

The plateaux on both sides of the Lake Malawi Rift Valley are composed of quartzites, sandstones, granites and gneisses, underlain by sedimentary rocks with coal measures to the east. In the south and north, these rock formations are intruded by numerous small Greenstone formations that host gold deposits.

In the southern portion of the Shire catchment, extensive deposits of limestone and gypsum are found, as well as good quality bauxite on Mulanje Mountain. A small deposit of monazite is also found near to Lake Chilwa in the south.

3.19.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into three groups:

- Moderately deep to very deep, well-leached ferralitic soils in the wetter northern, western and southeastern parts of the sub-catchment;
- Moderately deep sandy soils derived from quartzites and sandstones and associated alluvial material along the floor of the Lake Malawi Rift Valley;
- Moderately deep, sandy loams on areas underlain by limestone deposits; and
- Small areas of sodic soils in the far south of the sub-catchment.

Land use comprises a mixture of densely populated communal lands with extensive subsistence agriculture, densely populated urban areas of Lilongwe, Zomba, Blantyre, Kotakota and Karonga, with commercial cultivation of maize, cotton and tobacco. Some stock farming (beef cattle and goats) takes place in the central and southern portions of the sub-catchment. Tourism on Lake Malawi is extremely important and several National Parks are located along the length of the rift valley. Numerous small and large communities are located along the major roads running north south alongside Lake Malawi, and alongside the main roads that connect Malawi with Zambia, Mozambique and Zimbabwe.

3.19.1.4 Surface water users

Large volumes of water are consumed by small- and medium-scale irrigation agriculture along the banks of rivers leading to the lake. Most of the water used for domestic consumption in the larger towns is obtained from nearby streams or dolomite formations.

3.19.1.5 Water management systems

The area falls under the jurisdiction of the Malawi Department of Water Affairs.

3.19.1.6 Human impacts on water resources (excluding mining)

The following could be expected to have an impact on water resources:

- Disposal of solid and liquid wastes at all major towns and cities;
- Urban run off from towns and villages;
- Non-point sources of domestic effluent in the urban and rural areas;
- Contaminated (fertilizers and pesticides) return flows from larger farms; and
- Litter and garbage on the main roads between towns and cities.

3.19.2 Mining and mineral processing operations

There are several small alluvial gold operations in the Tanzanian sector of this sub-catchment (Ruhuhu River (**Figure 3.4**; **Table 3.18**)), with many artisan miners extracting gold and selling it to Tanzanian buyers. The only other mineral deposits of note are the coal and limestone workings at several points along the lakeshore on both the Tanzanian (**Table 3.18**) and Malawian sides (**Table 3.19**). A few artisan miners make a living extracting low-grade rubies from Mulanje Mountain and gold from the Lisungwe diggings (**Table 3.19**; **Figure 3.4**).

Table 3.18: Mining operations in the Tanzanian sector of the Shire sub-catchment.

Code Number	Name of Mine	Commodity (ies) Mined	Status	Relative Size	Probable Impact
T-1	Liweta	Coal	Prospecting	Very small	Very low
T-2	Mchuchuma	Gold – alluvial	Operating	Artisan (many)	Low
T-3	Ketewaka	Iron	Prospecting	Very small	Very low
T-4	Mbamba	Coal	Operating	Very small	Low
T-5	Songwe	Coal	Operating	Very small	Low
T-6	Songwe-Kiwira	Coal, chrome	Operating	Very small	Very low

Table 3.19: Mining operations in the Malawi sector of the Shire sub-catchment.

Code Number	Name of Mine	Commodity (ies) Mined	Status	Relative Size	Probable Impact
N-1	Misuku	Coal	Prospecting	Very small	Very low
N-2	Mzuzu	Copper	Prospecting	Very small	Very low
N-3	Mchenga	Coal	Operating	Very small	Very low
N-4	Dwangwa	Limestone	Operating	Small	Very low
N-5	Dwangwa-Coal	Coal	Operating	Very small	Very low
N-6	Ntchisi	Limestone	Operating	Small	Very low
N-7	Mchinji	Iron	Prospecting	Small	Very low

N-8	Mphunzi	Limestone	Operating	Small	Very low
N-9	Nankumba	Gypsum	Operating	Very small	Very low
N-10	Kadango	Gypsum	Prospecting	Very small	Very low
N-11	Machinga	Gypsum	Prospecting	Very small	Very low
N-12	Matale	Coal	Operating	Small	Very low
N-13	Kasamba	Coal	Operating	Small	Very low
N-14	Lisungwe	Gold - alluvial	Operating	Artisan (few)	Low
N-15	Blantyre	Gypsum	Operating	Small	Low
N-16	Mlanje	Corundum – Ruby	Operating	Very small	Very low
N-17	Luchenza	Copper	Prospecting	Small	Very low
N-18	Kangankunde	Monazite, Strontium	Startup	Small	Very low

3.17.3 Alluvial mining

Several stretches of alluvial terraces close the Shire River at Lisungwe are worked for alluvial gold deposits.

3.17.4 Monitoring systems

The Malawi Department of Water Affairs carries out occasional sampling of water to test the quality of water supplied to towns.

3.17.5 Water quality data

None available.

3.17.6 Implications for water quality and quantity management

There is no evidence to suggest that the artisan mining operations near Lisungwe have had any effect on water quality. Similarly, the other mining operations in this sub-catchment appear to have had very minor, localized effects.

3.20 The Mazowe (Mozambique) sub-catchment

3.20.1 General description

3.20.1.1 Hydrology

This area comprises the downstream portion of the Mazowe River after it flows out of Zimbabwe. A large number of seasonal streams drain eastwards from Zimbabwe into this zone. This portion of the Zambezi basin lies in a relatively dry zone with annual rainfalls averaging between 550 and 650 mm.

3.20.1.2 Geology

This sub-catchment is underlain by quartzites, sandstones, granites and gneisses, underlain by Karoo Supergroup sedimentary rocks. The rock formations are intruded by occasional small pegmatites and Greenstone formations that are host to a variety of minerals including small deposits of gold.

3.20.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into two main groups:

- Shallow to moderate, sandy soils on the hillslopes and valleys; and
- Moderately deep sandy soils derived from quartzites and sandstones and associated alluvial material along the floor of the Mazowe River valley.

Land use comprises a mixture of sparsely populated areas with subsistence agriculture and the small communities associated with the small active mining ventures in this sub-catchment. Livestock consists almost entirely of goats and most families rely on fish caught from the Mazowe River. Areas of vegetation have been removed around settlements to make charcoal for fuel.

3.20.1.4 Surface water users

There is some consumption of water for small towns and communities, as well as for subsistence agriculture.

3.20.1.5 Water management systems

The area falls under the jurisdiction of the Mozambican Ministerio De Aguas.

3.20.1.6 Human impacts on water resources (excluding mining)

The following could be expected to have an impact on water resources:

- Minor disposal of solid and liquid wastes at urban centres; and
- Non-point sources of domestic effluent in the urban and rural areas;

3.20.2 Mining and mineral processing operations

This sub-catchment hosts three small mining operations, one of which was abandoned during the civil war (**Table 3.20**; **Figure 3.4**).

Table 3.20: Mining operations in the Mazowe (Mozambique) sub-catchment.

Code Number	Name of Mine	Commodity (ies) Mined	Status	Relative Size	Probable Impact
M-11	Mazowe	Fluorspar	Abandoned	Very small	Very low
M-12	Luenha – A	Kyanite	Operating	Very small	Very low
M-13	Guro	Kyanite	Operating	Very small	Very low
M-15	Guro – South	Kyanite	Abandoned	Small	Very low
M-17	Luenha – Iron	Iron	Prospecting	Small	Very low
M-18	Luanha – B	Iron	Prospecting	Small	Very low
M-19	Luanha – C	Kyanite	Operating	Very small	Very low

3.20.3 Alluvial mining

No evidence available, though it is highly likely that artisan miners work the reaches of the Mazowe River for alluvial gold.

3.20.4 Monitoring systems

This area falls within the jurisdiction of the e Mozambican Departimento De Aguas.

3.20.5 Water quality data

None available.

3.20.6 Implications for water quality and quantity management

There is no evidence to suggest that any of the mines located within this sub-catchment have had any adverse effects on water quality. However, the Mazowe River contains poor water quality caused by the numerous alluvial gold diggers upstream in Zimbabwe.

3.21 The Lower Zambezi (Mozambique) sub-catchment

3.21.1 General description

3.21.1.1 Hydrology

This area comprises the most downstream portion of the Zambezi basin as it flows to the Indian Ocean. A large number of seasonal streams drain northwards from the mountainous region on the border between Zimbabwe and Mozambique, into the Zambezi River. This portion of the Zambezi basin lies in a relatively moist zone with annual rainfalls averaging over 1,000 mm.

3.21.1.2 Geology

This sub-catchment is underlain by crystalline basement rocks, predominantly quartzites, sandstones, granites and gneisses. Many of these rocks outcrop at surface and are easily visible as large dwalas or batholiths.

3.21.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into two main groups:

- Moderately deep to deep sandy soils across most of the sub-catchment;
- Shallow, sandy soils on the hillslopes; and
- Deep deposits of rich alluvial soils on the river terraces flanking both banks of the Zambezi River.

Land use comprises a mixture of sparsely populated areas with subsistence agriculture and small administrative centres, as well as larger commercial farming enterprises that are engaged in growing irrigated sugar cane, cashew nuts and some cotton. Livestock consists entirely of goats and most families rely on fish caught from the Zambezi River.

3.21.1.4 Surface water users

There is some consumption of water for small towns and communities, as well as for subsistence agriculture. Irrigation of sugar cane and cashew nut plantations occurs closer to the coast, using water abstracted from the Zambezi River.

3.21.1.5 Water management systems

The area falls under the jurisdiction of the Mozambican Ministerio De Aguas.

3.21.1.6 Human impacts on water resources (excluding mining)

The following could be expected to have an impact on water resources:

- Minor disposal of solid and liquid wastes at urban centres; and
- Non-point sources of domestic effluent in the urban and rural areas;

3.21.2 Mining and mineral processing operations

This sub-catchment hosts a few small prospecting operations and an extensive area of artisan mining (**Table 3.21**; **Figure 3.4**).

Table 3.21: Mining operations in the Lower Zambezi (Mozambique) sub-catchment.

Code Number	Name of Mine	Commodity (ies) Mined	Status	Relative Size	Probable Impact
M-14	Luenha Alluvial	Gold - Alluvial	Operating	Artisan (many)	High
M-16	Zambezi – A	Iron	Prospecting	Small	Very low
M-20	Zambezi – B	Fluorite	Prospecting	Small	Very low
M-21	Zambezi – C	Fluorite	Prospecting	Small	Very low

There is some evidence that the artisan mining for gold at Luenha causes an extensive amount of sediment to enter the nearby rivers and mercury is also released into the water from gold processing operations. There are also extensive deposits of heavy mineral sands along the coast near the Zambezi Delta at Chinde.

3.21.3 Alluvial mining

No evidence available.

3.21.4 Monitoring systems

This area falls within the jurisdiction of the e Mozambican Departimento De Aguas.

3.21.5 Water quality data

None available.

3.21.6 Implications for water quality and quantity management

None.

3.22 The Chamabonda sub-catchment

3.22.1 General description

3.22.1.1 Hydrology

This is Zone Z1 of Area A (ZSG, 1984), located in the extreme northwest of Zimbabwe (**Figure 3.2**). The catchment zone comprises a series of small, ephemeral rivers that flow into the Zambezi shortly above or shortly below Victoria Falls. The largest river is the Chamabonda Vlei.

3.22.1.2 Geology

The Upper Karoo Batoka Basalt Formation underlies the catchment, covered in some areas by Kalahari Sands (**Figure 3.6**; ZGS, 1999).

3.22.1.3 Pedology, agriculture and land use

The soils are in two groups: the Kalahari Sands and very shallow, gravelly soils overlying the basalts (DRSS, 1979). It lies within Natural Regions IV and V: fairly low and unreliable rainfall under 650mm per annum (ZSG, 1997; Surveyor General and AGRITEX, 1998). The predominance of Kalahari Sands makes the area generally unsuitable for agriculture. Land use is largely Parks & Wildlife Land and Forestry Commission Land38, with sparsely populated Communal Land in the east and a few private farms, some devoted to the tourist industry, along the railway line (ZSG, 1998).

3.22.1.4 Surface water users

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38 Zambezi National Park, Victoria Falls National Park, Matetsi Safari Area and Panda Masuie Forest Land

The only settlements of any size are the resort town of Victoria Falls and the border post of Kazangula. The other main use of water is tourist use of the Zambezi River: boating, canoe safaris, white water rafting, scenic value, fishing and game viewing. The Zambezi River, along with a few boreholes, is the only source of water for wild animals in the Parks & Wildlife Land in the dry season.

3.22.1.5 Water management systems

This area falls under the management of the Gwayi Catchment Council under ZINWA.

3.22.1.6 Human impacts on water resources (excluding mining)

The following could be expected to have an impact on water resources:

- Disposal of domestic and commercial solid waste, Victoria Falls and Kazangula;
- Disposal of domestic and commercial liquid effluent, Victoria Falls and Kazangula;
- Fuel loss and litter on the main roads and the railway;
- Run off from Victoria Falls International Airport;
- Minor non-point impact from sparse, subsistence agriculture in Hwange Communal lands; and
- Non-point impact from minefield in northeast.

3.22.2 Mining and mineral processing operations

The catchment falls under the Bulawayo Mining District (ZGS, 1995). There are no known mining or mineral processing operations in the area. There are no current legal mineral exploration activities39 (ZGS, 2001). There are no known minerals processing operations in the sub-catchment.

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39 This refers to current Exclusive Prospecting Orders

3.22.3 Alluvial mining

Neither known nor likely.

3.22.4 Monitoring systems

None.

3.22.5 Water quality data

None.

3.22.6 Implications for water quality and quantity management

None.

3.23 The Matetsi sub-catchment

3.23.1 General description

3.23.1.1 Hydrology

This is Zone M (ZSG, 1984), located in the extreme northwest of Zimbabwe (**Figure 3.2**). The catchment is that of the Matetsi River which flows into the Zambezi shortly below the Batoka Gorge. The western end of the catchment contains the Kazuma Pan wetlands, a permanent wetland and grassy pan depression area.

3.23.1.2 Geology

The Upper Karoo Batoka Basalt Formation underlies the catchment, covered in some areas by Kalahari Sands (**Figure 3.6**; ZGS, 1999).

3.23.1.3 Pedology, agriculture and land use

The soils are in two groups: the Kalahari Sands and very shallow, gravelly soils overlying the basalts (DRSS, 1979). It lies within Natural Regions IV and V: fairly low and unreliable rainfall under 650mm per annum (ZSG, 1997; Surveyor General and AGRITEX, 1998). Land use is largely Parks & Wildlife Land and Forestry Commission Land40, with sparsely populated Communal Land in the east and a few private farms along the railway line (ZSG, 1998). Farming is generally extensive to semi-extensive: livestock and a few drought resistant crops.

3.23.1.4 Surface water users

The only settlement of any size is the border post of Mpandamatenga. The other main use of water is use of the Zambezi River for tourist purposes: white water rafting, scenic value, fishing and game viewing. The Kazuma Pan wetlands are of critical importance to wildlife, including migratory birds (DNP&WM, 1990).

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40 Kazuma Pan National Park, Matetsi Safari Area and Kazuma and Fuller Forest Lands

3.23.1.5 Water management systems

This area falls under the management of the Gwayi Catchment Council under ZINWA.

3.23.1.6 Human impacts on water resources (excluding mining)

The following could be expected to have an impact on water resources:

- Disposal of domestic solid waste, Mpandamatenga;
- Disposal of domestic liquid effluent, Mpandamatenga;
- Fuel loss and litter on the main road and the railway; and
- Minor impact from sparse, subsistence agriculture in Hwange Communal lands.

3.23.2 Mining and mineral processing operations

The catchment falls under the Bulawayo Mining District (ZGS, 1995). There are a few calcite deposits, all now out of production (**Table 3.22**).

Table 3.22: Mining operations in the Matetsi sub-catchment.

Name	Commodity	Status	Total produced /t	Potential Impact
Rhocal	Calcite	Closed 1940	54776.0	Low

See ZGS (1988a) for locations.

There are no current legal mineral exploration activities (ZGS, 2001). There are no known minerals processing operations in the sub-catchment.

3.23.3 Alluvial mining

Neither known nor likely.

3.23.4 Monitoring systems

None.

3.23.5 Water quality data

None.

3.23.6 Implications for water quality and quantity management

It is possible that Rhocal and associated calcite deposits contributed somewhat to the silt load in the Matetsi River in the first half of the last century. However, current impact is likely to be minimal.

3.24 The Deka sub-catchment

3.24.1 General description

3.24.1.1 Hydrology

This is Zone D of Area A (ZSG, 1984), located in the northwest of Zimbabwe. The catchment is that of the Deka River which flows into the Zambezi shortly above the Devil's Gorge (**Figure 3.2**). The southwestern end of the catchment, and headwaters of the Deka River, is the Tom's Vlei wetlands, a wetland and grassy pan depression area.

3.24.1.2 Geology

The sub-catchment is underlain by the Upper Karoo Batoka Basalt Formation in the southwest, Lower Karoo Group sediments, containing the Hwange coal seams, in the central area, Upper Karoo Group sediments in the north and Kalahari Sands in the south (**Figure 3.6**; ZGS, 1999).

3.24.1.3 Pedology, agriculture and land use

The soils are in two groups: the Kalahari Sands and very shallow, gravelly soils overlying the basalts (DRSS, 1979). It lies within Natural Regions IV and V: fairly low and unreliable rainfall under 650mm per annum (ZSG, 1997; Surveyor General and AGRITEX, 1998). Land use comprises Parks & Wildlife Land41 in the south, the Hwange Town and sparsely populated Communal Land in the north (ZSG, 1998).

3.24.1.4 Surface water users

Wankie Colliery and Hwange Thermal Power Station are the main water users, extracting water from the Zambezi River via a pipeline from the Deka Drum site. Hwange Town is also a water user for domestic and commercial purposes. The other main use of water is use of the Zambezi River for tourist purposes: white water rafting, scenic value, fishing and game viewing. The Deka River, when flowing, and the Tom's Vlei wetlands in the southwest are of importance to wildlife.

3.24.1.5 Water management systems

This area falls under the management of the Gwayi Catchment Council under ZINWA.

3.24.1.6 Human impacts on water resources (excluding mining)

The following could be expected to have an impact on water resources:

- Disposal of waste from the Power Station
- Disposal of domestic and commercial solid waste, Hwange Town
- Disposal of domestic and commercial liquid effluent, Hwange Town
- Run off, Hwange Town Airport.
- Fuel loss and litter on the main road and the railway
- Minor non-point impact from sparse, subsistence agriculture in Hwange Communal lands

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41 Hwange National Park and Matetsi Safari Area

- Non-point impact from minefield in far north.

3.24.2 Mining and mineral processing operations

The catchment falls under the Bulawayo Mining District (ZGS, 1995). The main mining operation is Wankie Colliery, where coal is mined from the Lower Karoo sediments. There is also a coking plant. Tin was mined at Labyrinth Mine in the south, but not any longer. There also are a few calcite deposits, all now out of production (**Table 3.23**).

Table 3.23: Mining Operations in the Deka sub-catchment.

Name	Commodity	Status	Total produced /t	Potential Impact
Antenup	Calcite	Closed 1964	5413.0	Low
Calrho	Calcite	Closed 1964	12776.0	Low
Gobe	Calcite	Closed 1964	14968.0	Low
Kalanga	Calcite	Closed 1966	8499.0	Low
Mwemba/Deka	Calcite	Closed 1968	13702.0	Low
PJG	Calcite	Closed 1965	60735.0	Low
Store	Calcite	Closed 1967	5012.0	Low
Wankie	Coal	In operation	145149888.0	High
Wankie	Pyrite	In operation	91276.0	High

See ZGS (1988a) for locations.

There is exploration for diamonds (ZGS, 2001).

3.24.3 Alluvial mining

Neither known nor likely.

3.24.4 Monitoring systems

No public monitoring currently. ZINWA intends to establish a few monitoring points. Wankie Colliery operates an internal monitoring system.

3.24.5 Water quality data

None available from ZINWA. The following data (**Table 3.24**) covers actual discharge from Wankie Colliery.

Table 3.24: Actual Discharge from Wankie Colliery, after Chenje and others (1998).

pH	8.4	Conductivity	290.5µS/cm	TDS	1699.4ppm	Total hardness	109.0ppm
Alkalinity	601.2ppm	BOD	180.0ppm	COD	3600ppm	Ammonia	2.7ppm N
HCO_3^-	733.5ppm	Cl^-	171.9ppm	PO_4^{3-}	0.6ppm	SO_4^{2-}	1589.6ppm
NO_3^-	20.8ppm N	Na	88.0ppm	Fe	1.4ppm	K	15.6ppm
Mg	11.0ppm	Ca	27.3ppm	K	15.6ppm		

3.24.6 Implications for water quality and quantity management

In the absence of any water quality data from the Deka River, it is only possible to make some general interpretations. The major concern is Wankie Colliery and Hwange Power Station. The production of coal and pyrite, and the conversion of coal to coke, is likely to be associated with acid mine drainage, and release of iron and sulphate into the Deka River. However, the data provided by Chenje *et al*. (1998) suggests that ammonia and nitrate, presumably from explosive residues, may also be a problem. Fly ash and hot water effluent from the power station are also possible areas of concern.

3.25 The Gwayi sub-catchment

3.25.1 General description

3.25.1.1 Hydrology

This is Zones G1-G6, B1-B3, S1-S6, IN and L of Area A (ZSG, 1984). The large Gwayi Sub-catchment comprises over half of Matabeleland North Province, stretching from the Devil's Gorge on the Zambezi River in the north to the City of Bulawayo on the central watershed (**Figure 3.2**). The Gwayi River is perennial, as are its major tributaries, the Shangani and Bembezi Rivers. The two major wetlands in the sub-catchment are the central Shangani valley (Zone S4 and the eastern part of Zone S2 of Area A of ZSG (1984)) and the Dandari Vlei at the head of the Lukosi River (southern Zone L of Area A; ZSG, (1984)).

3.25.1.2 Geology

See **Figure 3.6** (ZGS, 1999). Karoo Supergroup rocks, covered by Kalahari Sands in many areas, underlie the northern and central thirds of the sub-catchment. The Karoo System rocks are broken by the crystalline Kamativi-Dete Inlier. The Archaean Zimbabwe Craton, comprising granitic terrain and the Bulawayo, Inyati and Midlands Greenstone Belts, underlies the southern third of the sub-catchment.

3.25.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into five groups:

- Kalahari Sands;
- Very shallow, gravelly soils derived from Upper Karoo sediments and basalts;
- Moderately deep sandy soils derived from Lower Karoo sediments;
- Shallow to moderately shallow clays and loams formed from Greenstone Belt rocks;
- Moderately shallow, coarse-grained sandy, kaolinitic soils derived from granites (DRSS, 1979).

The sub-catchment lies generally within Natural Region IV: fairly low rainfall of 450mm to 650mm per annum (ZSG, 1997; Surveyor General and AGRITEX, 1998).

Land use is mainly Communal Lands in the northern and central areas and commercial and resettlement farming in the south (ZSG, 1998). Farming is generally extensive to semi-extensive: livestock and a few drought resistant crops. In parts of the southeast, irrigation allows the growing of more sensitive crops on the commercial farms. There is some Parks & Wildlife Land and Forestry Commission Land42 in the northwest.

The major settlements are the Cities of Bulawayo in the far southeast and Gweru in the far east, Nkayi Village and Lupane Town in the central area and Kamativi and Dete Villages in the north. The most densely populated areas away from the cities are Lupane and Nkayi Communal lands in the central area and the Resettlement Areas in Bubi and Umguza Districts (ZSG, 1998).

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42 Hwange National Park, Deka Safari Area and Sikumi, Ngamo and Gwayi group Forest Lands

3.25.1.4 Surface water users

The City of Bulawayo draws water from the Khami and Mguza Rivers (tributaries of the upper Gwayi River: Zones G3 and G5 of Area A (ZSG, 1984). Bulawayo also extracts considerable water from the Nyamandhlovu Aquifer, which may have a deleterious affect on water levels in rivers in Zones G4, G5 and G6 (ZSG, 1984).

Irrigation by commercial agriculture is a major water user in Zones S5, S6 (note Shangani Tiyabenzi Dam), B3, G3, G4, G5 and G6 (ZSG, 1984). There are major irrigation projects in the middle Shangani valley, notably the rice project (Zones S2 and S4 in ZSG (1984)).

3.25.1.5 Water management systems

The sub-catchment falls under the Gwayi Catchment Council of ZINWA. This sub-catchment is also the site of the proposed Zambezi Bulawayo Pipeline Project, which is scheme designed to extract water from the Zambezi River and transport it by pipeline across the Gwayi Sub-catchment to Lupane, Nyamandhlovu and ultimately the water-stressed City of Bulawayo.

3.25.1.6 Human impacts on water resources (excluding mining)

The following could be expected to have an impact on water resources:

- Landfills, urban areas of Bulawayo, Gweru, Lupane, Dete and Kamativi;
- Disposal of liquid effluent, urban areas of Bulawayo, Gweru, Lupane, Dete and Kamativi;
- Urban run off, urban areas of Bulawayo, Gweru, Lupane, Dete and Kamativi;
- Non-point domestic effluent, rural areas;
- Non-point impact of agriculture (pesticides, fertilizers, etc), especially in the south and southeast where commercial agriculture is practiced;
- Non-point impact of irrigation in redistribution of river waters;
- Minor non point impact from sparse, subsistence agriculture in Communal lands;
- Sawmills, Gwayi Forest Land and neighbouring Forest Lands;
- Fuel loss and litter on the main roads and railways;
- Run off, Bulawayo International Airport, Induna Airport (Bulawayo) and Moffat Airport (Gweru); and
- Non-point impact from minefield in far north.

3.25.2 Mining and mineral processing operations

The catchment falls mainly under the Bulawayo Mining District, as well as the Gweru Mining District in the southeast (ZGS, 1995). The main mining activity is gold mining in the Greenstone Belts in the south, the Shangani nickel mine and, historically, tin mining in the Kamativi-Dete Inlier in the north. Fireclay and kaolin are quarried in the central area (**Table 3.25**).

Table 3.25: Mining operations in the Gwayi sub-catchment.

Name	**Commodity**	**Status**	**Total produced /t**	Potential Impact
Chikodzi	Agate	Closed 1982	29.0	Low
Mazibope	Agate	Closed 1974	46.7	Low
Chikodzi	Amethyst	Closed 1982	25.5	Low
Mazibope	Amethyst	Closed 1974	18.3	Low
Gothic	Antimony	Closed 1984	1083.0	High
Bet	Asbestos	Closed 1954	1056.2	Low
Bemas	Clay	Closed 1984	375739.0	Low
Shangani	Cobalt	In operation	227.4	High: AMD possible
Clare	Diamond	Closed 1913	0.74ct	Low
Colossus	Diamond	Closed 1941	143.6ct	Low
Somabula	Diamond	Close 1960	15896ct	Medium
Wessels	Diamond	Closed 1912	81ct	Low
Berg	Fireclay	Closed 1984	11269.0	Low
Dagamella	Fireclay	Closed 1980	32176.0	Low
Firdon	Fireclay	Open in 1984	348625.0	Low
Inyantue	Fireclay	Closed 1977	99564.0	Low
Entuba	Fluorite	Closed 1965	1395.0	Low
Fluorite The First	Fluorite	Closed 1967	3177.0	Low
Isabella (B & S or Motapa)	Gold	Operational	9.5	High: Arsenic possible, large open pits
Lonely	Gold	Closed, reworking dumps	34.9	High: Size
Old Nic	Gold	Closed	6.6	Medium
Queens	Gold		5.2	Medium
Sunace	Gold		8.2	Medium
Turk	Gold	In operation	12.6	High: Arsenic possible
Athi	Kaolin	Closed 1979	2315.3	Low
Fuesi	Kaolin	Closed 1976	3440.2	Low
Elbas	Lead	Closed 1970	183.0	Medium: AMD possible
Pilgrim	Mercury	Closed 1941	0.0064	High
Shangani	Nickel	In operation	29443.0	High: AMD possible
Ivene	Quartz	Closed 1959	43756.0	Low

Leek	Quartz	Closed 1984	384338.0	Low
Osage	Silver	Open in 1984	5.9	Medium: AMD possible
Athi	Talc	Closed 1968	2633.0	Low
Gwaai	Tantalum	Closed 1981	34.6	Low
Kamativi	Tantalum	Closed 1984	559.1	Low
Lutope	Tantalum	Closed 1979	7.8	Low
Wolf Cub	Tantalum	Closed 1968	8.2	Low
Gwaai	Tin	Closed 1983	454.7	Low
Kamativi	Tin	Closed 1980s	23834.0	Medium
Lutope	Tin	Closed 1983	996.000	Low
RHA	Tungsten	Closed 1979	1247.7	Low

For locations, see ZGS (1988a) and ZGS (1988b).

There is considerable exploration taking place in the south, mainly for gold, silver, nickel, diamonds, asbestos and various base metals, and a single EPO for diamonds and garnet south of Hwange (ZGS, 2001).

3.25.3 Alluvial mining

Chiyanike (1997) has reported alluvial mining of gold from the Gwayi, Shangani and Bembezi Rivers. It may also take place in tributaries of these rivers, especially the Mguza and Gweru.

3.25.4 Monitoring systems

ZINWA has a number of water quality monitoring points on the Gwayi and Mgusa Rivers. It is in the process of establishing regular monthly sampling operations. Some mines carry out their own monitoring.

3.25.5 Water quality data

Water quality data are available from ZINWA for two monitoring stations on the Mgusa River.

3.25.6 Implications for water quality and quantity management

The two lone water quality data points lie in an area of historical gold mining, and it is possible that this activity may relate to the elevated levels of total dissolved and suspended solids and sodium reported in the diagrams above. However, it is more likely that this effect arises from the impact of the City of Bulawayo, some few kilometres upstream.

Mining and minerals processing operations in the sub-catchment that have high potential impact fall into groups:

- Various gold mines in the Bubi Greenstone Belt, which might contribute arsenic and acid mine drainage;
- Shangani mine, which might contribute acid mine drainage and metals such as nickel, copper and cobalt;
- Pilgrim mine in the Bubi Greenstone Belt, now closed, may still contribute mercury contamination
- Gothic mine in the Lower Gweru Greenstone Belt, which may contribute acid mine drainage and metals such as nickel, copper and cobalt antimony
- Alluvial gold mining in the Upper Gwayi River and its tributaries
- Lead and tin mining in the Kamativi-Dete Inlier
- The Kamativi tin smelter, now defunct

The larger gold, tin and nickel mines all have large waste rock and tailing dumps.

Thus it can be seen that the major impact of mining operations in the sub-catchment is likely to come from the Greenstone Belts that lie in the headwaters of the Gwayi and its tributaries. Such impact as they have is therefore likely to be felt to some extent, throughout the river system, although dilution will have an effect over distance. There is no significant impact of mining in the Lupane – Nkayi (central) areas, but mining once again has a potential impact on the river system in the Kamativi area, where shallow soils increase water system vulnerability.

3.26 The Sebungwe and Lwizilukulu sub-catchments

3.26.1 General description

3.26.1.1 Hydrology

This is Zones Z2 and R of Area A (ZSG, 1984). The area comprises a series of small sub-catchments, whose rivers flow from the Chizarira Plateau into Lake Kariba. The largest of these rivers are the Mlibizi, Sebungwe and Lwizilukulu (Rwizi Ruhuru). None are perennial (**Figure 3.2**). There is a small wetland associated with the Chibwatata Hot Springs, near Binga Town.

3.26.1.2 Geology

See **Figure 3.6** (ZGS, 1999). The Chizarira Plateau is composed of Sijarira Group quartzites and associated rocks. Karoo Supergroup sedimentary rocks underlie the remainder of the area.

3.26.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into three groups:

- Very shallow, gravelly soils derived from Upper Karoo sediments and basalts;
- Moderately deep sandy soils derived from Lower Karoo sediments;
- Moderately deep kaolinitic sandy to loamy sand soils derived from Sijarira Group sediments (DRSS, 1979).

The sub-catchment lies generally within Natural Region V: low and erratic rainfall: below 650mm; the exception is the Chizarira Plateau, which is in Natural Region III with higher rainfall and deeper soils (ZSG, 1997; Surveyor General and AGRITEX, 1998).

Land use comprises the sparsely populated Manjolo and Siabuwa Communal Lands and Parks & Wildlife Land and Forestry Commission Land43 (ZSG, 1998). Such farming as takes place is limited to livestock production (especially goats) and a few drought resistant crops. The major settlement is Binga.

3.26.1.4 Surface water users

There is some consumption of water for small-scale agriculture in the Communal Lands, as well as extraction for Binga Town. The other major use is tourism on Lake Kariba: boating, fishing and game viewing.

3.26.1.5 Water management systems

The area falls under the Gwayi Catchment Council of ZINWA.

3.26.1.6 Human impacts on water resources (excluding mining)

The following could be expected to have an impact on water resources:

- Disposal of solid waste, Binga;
- Disposal of liquid effluent, Binga;
- Urban run off, Binga;

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43 Chizarira National Park, Chete Safari Area and Sijarira and Kavira Forest Lands

- Non-point domestic effluent, rural areas;
- Minor non-point impact from sparse, subsistence agriculture in Communal lands;
- Fuel loss and litter on the main road to Binga;
- Litter and fuel loss from boating, Lake Kariba.

3.26.2 Mining and mineral processing operations

The catchment falls under the Bulawayo Mining District (ZGS, 1995). There are limited coal resources and a few pegmatites in the area (**Table 3.26**).

Table 3.26: Mining operations in Sebungwe and Lwizilukulu sub-catchments.

Name	Commodity	Status	Total produced /t	Potential Impact
Tinde	Fluorite	Closed 1978	5980.0	Low
Sebungwe	Diamond		0.0031ct	Low

See ZGS (1988a) for location.

There is no legal exploration taking place (ZGS, 2001), although historically there has been much exploration for diamonds in the area.

3.26.3 Alluvial mining

Neither known nor likely.

3.26.4 Monitoring systems

None.

3.26.5 Water quality data

None available.

3.26.6 Implications for water quality and quantity management

There is no evidence to suggest that mining operations have had an influence on water quality in the area.

3.27 The Sengwa sub-catchment

3.27.1 General description

3.27.1.1 Hydrology

This is Zone Z3 of Area A (ZSG, 1984). The sub-catchment comprises the valley of the Sengwa River and its tributaries, the Busi and the Rutope (Lutope) (**Figure 3.2**). None of the rivers are perennial. There are some small wetlands associated with the Upper Busi River.

3.27.1.2 Geology

See **Figure 3.6** (ZGS, 1999). The geology consists mainly of Karoo Supergroup sediments, capped on the Mafungabusi (Mapfungautse) Plateau by Karoo basalt, Gokwe Formation sediments and Kalahari Sands.

3.27.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into four groups:

- Kalahari Sands;
- Moderately deep sandy soils derived from Karoo sediments;
- Moderately deep kaolinitic sandy to loamy sand soils derived from Sijarira Group sediments; and
- A few locally developed salty vertisols (DRSS, 1979).

The sub-catchment lies in three Natural Regions: Region V in the Zambezi Valley: low and erratic rainfall: below 650mm; Region IV in the middle Sengwa Valley: fairly low rainfall of 450mm to 650mm per annum; Region III on the Mafungabusi Plateau and in the Rutope valley: higher rainfall and deeper soils (ZSG, 1997; Surveyor General and AGRITEX, 1998).

Land use comprises the Siabuwa, Omay, Kana and Gokwe Communal Lands and Parks & Wildlife Land and Forestry Commission Land[44] (ZSG, 1998). Such farming as takes place in the north is limited to livestock production (especially goats) and a few drought resistant crops, with more croppage in the Gokwe and Kana Communal Lands. The Zambezi Valley is sparsely populated, but the Rutope Valley is more densely settled. The largest settlement is Siabuhwa Village.

3.27.1.4 Surface water users

There is some consumption of water for small-scale agriculture in the Communal Lands. The other use is tourism on Lake Kariba: boating, fishing and game viewing.

3.27.1.5 Water management systems

The area falls under the Sanyati Catchment Council of ZINWA.

3.27.1.6 Human impacts on water resources (excluding mining)

The following could be expected to have an impact on water resources:

- Non-point domestic effluent, rural areas;
- Minor non-point impact from sparse, subsistence agriculture in Communal lands;
- Fuel loss and litter on the main road from Gokwe to Sengwa Colliery;
- Litter and fuel loss from boating, Lake Kariba.

3.27.2 Mining and mineral processing operations

The catchment falls under the Bulawayo, Harare and Gweru Mining Districts (ZGS, 1995). There are limited coal resources in the area.

Table 3.27: Mining operations in the Sengwa sub-catchment.

Name	**Commodity**	**Status**	**Total produced /t**	**Potential Impact**
Sengwa	Coal	Closed	some in late 1980s	Medium

See ZGS (1988a) for location.

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44 Chizarira National Park, Chirisa Safari Area and Mafungabusi Forest Land

There are currently no legal exploration activities taking place.

3.27.3 Alluvial mining

Neither known nor likely.

3.27.4 Monitoring systems

None.

3.27.5 Water quality data

None available from ZINWA. The following data covers actual discharge from Sengwa Colliery (**Table 3.28**).

Table 3.28: Actual discharge from Sengwa Colliery, after Chenje *et al*. (1998).

pH	7.6	Fe	0.3ppm Fe	SO_4^{2-}	10ppm	Total hardness	160ppm
Alkalinity	169ppm	Cl^-	3ppm	SO_4^{2-}	10ppm	Ca	53ppm
NO_3^-	0.39ppm N						

3.27.6 Implications for water quality and quantity management

The only significant mining operation in the sub-catchment was the Sengwa Colliery, now closed. It is to be expected that the colliery may have contributed acid mine drainage, sulphates and iron to the river system, especially given its adjacency to the Sengwa River. However, the limited data from Chenje *et al*. (1998) suggest that the problem may not be very severe. There is also the potential for fluorine contamination from associated Upper Karoo sediments (cf. Magalela, 1997).

An option frequently discussed in the feasibility studies and environmental impact assessment for the colliery was the rerouting of the Sengwa River away from the colliery through an old river channel, a few kilometres to the west. Were this option to be undertaken sometime in the future, during a putative reopening of the colliery, it is probable that the impact of the colliery itself would be reduced. Impact on the river system would thus be the diversion itself, as well as the exposure of the river water to lithologies such as burnt coal measures.

3.28 The Ume sub-catchment

3.28.1 General description

3.28.1.1 Hydrology

This is Zone Z5 of Area A (ZSG, 1984). The sub-catchment comprises the valley of the Ume River and its tributary, the Sessami (**Figure 3.2**). Neither is perennial.

3.28.1.2 Geology

See Figure 3.6 (ZGS, 1999). The geology consists mainly of Karoo Supergroup sediments, capped on the Mafungabusi (Mapfungautse) Plateau by Karoo basalt, Gokwe Formation sediments and Kalahari Sands. The Matuzviadonha (Matusadona) Mountains are formed of a crystalline inlier.

3.28.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into four groups:

- Moderately deep sandy soils derived from Karoo sediments (most of the sub-catchment);
- Very shallow, gravelly soils derived from the crystalline inliers; and
- Moderately deep kaolinitic sandy to loamy sand soils derived from Karoo basalts on the Mafungabusi Plateau (DRSS, 1979).

The sub-catchment lies in three Natural Regions: Region V in the Zambezi Valley: low and erratic rainfall: below 650mm; Region IV in the middle Sengwa Valley: fairly low rainfall of 450mm to 650mm per annum; Region III on the Mafungabusi Plateau and in the Rutope valley: higher rainfall and deeper soils (ZSG, 1997; Surveyor General and AGRITEX, 1998).

Land use comprises the Omay and Gokwe Communal Lands and Parks & Wildlife Land and Forestry Commission Land45 (ZSG, 1998). Such farming as takes place in the north is limited to livestock production (especially goats) and a few drought resistant crops, with more croppage in the Gokwe Communal Land. The Zambezi Valley is sparsely populated, but the Sessami Valley is more densely settled. The largest settlements are Gokwe Town, and Bumi Hills and Siakobvu Villages.

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45 Matusadona National Park and Mafungabusi Forest Land

3.28.1.4 Surface water users

There is some consumption of water by Gokwe Town and for small-scale agriculture in the Communal Lands. The other use is tourism on Lake Kariba: boating, fishing and game viewing.

3.28.1.5 Water management systems

The area falls under the Sanyati Catchment Council of ZINWA.

3.28.1.6 Human impacts on water resources (excluding mining)

The following could be expected to have an impact on water resources:

- Landfills, Gokwe;
- Disposal of liquid effluent, Gokwe;
- Urban run off, Gokwe;
- Non-point domestic effluent, rural areas;
- Non-point impact of agriculture (pesticides, fertilizers, etc);
- Fuel loss and litter on the main road from Gokwe to Sengwa Colliery;
- Litter and fuel loss from boating, Lake Kariba.

3.28.2 Mining and mineral processing operations

The catchment falls under the Gweru and Harare Mining Districts (ZGS, 1995). There are limited coal resources in the area.

Currently, there are no legal exploration activities taking place.

3.28.3 Alluvial mining

Neither known nor likely.

3.28.4 Monitoring systems

None.

3.28.5 Water quality data

None.

3.28.6 Implications for water quality and quantity management

None, unless coal exploration or mining is begun.

3.29 The Sanyati-Munyati sub-catchment

3.29.1 General description

3.29.1.1 Hydrology

This is Zones S, UN1-UN6 and US of Area C (ZSG, 1984). The large Sanyati-Munyati Sub-catchment stretches from Lake Kariba to the Midlands towns of Kwekwe and Kadoma and to Chivhu in Mashonaland East (**Figure 3.2**). The Sanyati River is referred to as Munyati above the confluence with the tributary Mupfure (see Section 3.10). The main tributaries of the Munyati are the Msweswe (Zone US of Area C in ZSG (1984) and the Sebakwe (Zone UN3 and UN4 of Area C in ZSG (1984)). All these rivers are perennial.

The Sebakwe is dammed at Sebakwe and Lower Zhivagwe (Dutchman's Pool) to provide water for the City of Kwekwe. The Ngezi, a tributary of the Upper Munyati (Zone UN5 of Area C in ZSG (1984), is dammed to provide water for Munyati Thermal Power Station. The Msweswe is dammed at Claw Dam to provide water for Kadoma Town.

3.29.1.2 Geology

See **Figure 3.6** (ZGS, 1999). The sub-catchment is generally underlain by crystalline rocks: granitic terrain east of Kwekwe and Kadoma, the Midlands Greenstone Belt in the Kadoma – Kwekwe – Empress triangle, Magondi Supergroup metasediments and gneisses in the area around Sanyati Mission and Copper Queen, Sijarira quartzites and associated rocks in the area around Machihiri and gneisses in the lower Sanyati valley. The Great Dyke cuts north to south across the sub-catchment west of Ngezi dam. An outlier of Upper Karoo sediments and basalts underlies the Featherstone area.

3.29.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into five groups:

- Very shallow, gravelly soils in the Sanyati valley;
- Moderately shallow hydromorphic silty clay loams, derived from the Magondi rocks;
- Shallow to moderately shallow kaolinitic clays and loams formed from Greenstone Belt rocks;
- Moderately shallow sands and loamy sands, coarse grained in places, formed from Upper Karoo sediments and basalts;
- Moderately shallow, coarse grained sandy, kaolinitic soils derived from granites, sodic in places; and
- Deep clays on the Great Dyke (DRSS, 1979).

The sub-catchment lies generally within Natural Region III: high rainfall and deep soils; the Sanyati valley is generally Region IV: fairly low rainfall of 450mm to 650mm per annum (ZSG, 1997; Surveyor General and AGRITEX, 1998).

Land use is mainly commercial farming, private and resettlement land with Communal Lands in the Sanyati valley and between Ngezi Dam and Featherstone (ZSG, 1998). Farming generally involves livestock production, cash crops and fodder crops, except in the Sanyati valley where poor soils and low rainfall limit agriculture to some livestock and a few drought resistant crops.

The major settlements are the City of Kwekwe and Kadoma Town, with settlements along the road and rail link between them, Empress Mine, Mvuma and Chivhu. The most densely populated areas are the Communal Lands and resettlement areas in the Munyati valley.

3.29.1.4 *Surface water users*

The City of Kwekwe draws water from the Sebakwe River, and Kadoma Town from the Msweswe River. Ngezi Dam supplies the Munyati Thermal Power Station.

Irrigation by commercial agriculture is a major water user in Zones UN2 - UN6 and S in Area C (ZSG, 1984).

3.29.1.5 *Water management systems*

The sub-catchment falls under the Sanyati Catchment Council of ZINWA.

3.29.1.6 *Human impacts on water resources (excluding mining)*

The following could be expected to have an impact on water resources:

- Landfills, urban areas of Kwekwe, Kadoma, Chivhu, Mvuma and Empress;
- Disposal of liquid effluent, urban areas of Kwekwe, Kadoma, Chivhu, Mvuma and Empress;
- Urban run off, urban areas of Kwekwe, Kadoma, Chivhu, Mvuma and Empress;
- Non-point domestic effluent, rural areas;
- Non-point impact of agriculture (pesticides, fertilizers, etc), especially where commercial agriculture is practiced;
- Non-point impact of irrigation in redistribution of river waters;
- Minor non-point impact from sparse, subsistence agriculture in the Sanyati valley;
- Fuel loss and litter on the main roads and railways; and
- Run off, Kwekwe and Eiffel Flats Airports and Thornhill Air Base.

3.29.2 *Mining and mineral processing operations*

The catchment falls under the Gweru and Kadoma Mining Districts (ZGS, 1995). The main mining activity is gold mining in the Greenstone Belts, iron at Redcliff (historically) and chrome along the Great Dyke (**Table 3.29**).

Table 3.29: Mining operations in the Sanyati-Munyati sub-catchment.

Name	Commodity	Status	Total produced /t	Potential Impact

Anzac	Antimony	Closed 1970	973.5	High
BD	Antimony	Closed 1984	686.8	High
Cam and Motor	Antimony	Closed 1969	247.4	High
Dalling	Antimony	Closed 1982	245.9	High
Globe and Phoenix	Antimony	Closed 1971	1832.9	High
Glover	Antimony	Closed 1977	402.1	High
Indarama	Antimony	Closed 1979	1591.7	High
Janet	Antimony	Closed 1971	169.9	High
Argosy	Barytes	Closed 1977	8793.3	Low
Cagal	Beryl	Closed 1974	479.7	Low
Gumbo's Dream	Beryl	Closed 1964	105.7	Low
Tengwe	Beryl	Closed 1963	102.8	Low
Cambrai	Chromium	Closed 1984	776791.0	Low
Netherburn	Chromium	Closed 1984	776086.0	Low
Falcon	Copper	Closed 1955	31225.4	Medium
Rivclay	Fireclay	Closed1966	15002.0	Low
Athens	Gold	Closed	5.9	High: Arsenic possible
Bell-Riverlea	Gold	In operation	10.0	High: Arsenic possible
Brompton	Gold	Closed?	7.8	Medium: Arsenic in Try Me body
Cam and Motor	Gold	Dump retreatment	147.2	High: Arsenic possible
Comrades Extension	Gold	Dump retreatment	5.7	High: Arsenic possible
Connemara	Gold	In operation	16.7	Medium
Eiffel blue	Gold	Closed	7.2	High: Arsenic possible
Falcon	Gold	Closed	12.7	High: Arsenic possible
Gaika	Gold	In operation	22.7	High: Size & Sb possible
Globe and Phoenix	Gold	Closed	124.1	High: Size & Sb possible
Golden Valley	Gold	In operation	31.1	High: Size
Indarama	Gold	In operation	6.1	High: Arsenic & Sb possible
Kanyemba	Gold		7.6	High: Arsenic possible
Mali	Gold		6.3	Medium
Owl	Gold		5.2	Medium
Patchway	Gold	Care & maintenance since 2000	18.0	Medium
Piper Moss	Gold		5.4	High: Arsenic & Sb possible
Sherwood Starr	Gold	Closed	15.2	High: Arsenic & Sb possible
Spectacle	Gold		8.6	Medium

Thistle Etna	Gold		6.7	Medium
Tiger Reef	Gold	In operation	5.0	High: Arsenic possible
Venice	Gold	In operation	13.8	High: Arsenic & Sb possible
Beacon Tor	Iron	Closed 1975	1560813.0	Low
Mel	Iron	Closed 1973	740380.0	Low
Orpheus	Iron	Closed 1975	1517260.0	Low
Ripple Creek	Iron	Closed 1980s	2205731.0	High
Tank	Iron	Closed 1979	5291475.0	High
Falcon Lime	Limestone	Closed 1982	167638	Low
Kwekwe	Limestone	In operation		Low
Ripple Creek Limestone	Limestone		7767965	Medium
Barton Farm	Magnesite	Closed 1984	868024	Medium
Dan	Manganese	Closed 1962	16502.0	Low
Ripple	Manganese	Closed 1952	1433.0	Low
Richmond	Mercury	Closed 1970	0.0099	High
Empress	Nickel	Closed 1982	52146.0	High: AMD possible
Tritan	Ochre	Closed 1978	1214	Low
Zoe	Ochre	Closed 1984	4066	Low
Empress	Palladium	Closed 1980	0.211	High
Zinca	Palladium	Closed 1981	0.013	Medium
Empress	Platinum	Closed 1980	0.093	Medium
Ngezi	Platinum	In operation	0.012	Low
Broadside	Quartz	Closed 1984	1055330.0	Medium
Duzi	Quartz	Closed 1981	133630.0	Low
Lone Kop	Quartz	Closed 1983	36535.0	Low
Rio Silica	Quartz	Closed 1981	321695	Low
Tritan	Talc	Closed 1979	1195.82	Low
Golden Valley	Tungsten	Closed 1967	463.5	Low
Scheelite King	Tungsten	Closed 1953	50.0	Low
Sunday	Tungsten	Closed 1944	50.3	Low
Tungsten (Homestead)	Tungsten	Closed 1954	92.8	Low
Umsweswe Tungsten	Tungsten	Closed 1955	84.2	Low
Copper Queen	Zinc	In operation	164.9	High: AMD & As possible
Sanyati	Zinc, copper	Starting operations		High: AMD and metals possible

See ZGS 1988a) and ZGS (1988b) for locations.

There is exploration for diamonds, gold, silver, copper, lead, zinc, nickel, cobalt, platinum, and arsenic (ZGS, 2001).

3.29.3 Alluvial mining

Alluvial mining of gold is widespread, especially in the Sanyati, Munyati, Msweswe and Sebakwe Rivers (**Figure 3.14**; Chiyanike, 1997).

3.29.4 Monitoring systems

ZINWA has a large number of sampling points in the sub-catchment, mainly on the Sanyati, Munyati, Kwekwe and Sebakwe Rivers.

3.29.5 Water quality data

Water quality data are available from ZINWA for several monitoring stations.

3.29.6 Implications for water quality and quantity management

The major impact of mining on the sub-catchment is to be expected from the gold mines, many of which also produce antimony, mainly located in the Midlands Greenstone Belt between Kwekwe and Kadoma. These gold mines, many of which are extensive in size, with six mines that have produced over 15t of gold and two that have produced over 100t of gold, are likely to contribute acid mine drainage, iron and sulphate to the many local streams and rivers that pass through the area. Many of these gold mines also contain arsenic and antimony sulphides, potentially releasing these highly toxic metals into the local waters. Some gold mines have mercury associated with them, e.g. Cactus Mine, and some are associated with bismuth.

The large iron ore mines, now closed, at Ripple Creek and Tank, are likely to have a high impact on the local stream systems, due to their immense size (over seven million tons of iron ore were extracted from the two sites alone) as well as acid mine drainage and iron possibly released into the water.

Three heavy metal mines in the sub-catchment deserve mention: Empress Mine, a one-time producer of nickel and palladium; zinc and copper producer, Copper Queen, and the recently started copper-lead-zinc mine at

Sanyati, all may well contribute or have contributed acidity and heavy metals such as nickel, lead, copper, cobalt and zinc to the local rivers. Copper Queen and Sanyati are located on highly vulnerable shallow, sandy soils. There was also a small mercury mine at Richmond, near to the Munyati River, where the main railway line crosses it.

Further high impact is to be expected from the three chrome smelters located in the sub-catchment, as well as the nickel smelter at Empress and the blast furnaces at Redcliff. Hexavalent chromium is associated with effluent from chrome smelters. The ZISCO and ZIMASCO smelters in the Kwekwe area are very close to the Sebakwe River, a major perennial tributary. The Empress smelter is in close proximity to the Munyati River itself.

There is extensive alluvial gold mining from the Midlands Greenstone Belt downstream and small-scale chrome mining along the Great Dyke (**Figure 3.14**).

Examination of the water quality data presented above shows elevated levels of total dissolved and suspended solids, total hardness, nitrates, phosphates and iron. The sites that figure most prominently in terms of values in excess of the "blue" limits are all located in the Kwekwe area46. This could be related to the very dense concentration of gold, antimony and iron producing mines, current and historical, in the Kwekwe area, as well as the Kwekwe smelter. However, the impact of the Kwekwe urban area cannot be discounted in this consideration, and commercial farming is quite likely to be the source of nitrates and phosphates.

The Sanyati – Munyati Sub-catchment is the most heavily mined area in the country, both currently and historically. The impact of mining is concentrated in the Midlands Greenstone Belt and the series of heavy metal producers in the lower Munyati and Sanyati valleys. The impact of the Midlands Greenstone Belt is accentuated by the fact that all the major rivers in the sub-catchment flow through it.

Extensive exploration continues, notably for gold and base metals. It is therefore indicated that the impact of mining on this sub catchments is not likely to decrease in the foreseeable future.

3.30 The Mupfure sub-catchment

3.30.1 General description

3.30.1.1 Hydrology

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46 Sites CR62,63,64 and 65

This is Zones UF1-UF4 of Area C (ZSG, 1984). The Mupfure River is a major tributary of the Sanyati River (see Section 3.9; **Figure 3.2**).

3.30.1.2 Geology

See **Figure 3.6** (ZGS, 1999). The sub-catchment is generally underlain by crystalline rocks: granitic terrain southeast of Chegutu, the Midlands Greenstone Belt in the Chegutu – Chakari area, Magondi Supergroup metasediments and gneisses in the area around Chirau and Chigaro. The Great Dyke cuts north to south across the sub-catchment, through Kutama and Selous. An outlier of Upper Karoo sediments underlies the area south of Beatrice.

3.30.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into six groups:

- Very shallow, gravelly soils in the lower Mupfure valley;
- Moderately shallow hydromorphic silty clay loams, derived from the Magondi rocks;
- Moderately deep kaolinitic sandy clay loams and deep kaolinitic clays formed from Greenstone Belt rocks;
- Moderately shallow sands and loamy sands, formed from Upper Karoo sediments;
- Moderately shallow, coarse grained sandy, kaolinitic soils derived from granites, sodic in places; and
- Deep clays on the Great Dyke (DRSS, 1979).

The lower Mupfure valley lies within Natural Region III: high rainfall and deep soils; the upper Mupfure valley is within Region IIb: high rainfall of up to 1000mm per annum and deep soils (ZSG, 1997; Surveyor General and AGRITEX, 1998).

Land use is mainly commercial farming, private and resettlement land with Communal Lands in the southeast (ZSG, 1998). Farming is generally intensive cash crops or livestock production.

The major settlements are Chegutu and Chakari Towns, with settlements along the road and rail link between Kadoma and Harare.

3.30.1.4 Surface water users

Chegutu and Chakari Towns draw water from the Mupfure River. Irrigation by commercial agriculture is a major water user.

3.30.1.5 Water management systems

The sub-catchment falls under the Sanyati Catchment Council of ZINWA.

3.30.1.6 Human impacts on water resources (excluding mining)

The following could be expected to have an impact on water resources:

- Landfills, urban areas of Chegutu and Chakari;
- Disposal of liquid effluent, urban areas of Chegutu and Chakari;
- Urban run off, urban areas of Chegutu and Chakari;
- Non-point domestic effluent, rural areas;
- Non-point impact of agriculture (pesticides, fertilizers, etc), throughout the sub-catchment;
- Non-point impact of irrigation in redistribution of river waters; and
- Fuel loss and litter on the main roads and railways.

3.30.2 Mining and mineral processing operations

The catchment falls under the Harare and Kadoma Mining Districts (ZGS, 1995). The main mining activities are gold mining in the Greenstone Belt and platinum and chrome along the Great Dyke (**Figures 3.6, 3.7 and 3.8**).

Table 3.30: Mining operations in the Mupfure sub-catchment.

Name	Commodity	Status	Total produced /t	Potential Impact
Dalny	Gold	In operation	64.0	High: Arsenic possible
Giant	Gold	Closed	17.5	High: Arsenic possible
Pickstone	Gold		11.7	High: Arsenic possible
Tom	Kaolin	Closed 1984	28199.0	Low
Lambourne	Limestone	Closed 1978	166018	Low
Perserverane	Nickel	Closed 1980	4657.0	High: AMD possible
Hartley(Selous)	Palladium	Operations suspended		High
Hartley (Selous)	Platinum	Operations suspended		High

See ZGS (1988a) and ZGS (1988b) for locations.

There is exploration for nickel, copper, PGEs, diamond, gold, silver and platinum (ZGS, 2001).

3.30.3 Alluvial mining

Alluvial mining of gold is widespread, especially along the Mupfure River (**Figure 3.14**; Chiyanike, 1997).

3.30.4 Monitoring systems

ZINWA conducts some monitoring within the sub-catchment.

3.30.5 Water quality data

Water quality data are available from ZINWA for several monitoring stations.

3.30.6 Implications for water quality and quantity management

High impact is expected from three sources:

- The arseniferous gold mines in the Chakari and Gadzema areas; and
- The large Hartley platinum mine and smelter.

The water quality data available from ZINWA is sparse, but two points are worth mentioning:

- High nitrate levels at Shurushuru in the Chakari area; and
- High iron levels in the Beatrice area.

Given the paucity of data, it is not possible to make any interpretations.

3.31 The Charara and Nyaodza sub-catchments

3.31.1 General description

3.31.1.1 Hydrology

This is Zone Z1 of Area C (ZSG, 1984). The area comprises a series of small sub catchments, whose rivers flow from the hills south of Makuti and Vuti into the eastern basin of Lake Kariba (**Figure 3.2**). The largest of these are the Charara (Chalala) and Nyaodza, neither of which is perennial.

3.31.1.2 Geology

See **Figure 3.6** (ZGS, 1999). Mainly gneisses underlie the area, with Karoo Supergroup sedimentary rocks in the land bordering Lake Kariba.

3.31.1.3 Pedology, agriculture and land use

Soils in the area are all very shallow and gravelly (DRSS, 1979). The lakeshore area lies within Natural Region V: low and erratic rainfall: below 650mm, and the hinterland lies within Natural Region IV: fairly low rainfall of 450mm to 650mm per annum (ZSG, 1997; Surveyor General and AGRITEX, 1998).

Land use comprises Hurungwe Communal Land and Zambezi Parks & Wildlife Land[47] (ZSG, 1998). Farming is mainly livestock production and drought resistant crops. The major settlements are Kariba Town and the growing Magunje village.

3.31.1.4 Surface water users

There is some consumption of water for agriculture in the Communal Lands, as well as by Magunje. The other major use is tourism on Lake Kariba: boating, fishing and game viewing.

3.31.1.5 Water management systems

The area falls under the Sanyati Catchment Council of ZINWA.

3.31.1.6 Human impacts on water resources (excluding mining)

The following could be expected to have an impact on water resources:

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47 Charara Safari Area

- Disposal of solid waste, Magunje and Kariba;
- Disposal of liquid effluent, Magunje and Kariba;
- Urban run off, Magunje and Kariba;
- Non-point domestic effluent, rural areas;
- Minor non-point impact from agriculture in Communal lands;
- Fuel loss and litter on the roads to Kariba and to Magunje; and
- Litter and fuel loss from boating, Lake Kariba; and
- Run off, Kariba Airport.

3.31.2 Mining and mineral processing operations

The catchment falls under the Harare Mining District (ZGS, 1995). Graphite is mined and there are numerous pegmatites in the south of the area.

Table 3.31: Mining operations in the Charara and Nyaodza sub-catchments.

Name	Commodity	Status	Total produced /t	Potential Impact
Kariba	Glitterstone			Low
Lynx	Graphite	Closed 1984	130785.0	Low
Catkin	Mica	Closed 1960	333.9	Low
Muyenza	Sillimanite	Closed 1966	76.2	Low

See ZGS (1988a) for locations.

There is some exploration for beryl and gold (ZGS, 2001).

3.31.3 Alluvial mining

Neither known nor likely.

3.31.4 Monitoring systems

ZINWA has a single monitoring station on the upper Nyaodza River.

3.31.5 Water quality data

Only one sampling point (**Figure 3.3**).

3.31.6 Implications for water quality and quantity management

Slightly elevated iron levels are reported from the upper Nyaodza monitoring point, however, there are no mining operations in the vicinity.

The only current mining activities in the area, quarrying of certain gemstones and dimension stones, mostly small-scale, are likely to have minimal impact on local rivers. Such impact as there is will be substantially diluted in the Zambezi, as the rivers all flow into Lake Kariba.

3.32 The Rukomeshe and Chewore sub-catchments

3.32.1 General description

3.32.1.1 Hydrology

This is Zone Z2 of Area C (ZSG, 1984). The area comprises a series of small sub-catchments, whose rivers flow from the hills north of Makuti and Vuti into the Zambezi River below Lake Kariba (**Figure 3.2**). The largest of these are the Rukomeshe (Rukomechi), Sapi and Chewore; none are perennial. There are wetlands at the confluences of the Sapi and Chewore Rivers with the Zambezi.

3.32.1.2 Geology

See **Figure 3.6** (ZGS , 1999). The area is underlain mainly by Karoo Supergroup sedimentary rocks, with gneisses in the hill country above the Zambezi Escarpment.

3.32.1.3 Pedology, agriculture and land use

Soils in the area can be divided into three groups:

- Very shallow and gravelly soils in the east; and
- Deep, heavily textured calcareous soils in the west; and
- Widespread, locally developed patches of Jesse Sand, a derivative of the Kalahari Sands(DRSS, 1979).

The area lies within Natural Region V: low and erratic rainfall: below 650mm, and the hinterland lies within Natural Region IV: fairly low rainfall of 450mm to 650mm per annum and Natural Region III: higher rainfall and deeper soils (ZSG, 1997; Surveyor General and AGRITEX, 1998).

Land use comprises Mukwichi Communal Land, Vuti resettlement area and Zambezi Parks & Wildlife Land48 (ZSG, 1998). Farming is mainly semi intensive livestock production, fodder crops and some cash crops. The major settlements are Makuti and Chirundu Villages.

3.32.1.4 Surface water users

There is some consumption of water for agriculture in the Communal Lands, as well as extraction for Makuti Town. The other major use is tourism on the Zambezi River: boating, fishing and game viewing. The Zambezi River provides the only dry season source of water for wildlife in the Zambezi Parks & Wildlife Land, which is an important tourist destination.

3.32.1.5 Water management systems

The area falls under the Manyame Catchment Council of ZINWA.

3.32.1.6 Human impacts on water resources (excluding mining)

The following could be expected to have an impact on water resources:

- Disposal of solid waste, Makuti and Chirundu;
- Disposal of liquid effluent, Makuti and Chirundu;
- Urban run off, Makuti and Chirundu;
- Non-point domestic effluent, rural areas;
- Minor non-point impact from agriculture in Communal lands; and
- Fuel loss and litter on the road from Makuti to Chirundu.

48 Mana Pools National Park and Hurungwe, Sapi and Chewore Safari Areas: this is a World Heritage Site

3.32.2 Mining and mineral processing operations

The catchment falls under the Harare Mining District (ZGS, 1995). Cordierite and emeralds have been mined in the hills in the south (**Table 3.32**).

Table 3.32: Mining operations in the Rukomeshe and Chewore sub-catchments.

Name	Commodity	Status	Total produced /t	Potential Impact
Chirundu	Uranium	Exploration only		Low
Makuti	Cordierite	Open in 1984	0.0756	Low

See ZGS (1988a) for location.

There is limited exploration for gold, copper, nickel and PGEs (ZGS, 2001).

3.32.3 Alluvial mining

Neither known nor likely.

3.32.4 Monitoring systems

None.

3.32.5 Water quality data

None available.

3.32.6 Implications for water quality and quantity management

There is no evidence to suggest impact of mining within this area.

3.33 The Angwa sub-catchment

3.33.1 General description

3.33.1.1 Hydrology

This is Zones A1-A2 of Area C (ZSG, 1984). The Angwa River flows from near Chinhoyi Caves to Lake Cahora Bassa in Mozambique (**Figure 3.2**). There are many wetlands in the Manyati area of the middle Angwa, Zone A1.

3.33.1.2 Geology

See **Figure 3.6** (ZGS, 1999). Magondi Supergroup gneisses and metasediments underlie most of the sub-catchment. Karoo Supergroup and Dande Formation sediments underlie the area north of the Zambezi Escarpment. The area around Mwami, east of Karoi, is intruded by numerous pegmatites, many of which are mined. For a more detailed description of these pegmatites, see Wiles (1961).

3.33.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into four groups:

- Very shallow, gravelly soils in the area along the Zambezi Escarpment and the Manyame Range;
- Moderately shallow to moderately deep hydromorphic silty clay loams, derived from Magondi metasediments;
- Moderately shallow, fine grained and highly micaceous sandy loams, derived from Magondi gneisses; and
- Moderately shallow sands and loamy sands, often sodic, formed from Upper Karoo and Dande sediments (DRSS, 1979).

The lower Angwa valley (below the Zambezi Escarpment) lies within Natural Region IV: fairly low rainfall of 450mm to 650mm per annum. The middle Angwa valley (from Darwin Gorge to the Zambezi Escarpment) lies within Natural Region III: high rainfall and deep soils. The upper Angwa valley (above Darwin Gorge) is within Region IIa: high and reliable rainfall of up to 1000mm per annum and deep soils (ZSG, 1997; Surveyor General and AGRITEX, 1998).

Land use above the Zambezi Escarpment is mainly commercial farming: private and resettlement land (ZSG, 1998). Farming is generally intensive cash crops or livestock production. The Dande Communal Land (below the escarpment) is very sparsely populated, with some limited livestock and cotton production. There is some Parks & Wildlife Land in the northwest and east49.

The major settlements are Karoi and Mhangura Towns, and Alaska and Lions Den Villages.

3.33.1.4 Surface water users

Irrigation by commercial agriculture is a major water user. Karoi and Mhangura Towns, and Alaska and Lions Den Villages draw water from within the sub-catchment.

3.33.1.5 Water management systems

The sub-catchment falls under the Manyame Catchment Council of ZINWA.

3.33.1.6 Human impacts on water resources (excluding mining)

The following could be expected to have an impact on water resources:

- Landfills, urban areas of Karoi, Mhangura, Alaska and Lions Den;
- Disposal of liquid effluent, urban areas of Karoi, Mhangura, Alaska and Lions Den;
- Urban run off, urban areas of Karoi, Mhangura, Alaska and Lions Den;
- Non-point domestic effluent, rural areas;
- Non-point impact of agriculture (pesticides, fertilizers, etc), throughout the sub-catchment;
- Non-point impact of irrigation in redistribution of river waters;
- Fuel loss and litter on the main roads from Chinhoyi to Karoi and Mhangura and from the railway to Lions Den; and
- Run off, Chinhoyi Airport.

3.33.2 Mining and mineral processing operations

49 Chewore and Doma Safari Areas

The catchment falls under the Harare Mining District (ZGS, 1995). The main mining activities are copper mining in the Magondi Belt (historical) and mining of pegmatites around Mwami (Miami).

Table 3.33: Mining operations in the Angwa sub-catchment.

Name	Commodity	Status	Total produced /t	Potential Impact
Alaska	Copper	Closed 1977	32736.0	Medium
Mangula	Copper	Closed, smelter closed	315306.0	High
Norah	Copper	Closed 1984	40759.0	Medium
Shackleton	Copper	Closed ?	67052.0	High
Shamrocke	Copper	Closed 1968	25363.0	Low
Gundi Park	Dolomite	Closed 1981	182320.0	Low
Sinoia Lime	Dolomite	Closed 1984	33264.0	Low
Springbok (Alaska dolomite)	Dolomite	In operation	872723.0	Medium
Whitelux	Dolomite	In operation	13363.0	Low
I Wonder	Garnet industrial	Closed 1974	90.7	Low
Golden Kopje	Gold		6.0	Medium
Chipungwe	Kyanite	Closed 1984	15141	Low
Sheba Group	Kyanite	Closed 1982	10510	Low
Beckett	Mica	Closed 1971	256.36	Low
Grand Parade	Mica	Closed 1956	540.79	Low
Last Hope	Mica	Closed 1981	206.02	Low
Mangula	Palladium	Closed 1980s	0.199	High
Mangula	Platinum	Closed 1980s	0.103	High
Float	Quartz	Closed 1975	22247.0	Low
Mangula	Selenium	Closed 1980s	1.9	Medium: AMD possible
Mangula	Silver	Closed 1980s	119.3	Medium
Shackleton	Silver	Closed 1984	54.3	Medium
St Anns	Topaz	Closed 1981	0.93631	Low
Honey	Tungsten	Closed 1983	95.7	Low
Makashi	Tungsten	Closed 1979	59.2	Low

See ZGS (1988a) and ZGS (1988b) for locations.

There is exploration for gold, lead copper and zinc (ZGS, 2001).

3.33.3 Alluvial mining

Extensive alluvial mining of gold takes place in the Angwa River (**Figure 3.14**; Chiyanike, 1997). Some of this is in the form of formalised claims through the Mining Commissioner, whilst the remainder is the work of small-scale panners, whose operations falls under Special Grants held by the Rural District Councils.

3.33.4 Monitoring systems

ZINWA has a number of monitoring stations in the sub-catchment.

3.33.5 Water quality data

Water quality data is available from ZINWA for several monitoring stations in this sub-catchment (**Figure 3.3**).

3.33.6 Implications for water quality and quantity management

Impact is expected from four sources:

- Historical copper mining operations, possibly contributing heavy metals and acid mine drainage;
- The Alaska copper smelter, which might contribute a similar impact;
- Alluvial gold mining in the Angwa River; and
- Impact of the numerous small-scale pegmatite workings (tungsten, tantalum, kyanite, mica, among others) in the country around Mwami.

The alluvial workings have a particularly high impact in the Angwa valley, since, prior to the arrival of panners, the valley was largely unsettled. Informal settlements developed by the panners have led to extensive deforestation in a previously pristine area.

Examination of the water quality data shows that total suspended solids, sulphate, fluoride and iron are elevated (though sulphate and fluoride are still within the "blue" limits) in the Angwa River after it receives drainage from the vicinity of the Alaska smelter. It is thus possible that the smelter is responsible for these elevations, although recent and current housing developments in the same area could also be responsible.

The Mwami River shows elevated levels of total suspended solids, chloride and magnesium: although only the first mentioned of these is outside the "blue" limits.

3.34 The Manyame sub-catchment

3.34.1 General description

3.34.1.1 Hydrology

This is Zones H1-H5 of Area C (ZSG, 1984). The long Manyame Sub-catchment stretches from Lake Cahora Bassa to the capital city of Harare and to Waddilove Mission in Mashonaland East (**Figure 3.2**). The Manyame River is perennial. The Manyame is dammed at Chivero (Hunyani Poort / McIlwaine) and Manyame Dam (Robertson) to provide water for the City of Harare, and at Seke (Prince Edward) and Harava (Henry Hallam) to provide water for the City of Chitungwiza.

3.34.1.2 Geology

See **Figure 3.6** (ZGS, 1999). The sub-catchment lies mainly on the Zimbabwe Craton, underlain by granites in the central and southern areas, with the Harare Greenstone Belt in the southeast and the Chinhoyi Greenstone Belt in the west. The Great Dyke crosses the sub-catchment NNE to SSW. The Zambezi Valley in the north is underlain by Dande Formation sediments (in contrast to ZGS (1999)).

3.34.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into four groups:

- Very shallow, gravelly soils in the hills along the Zambezi Escarpment, the Manyame Range and the Mvurwi Range;
- Moderately shallow, coarse grained sandy, kaolinitic soils derived from granites;
- Deep kaolinitic clays, formed from the Greenstone Belt rocks;
- Moderately shallow to moderately deep sands, sodic in places, formed from Dande sediments (DRSS, 1979).

The sub-catchment lies generally within Natural Region IIa: high and reliable rainfall of up to 1000mm per annum and deep soils; the Zambezi valley is in Region IV: fairly low rainfall of 450mm to 650mm per annum (ZSG, 1997; Surveyor General and AGRITEX, 1998).

Land use is mainly commercial farming, private and resettlement land with Communal Lands in the Zambezi valley (ZSG, 1998). Farming is generally intensive livestock and cash crop production, except in the Zambezi valley where poor soils and low rainfall limit agriculture to some livestock, cotton and a few drought resistant crops.

The major settlements are the metropolitan area of the Cities of Harare and Chitungwiza, and Chinhoyi and Norton Towns, with settlements along the road and rail link from Harare to Chinhoyi. Mahuwe Village at the foot of the Zambezi Escarpment is a growth point for the surrounding Communal Lands.

3.34.1.4 Surface water users

The Cities of Harare and Chitungwiza, including the Harare Thermal Power Station, draw water from the Manyame River.

Irrigation by commercial agriculture is a major water user above the Zambezi escarpment. There is a large ARDA estate near Mushumbi Pools, growing cotton under irrigation from the Manyame River.

3.34.1.5 Water management systems

The sub-catchment falls under the Manyame Catchment Council of ZINWA.

3.34.1.6 Human impacts on water resources (excluding mining)

The following could be expected to have an impact on water resources:

- Landfills, urban areas of Harare, Chinhoyi, Norton and Chitungwiza (cf. Moyo, 1997, Rakodi, 1995);
- Disposal of liquid effluent, urban areas of Harare and Chitungwiza, which is done into tributaries feeding Manyame and Chivero Dams (cf. Moyo, 1997, Rakodi, 1995), as well as Chinhoyi and Norton;
- Urban run off, urban areas of Harare, Chinhoyi, Norton and Chitungwiza;
- Non-point domestic effluent, rural areas;
- Non-point impact of agriculture (pesticides, fertilizers, etc), especially where commercial agriculture is practiced;
- Non-point impact of irrigation in redistribution of river waters;
- Minor non-point impact from sparse subsistence agriculture in the Zambezi valley;
- Fuel loss and litter on the main roads and railways; and
- Run off, Harare International and Charles Prince Airports.

3.34.2 Mining and mineral processing operations

The catchment falls under the Harare Mining District (ZGS, 1995). The main mining activity is chrome mining along the Great Dyke and some gold mines, now mostly out of production.

Table 3.34: Mining operations in the Manyame sub-catchment.

Name	Commodity	Status	Total produced /t	Potential Impact
Ethel	Asbestos	Closed 1966	38177.0	Low
Caesar	Chromium	Closed 1982	552719.0	Low
Feock	Chromium	Open in 1984	1193688.0	Medium
Sutton	Chromium	Open in 1984	794948.0	Low
Umvukwe Chrome	Chromium	Open in 1984	2054504.0	Medium
Vanad	Chromium	Open in 1984	785294.0	Low
Barry	Clay	Closed 1971	130191.0	Low
Muriel	Copper	Closing in 2002	13759.0	Low
Muriel	Gold	Closing in 2002	29.7	Medium
Eldorado	Gold	In operation	15.3	Medium
Eureka	Gold	Closed		High: large pits, AMD possible
Kia Ora	Gold		13.4	High: Size
Jester	Mtorolite	Closed 1984	7.577	Medium
Lomsil	Quartz	Closed 1980	18104.0	Low

See ZGS (1988a) and ZGS (1988b) for locations.

There is exploration for gold, copper, zinc, silver arsenic, PGEs and nickel (ZGS, 2001).

3.34.3 Alluvial mining

Alluvial mining of gold takes place in the Manyame River (**Figure 3.14**; Chiyanike, 1997).

3.34.4 Monitoring systems

ZINWA carries out extensive monitoring of the Manyame River, although this is mainly in the vicinity of the Harare – Chitungwiza metropolitan area.

3.34.5 Water quality data

Water quality data are available from ZINWA for several monitoring stations.

3.34.6 *Implications for water quality and quantity management*

Impact from mining is expected from three main sources:

- Chrome mining, both large scale and small scale, along the Great Dyke, with extensive excavations;
- Historical gold mining operations in the Chinhoyi Greenstone Belt, notably Kia Ora, with associated acid mine drainage; and
- Alluvial gold mining of the Manyame river and its tributaries in the area north of Banket.

Examination of the available water quality data shows clear affects of the Harare – Chitungwiza metropolitan area on various parameters. This issue has been explored extensively by authorities such as Machena (1997), Mathuthu and others (1997) Staneva (1997) and Zaranyika (1997). Unfortunately, no water quality data were available on the Manyame River downstream of the main mining areas of the Great Dyke and the Chinhoyi Greenstone Belt.

3.35 The Musengezi sub-catchment

3.35.1 *General description*

3.35.1.1 *Hydrology*

This is Zones UG1 and UG2 of Area C (ZSG, 1984). The Musengezi Sub-catchment stretches from Lake Cahora Bassa to the Mvurwi area (**Figure 3.2**) and is perennial. Its main tributaries are the Hoya and the Mukumbura.

3.35.1.2 *Geology*

See **Figure 3.6** (ZGS, 1999). Granites in the south and Zambezi Mobile Belt gneisses in the north underlie the upper part of the sub-catchment. The lower part of the catchment – the Zambezi Valley – is underlain by Upper Karoo Group and Dande Formation sediments (in contrast to **Figure 3.6**). The northernmost end of the Great Dyke enters the sub-catchment from the west.

3.35.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into three groups:

- Very shallow, gravelly soils in the hills along the Zambezi Escarpment;
- Moderately shallow, coarse grained sandy, kaolinitic soils derived from granites; and
- Moderately shallow to moderately deep sands, highly sodic in places, formed from Upper Karoo and Dande sediments (DRSS, 1979).

Above the Zambezi Escarpment, the sub-catchment lies generally within Natural Region IIa: high and reliable rainfall of up to 1000mm per annum and deep soils. Land below the escarpment is in Region IV: fairly low rainfall of 450mm to 650mm per annum (ZSG, 1997; Surveyor General and AGRITEX, 1998).

Land use is commercial farming, private and resettlement land, south of the Zambezi Escarpment (ZSG, 1998), with intensive livestock and cash crop production. Below the escarpment are Communal Lands and an ARDA Estate, where poor soils and low rainfall limit agriculture to some livestock, cotton and a few drought resistant crops.

The major settlements are Muzarabani, Centenary and Mvurwi Towns. Population is growing significantly in the Muzarabani area.

3.35.1.4 Surface water users

Irrigation by commercial agriculture is a major water user above the Zambezi Escarpment, and at the ARDA estate near Muzarabani. The town draws water for domestic use.

3.35.1.5 Water management systems

The sub-catchment falls under the Manyame Catchment Council of ZINWA.

3.35.1.6 Human impacts on water resources (excluding mining)

The following could be expected to have an impact on water resources:

- Landfills, urban areas of Centenary, Muzarabani and Mvurwi;
- Disposal of liquid effluent, urban areas of Centenary, Muzarabani and Mvurwi;

- Urban run off, urban areas of Centenary, Muzarabani and Mvurwi;
- Non-point domestic effluent, rural areas;
- Non-point impact of agriculture (pesticides, fertilizers, etc), especially where commercial agriculture is practiced;
- Non-point impact of irrigation in redistribution of river waters;
- Minor non-point impact from sparse subsistence agriculture in the Zambezi valley; and
- Fuel loss and litter on the main roads from Mvurwi to Muzarabani.

3.35.2 Mining and mineral processing operations

The catchment falls under the Harare Mining District (ZGS, 1995). The main mining activity is small-scale chrome mining along the Great Dyke.

There is exploration for gold, silver, nickel, PGEs, and diamonds (ZGS, 2001).

3.35.3 Alluvial mining

Not reported, and unlikely.

3.35.4 Monitoring systems

None.

3.35.5 Water quality data

None available.

3.35.6 Implications for water quality and quantity management

The only impact from mining to be expected is that which may arise from small-scale chrome mining along the Great Dyke.

3.36 The Ruya sub-catchment

3.36.1 General description

3.36.1.1 Hydrology

This is Zone M2 of Area D (ZSG, 1984; **Figure 3.2**). The Ruya River is dammed at Frogmore near Mvurwi.

3.36.1.2 Geology

See **Figure 3.6** (ZGS, 1999). North of Mount Darwin, Zambezi Mobile Belt gneisses underlie the sub-catchment. South of Mount Darwin is the Darwin Greenstone Belt and granitic terrain.

3.36.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into two groups:

- Moderately shallow, coarse grained kaolinitic sands and sandy loams, derived from the granites and gneisses; and
- Moderately deep to deep, granular clays, formed from the Greenstone Belt (DRSS, 1979).

South and northwest of Mount Darwin, the sub-catchment lies generally within Natural Region IIa: high and reliable rainfall of up to 1000mm per annum and deep soils. Northwest of Mount Darwin is in Region III, high rainfall and deep soils and Region IV: fairly low rainfall of 450mm to 650mm per annum (ZSG, 1997; Surveyor General and AGRITEX, 1998).

Land use south and northwest of Mount Darwin is commercial farming, private and resettlement land (ZSG, 1998), with intensive livestock and cash crop production. Northeast of Mount Darwin are Communal Lands, soils are somewhat poorer and rainfall slightly lower, limiting agriculture to drought resistant crops and livestock supported by fodder crops.

The major settlements are Mount Darwin, Mutepatepa and Rushinga.

3.36.1.4 Surface water users

The towns draw water from within the sub-catchment. Irrigation by commercial agriculture is a major water user.

3.36.1.5 Water management systems

The sub-catchment falls under the Mazowe Catchment Council of ZINWA.

3.36.1.6 Human impacts on water resources (excluding mining)

The following could be expected to have an impact on water resources:

- Landfills, urban areas of Mount Darwin, Mutepatepa and Rushinga;
- Disposal of liquid effluent, urban areas of Mount Darwin, Mutepatepa and Rushinga;
- Urban run off, urban areas of Mount Darwin, Mutepatepa and Rushinga;
- Non-point domestic effluent, rural areas;
- Non-point impact of agriculture (pesticides, fertilizers, etc), especially where commercial agriculture is practiced;
- Non-point impact of irrigation in redistribution of river waters;
- Minor non-point impact from sparse, subsistence agriculture in the Zambezi valley; and
- Fuel loss and litter on the main roads from to Mount Darwin and Rushinga.

3.36.2 Mining and mineral processing operations

The catchment falls under the Harare Mining District (ZGS, 1995). The main mining activities are pegmatite mining.

Table 3.35: Mining operations in the Ruya sub-catchment.

Name	Commodity	Status	Total produced /t	Potential Impact
Mount Darwin	"Black Granite" Dolerite			Medium
Rushinga	Dolomite	Closed 1984	66204.0	Low

Dolomite				
Kaseke	Talc	Production started in 1985		Low
Birthday Gift	Tantalum	Closed 1980	6.7	Low

See ZGS (1988a) for locations.

There is also small-scale production of glitterstone in the Rushinga area (Barton and others, 1991).

There is exploration for PGEs, vanadium and diamond (ZGS, 2001).

3.36.3 Alluvial mining

Alluvial mining of gold takes place in the Ruya River (Chiyanike, 1997), as well as most tributaries draining the greenstone belts (**Figure 3.14**). This has been taking place since early in the twentieth century (Leitner and Phaup, 1974). There has also been eluvial mining of tantalum (Leitner and Phaup, 1974).

3.36.4 Monitoring systems

ZINWA is currently setting one up.

3.36.5 Water quality data

None available.

3.36.6 Implications for water quality and quantity management

The major impact of mining is expected to be that arising from alluvial mining of gold. Some impact from exploitation of dimension stone (mainly dolerite) and industrial minerals may also take place, principally in terms of siltation.

3.37 The Mazowe sub-catchment

3.37.1 General description

3.37.1.1 Hydrology

*This is Zones M1, M3-M7, UR1-UR4, IY1-IY3 and N1-N3 of Area D (ZSG, 1984). The major tributaries of the perennial Mazowe (Mazoe) River are the Nyadiri (Zones N1-N3), Nyagui (IY1-IY3) and Marodzi (Umrodsi) (UR1-UR4) (**Figure 3.2**). The Mazowe is dammed at Mazowe Dam in the Iron Mask Range (Zone M7).*

3.37.1.2 Geology

See **Figure 3.6** (ZGS, 1999). The Zimbabwe Craton underlies most of the sub-catchment: Dindi Greenstone Belt, Makaha Greenstone Belt, Harare-Bindura-Shamva Greenstone Belt and granitic terrain. Zambezi Mobile Belt gneisses underlie the far north. The granites in the Mutoko and Murehwa areas are widely intruded by Mashonaland Dolerites.

3.37.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into two groups:

- Moderately shallow to deep, coarse grained kaolinitic sands and sandy loams, tending towards clays in the area north of Marondera, derived from the granites and gneisses; and
- Moderately deep to deep, granular clays, formed from the Greenstone Belt and the dolerites (DRSS, 1979).

The western half of the sub-catchment, from Harare to Bindura, Murehwa and Shamva, lies within Natural Region II: high and reliable to semi reliable rainfall of up to 1000mm per annum and deep soils. Mutoko and Katiyo lie in Region III, with moderately high rainfall and deep soils . The northeast of the sub-catchment, beyond Mutoko, lies in Region IV: fairly low rainfall of 450mm to 650mm per annum (ZSG, 1997; Surveyor General and AGRITEX, 1998).

Land in the south and west is commercial farming, private and resettlement land (ZSG, 1998), with intensive livestock and cash crop production. In the north and east land use is Communal Land and conventional resettlement land, with soils that are somewhat poorer and rainfall slightly lower, limiting agriculture to drought resistant crops and livestock supported by fodder crops.

The major settlements are the eastern edges of the City of Harare, and the towns of Goromonzi, Mazowe, Bindura, Shamva, Murehwa and Mutoko.

3.37.1.4 Surface water users

Goromonzi, Bindura, Shamva, Murehwa and Mutoko draw water from within the sub-catchment. The City of Marondera, although located in the Save Catchment, draws its water supply from Longlands Dam on the Nyambuya River, a tributary of the Nyagui. The City of Harare draws water from outside the sub-catchment.

Irrigation by commercial agriculture is a major water user, notably use of water from Mazowe Dam for citrus estates.

3.37.1.5 Water management systems

The sub-catchment falls under the Mazowe Catchment Council of ZINWA.

3.37.1.6 Human impacts on water resources (excluding mining)

The following could be expected to have an impact on water resources:

- Landfills, urban areas of Harare, Goromonzi, Mazowe, Bindura, Shamva, Murehwa and Mutoko;
- Disposal of liquid effluent, urban areas of Harare, Goromonzi, Mazowe, Bindura, Shamva, Murehwa and Mutoko;
- Urban run off, urban areas of Harare, Goromonzi, Mazowe, Bindura, Shamva, Murehwa and Mutoko;
- Non-point domestic effluent, rural areas;
- Non-point impact of agriculture (pesticides, fertilizers, etc), especially where commercial agriculture is practiced;
- Non-point impact of irrigation in redistribution of river waters;
- Minor non-point impact from sparse, subsistence agriculture in the northeast;
- Fuel loss and litter on the main roads and railways; and
- Run off from Trojan Airport.

3.37.2 Mining and mineral processing operations

The catchment falls under the Harare Mining District (ZGS, 1995). The main mining activities are gold production, nickel mining, dolerite quarrying and pegmatite mining:

Table 3.36: Mining operations in the Mazowe sub-catchment.

Name	Commodity	Status	Total produced /t	Potential Impact
Murehwa	"Black Granite" Dolerite			Medium
Ganyanhewe	Amazonite	Closed 1967	2503.0	Medium
Kataha	Amazonite	Closed 1972	1145.0	Medium
Dodge	Barytes	In operation	30524.0	Low
Augustus	Beryl	Closed 1961	168.7	Low
Eagle	Beryl	Closed 1970	155.4	Low
Fungwe	Beryl	Closed 1970	140.3	Low
God's Gift Group	Beryl	Closed 1983	330.7	Low
Hotspur	Beryl	Closed 1970	157.1	Low
Mabelle	Beryl	Closed 1970	102.2	Low
Mistress	Beryl	Closed 1982	233.3	Low
Rabbit Warren	Beryl	Closed 1969	115.5	Low
Benson	Caesium	Closed 1965	22.7	Low
New Barakaat	Caesium	Closed 1967	25.1	Low
Ulva	Citrine	Closed 1983	21.5	Low
Madziwa	Cobalt	In operation	146.2	High: AMD possible
Trojan	Cobalt	In operation	252.7	High: AMD possible
Ndiri	Corundum	Closed 1980	2511.9	Low
O'Briens	Corundum	Closed 1983	162237.7	Low
Weluzani	Corundum	Closed 1979	1421.8	Low
Augustus	Feldspar	Closed 1974	6647.0	Low
Mistress	Feldspar	Closed 1984	7730.0	Low
Patronage	Feldspar	Closed 1981	1677.0	Low
Lucky Fish	Garnet Gem	Closed 1969	4.1	Low
Treasure Casket	Garnet Gem	Closed 1969	7.4	Low
Lindemann	Garnet industrial	Closed 1977	112.0	Low
Manyuchi	Garnet industrial	Closed 1983	245.1	Low
Acturus/Planet	Gold	In operation	36.0	High: Arsenic possible
Freda Rebecca	Gold	In operation	17.4	High: Arsenic possible
Gladstone	Gold	In operation	5.7	High: Arsenic possible
Jumbo	Gold	In operation	5.3	High: Size
Kimberley Reefs	Gold		8.0	High: Arsenic possible
Mazowe	Gold	In operation	31.8	High: Size
Prince of Wales	Gold	Closed	15.5	High: Arsenic possible

Shamva	Gold	In operation	68.7	High: Size & Arsenic possible
Ky	Kyanite	Closed 1977	31453	Low
Early Worm	Limestone	Open in 1984	576463	Medium
Mbebi	Limestone	Closed 1984	115983	Low
Sternblick	Limestone	Open in 1984	5789587	Medium
Arcadia	Lithium	Closed 1972	7750.0	Low
Casa Ventura	Lithium	Closed 1981	606.0	Low
Fungwe	Lithium	Closed 1969	601.0	Low
Mauve	Lithium	Closed 1958	4922.0	Low
Mistress	Lithium	Closed 1971	1740.0	Low
Winston	Lithium	Closed 1967	1122.0	Low
Madziwa	Nickel	In operation	29306.0	High: AMD possible
Trojan	Nickel	In operation	69937.0	High: AMD possible
Trojan	Platinum	In operation		Medium
Iron Duke	Pyrite	In operation	2180495.0	High
Barauta	Sapphire	Closed 1971	0.00019	Low
Benson Group	Tantalum	Closed 1983	167.0	Low
Beryl Rose	Tantalum	Open in 1984	26.8	Low
Bush Ridge	Tantalum	Closed 1981	8.8	Low
Joking	Tantalum	Closed 1963	5.4	Low
Mabelle	Tantalum	Closed 1982	5.2	Low
Mauve	Tantalum	Closed 1983	22.8	Low
Mistress	Tantalum	Closed 1984	31.0	Low
Mkanga	Tantalum	Closed 1981	6.9	Low
Patronage	Tantalum	Closed 1980	6.6	Low
Wanroo	Tantalum	Closed 1962	5.1	Low
Alton	Tungsten	Closed 1971	532.35	Low
Ball	Tungsten	Closed 1971	294.250	Low
Hill Top	Tungsten	Closed 1980	65.120	Low
Kakonde	Tungsten	Closed 1972	76.9	Low
RAN	Tungsten	W closed 1965, producing Au only	772.0	Low
Scheelite King	Tungsten	Closed 1981	860.3	Low
Winter's Tale	Vermiculite	Closed 1959	1647.18	Low

See ZGS (1988a) and ZGS (1988b) for locations.

There is exploration for gold, copper, zinc, lead, tantalum, PGEs, arsenic, silver, nickel, kyanite and mica (ZGS, 2001).

3.37.3 Alluvial mining

Alluvial mining of gold is reported by Chiyanike (1997) from the Mazowe, Nyadiri and Nyagui Rivers (**Figure 3.14**). Other tributaries, such as the Mufurudzi River, are also alluvial mined. The alluvial mining is very extensive.

3.37.4 Monitoring systems

ZINWA is currently setting up a monitoring system.

3.37.5 Water quality data

None available from ZINWA. Chenje and other (1998) provided data on discharges from Trojan Mine.

Table 3.37: Actual discharge from Trojan Mine, after Chenje *et al*. (1998).

PH	7.07	Alkalinity	140ppm	TDS	221ppm	Total hardness	84ppm
NO_3^-	8.06ppm N	Cl^-	2ppm	PO_4^{3-}	0.2ppm	SO_4^{2-}	13ppm
Mg	8ppm	Ca	34ppm	K	4.6ppm		

*Gratwicke (1999), in a study on rivers downstream of the Mazowe Group and iron Duke Mines, provides the following data (**Table 3.38**):*

Table 3.38: Data from Mazowe area: range over 9 months, after Gratwicke (1999).

Site name (Gratwicke 1999)	**Mine**	**Citrus Bridge**	**After confluence**
pH	3.10 – 6.90	6.95 – 7.94	6.29 – 7.92
Conductivity / µS/cm	125 – 5000	348 – 475	330 – 490
Dissolved O / ppm	0.00 – 6.84	5.18 – 7.52	4.10 – 7.40
Location relative to mines	Below Iron Duke	Below Mazowe Group	Below both

3.37.6 Implications for water quality and quantity management

The most significant impacts of mining to be expected are:-

- Alluvial mining of gold in the Mazowe River and many of its tributaries;
- Several large and arseniferous gold mines in the Harare-Bindura-Shamva[50] Greenstone Belt, with possible associated acid mine drainage;
- Two large nickel-cobalt producing mines near Bindura, and the associated Trojan smelter, with acid mine drainage and heavy metal release: data from Chenje and others (1998) suggests that nitrate contamination may also be a problem; and
- Iron Duke pyrite mine, with possible acid mine drainage.

Gratwicke's (1999) study shows serious acidity and salinization problems associated with Iron Duke Mine, but also shows that these are limited beyond the confluence of the Yellow Jacket River (which drains the Iron Duke Mine area) and the Mazowe river. Furthermore, recent dump rehabilitation at iron Duke should have improved the situation.

Widespread quarrying of dolerite ("black granite") alters local drainage patterns and provides depressions for development of stagnant pools of water.

The Mazowe Sub-catchment contains several of Zimbabwe's largest current mining operations as well as some of the greatest concentrations of alluvial gold mining. The sub-catchment is also densely populated and a major grain producer. The sub-catchment thus definitely deserves further study, especially given the continuation of exploration activities in the area.

3.38 The Ruenya sub-catchment

3.38.1 General description

3.38.1.1 Hydrology

This is Zones R1-R6 of Area D (ZSG, 1984). The main tributaries of the Ruenya (Luenha) River are the Nyangadzi (Zone R4) and the Nyangombe (Zones R5 and R6). The Mudzi River (Zone R1) flows into the Ruenya in Mozambique (**Figure 3.2**).

3.38.1.2 Geology

See **Figure 3.6** (ZGS, 1999). The Zimbabwe Craton underlies most of the sub-catchment: the Makaha Greenstone Belt and granitic terrain. Zambezi Mobile Belt gneisses underlie the far north. The granites are

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50 Arsenic contamination has been a major problem associated with mining in the Shamva area fro quite some time (Stidolph, 1977)

widely intruded by Mashonaland Dolerites. Umkondo sediments and dolerites underlie the southeast edge of the sub-catchment.

3.38.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into two groups:

- Moderately shallow to deep, coarse grained kaolinitic sands and sandy loams, derived from the granites and gneisses; and
- Moderately deep to deep, granular clays, formed from the Greenstone Belt and the dolerites (DRSS, 1979).

The area south and west of Chiendambuya lie within Natural Region II: high and reliable to semi reliable rainfall of up to 1000mm per annum and deep soils. Mapako and Mayo lie in Region III, with moderately high rainfall and deep soils. The northeast lies in Region IV: fairly low rainfall of 450mm to 650mm per annum. The area around Nyanga, Sanyatwe and Juliasdale lies in Region I, with over 900mm rainfall and over 1700m altitude (ZSG, 1997; Surveyor General and AGRITEX, 1998).

Land in the south and west is commercial farming, private and resettlement land (ZSG, 1998), with intensive livestock and cash crop production. Land use in the mountain country around Nyanga is specialised agriculture, mainly tea, coffee and fruit growing, and forestry. In the northeast land use is Communal Land and conventional resettlement land, with soils that are somewhat poorer and rainfall slightly lower, limiting agriculture to drought resistant crops and livestock supported by fodder crops.

The major settlements are Nyamapanda border post and Nyanga town.

3.38.1.4 Surface water users

Irrigation by commercial agriculture is a major water user. The towns of Nyamapanda and Nyanga draw drinking water from within the sub-catchment.

3.38.1.5 Water management systems

The sub-catchment falls under the Mazowe Catchment Council of ZINWA.

3.38.1.6 Human impacts on water resources (excluding mining)

The following could be expected to have an impact on water resources:

- Landfills, urban areas of Nyamapanda and Nyanga;
- Disposal of liquid effluent, urban areas of Nyamapanda and Nyanga;
- Urban run off, urban areas of Nyamapanda and Nyanga;
- Non-point domestic effluent, rural areas;
- Non-point impact of agriculture (pesticides, fertilizers, etc), especially where commercial agriculture is practiced;
- Non-point impact of irrigation in redistribution of river waters; and
- Minor non-point impact from sparse, subsistence agriculture in the northeast.

3.38.2 Mining and mineral processing operations

The catchment falls under the Harare Mining District (ZGS, 1995). The main mining activities are alluvial gold production, nickel mining, dolerite quarrying and pegmatite mining.

Table 3.39: Mining operations in the Ruenya sub-catchment.

Name	Commodity	Status	Total produced /t	Potential Impact
Mutoko	"Black Granite" Dolerite			Medium
Good Days	Beryl	Closed 1970	315.9	Low
Jordywitt	Beryl	Closed 1960	105.2	Low
Inyati	Copper	Closed	69496.0	High
Inyati	Silver	Closed	10.8	Medium
Inyati	Gold	Closed		Medium
Gray	Talc	Closed 1976	2554.8	Low
Matedza (Jeep)	Talc	Closed 1973	1971.8	Low
Takagara	Talc	Closed 1976	1816.8	Low

See ZGS (1988a) for locations.

There is exploration for beryl, silver, gold, tantalum and base metals (ZGS, 2001).

3.38.3 Alluvial mining

Alluvial mining of gold takes place in the Ruenya River (**Figure 3.14**; Chiyanike, 1997). It may also take place in the Mudzi River.

3.38.4 Monitoring systems

ZINWA is currently setting one up.

3.38.5 Water quality data

None available from ZINWA. Chenje and others (1998) provide some data on discharges from Inyati Mine (**Table 3.40**).

Table 3.40: Actual Discharge from Inyati Mine, after Chenje *et al*. (1998).

PH	6.8	TDS	1060ppm	Total hardness	155ppm	SO_4^{2-}	560ppm
NO_3^-	4ppm N	Na	35ppm				

3.38.6 Implications for water quality and quantity management

The main impact to be expected is from the Inyati Mine, with possible heavy metals and acid mine drainage. Alluvial gold mining will also affect the rivers. Widespread quarrying of dolerite ("black granite") alters local drainage patterns and provides depressions for development of stagnant pools of water.

3.39 The Kairezi sub-catchment

3.39.1 General description

3.39.1.1 Hydrology

This is Zones G1-G2 of Area F (ZSG, 1984). The main tributary of the Kairezi (Gairezi) River is the Matisi River.

3.39.1.2 Geology

See **Figure 3.6** (ZGS, 1999). Umkondo sediments and dolerites, along with some granites and Mashonaland Dolerites, underlie most of the sub-catchment. Mozambique Belt gneisses underlie the far north.

3.39.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into two groups:

- Moderately shallow to deep, coarse grained kaolinitic sands and sandy loams, derived from the granites and gneisses; and
- Moderately deep to deep, granular clays, formed from the dolerites (DRSS, 1979).

Most of the sub-catchment lies in Region I: over 900mm rainfall and over 1700m altitude. North of Nyamaropa lies in Region IV: fairly low rainfall of 450mm to 650mm per annum (ZSG, 1997; Surveyor General and AGRITEX, 1998).

Land use in the mountain country is specialised agriculture, mainly tea, coffee and fruit growing, and forestry. In the north, land use is Communal Land and conventional resettlement land, with soils that are poorer and rainfall lower, limiting agriculture to drought resistant crops and livestock supported by fodder crops.

3.39.1.4 Surface water users

Irrigation by tea and coffee estates and fruit plantations is a major water user, as is the Nyamaropa irrigation project.

3.39.1.5 Water management systems

The sub-catchment falls under the Mazowe Catchment Council of ZINWA.

3.39.1.6 Human impacts on water resources (excluding mining)

The following could be expected to have an impact on water resources:

- Non-point domestic effluent, rural areas;
- Non-point impact of agriculture (pesticides, fertilizers, etc), especially where commercial agriculture is practiced;
- Non-point impact of irrigation in redistribution of river waters; and
- Minor non-point impact from sparse, subsistence agriculture in the north.

3.39.2 Mining and mineral processing operations

The catchment falls under the Harare Mining District (ZGS, 1995). The only mining activity is quarrying of kyanite in the far north.

There is no current legal exploration.

3.39.3 Alluvial mining

Alluvial mining of gold takes place along the Kairezi River and some of its tributaries (**Figure 3.14**).

3.39.4 Monitoring systems

None.

3.39.5 Water quality data

None available.

3.39.6 Implications for water quality and quantity management

The major impact to be expected is that arising from the alluvial mining of gold along the Kayirezi River and its tributaries.

3.40 Summary of impacts of mining operations on water resources and water quality in the Zambezi basin

The wide variety of mining operations and mineral processing activities located within the Zambezi basin have differing degrees of impact on both the water resources available to other users and on the water quality of these resources. From the available data, it seems clear that those mining operations that are located within low rainfall regions of the basin (where physical weathering processes predominate) have relatively low and/or localized impacts on the water resources. In contrast, mining operations located in the wetter regions of the basin where chemical weathering processes predominate tend to have far more extensive impacts. This seems to be due to the presence of ample moisture within the soil profile that enables continual chemical changes to take place and allows the water available to mobilize and transport the different contaminants that become available.

A summarized overview of the actual and anticipated impacts of mining operations and mineral processing plants in each sub-catchment of the Zambezi basin is given in **Table 3.41**. This information provides a useful impression that could be used to focus water resource management plans and water quality management plans in the different component areas of the Zambezi basin.

4. THE LIMPOPO BASIN

In order to provide a suitable background for subsequent descriptions of the impacts of mining on water resources in the Limpopo basin, this section starts with a brief overview of the catchment characteristics. This is then followed by condensed descriptions of the information relating to mining activities and their impacts in each sub-catchment.

The Olifants basin is actually a sub-catchment of the Limpopo basin but has been treated separately in this report (see **Section 5**). As a result, the figures used in this report for the catchment area, runoff, and population of the Limpopo basin exclude the relevant details for the Olifants basin.

4.1 Introduction

The Limpopo River is one of the most important rivers in southern Africa and its basin comprises portions of four SADC states (Botswana, Mozambique, South Africa and Zimbabwe; **Table 4.1**; **Figure 1.1**). The basin is located between 19.5 ° and 26.5 ° South latitude and between 25.5 ° and 34.5 ° East longitude, with a total basin area of approximately 282,000 km^2, comprising roughly 9% of the total area of the four basin states. The area contributed to the basin by each state varies between 7.4% (Mozambique) and 12.8% (Botswana; **Table 4.1**).

Table 4.1: Area statistics for the four SADC states comprising the Limpopo basin (excluding the Olifants sub-basin, which is dealt with in **Section 5**). [Data obtained from Midgley *et al*. (1995), SARDC (1996) and Boroto & Görgens (1999)].

Country	Total Area of Country (km^2)	Country Area in Basin (km^2)	Proportion of Country Area (%)	Proportion of Basin Area (%)
Botswana	600,370	70,000	11.7	24.8
South Africa	1,219,912	102,900	8.4	36.5
Mozambique	801,590	59,000	7.4	20.9
Zimbabwe	390,759	49,900	12.8	17.8
Totals:	3,012,631	281,800	9.4	100.0

The Limpopo River has a relatively dense network of tributary streams and rivers, though most of these tributaries only have either seasonal or episodic flows. In historical times, the Limpopo River was considered to be a strong-flowing perennial river but is now regarded as a weakly perennial river where flows frequently cease and, during drought periods, no surface water is present over large stretches of the middle and lower reaches of the river.

The Limpopo basin encompasses an important ecological transition zone that marks the junction of four separate bio-climatic regions. The area is considered to be very important in terms of the diversity of its fauna and flora and also contains several important conservation areas. In addition, the Limpopo basin supports a very large population, including some of the region's poorest rural communities, as well as numerous urban areas and farming communities and important forestry areas.

4.1.1 *Geology, topography and soils*

The Limpopo basin is located over the northern lobe of the Kalahari Craton, with the Limpopo River valley marking the approximate position of the Limpopo Mobile Belt where considerable mineralization has taken place. The Archaean Craton rocks comprise predominantly crystalline granitic and gneissic rocks, intruded by various Greenstone belts as well as dolerite dykes and sills. Karoo System rocks overlie large areas of the southern portion of the basin and these are also associated with younger sedimentary and crystalline rocks consisting predominantly of sandstones, mudstones, conglomerates and shales. Recent sedimentary deposits line most of the river valleys and provide important farming areas (Du Toit, 1960).

In the southern (South African) portion of the basin, the Bushveld Igneous Complex forms an extremely important feature and contains a very large proportion of the region's mineral wealth. The geological features of this area consist mostly of basic mafic and ultramafic intrusive rocks, accompanied by extensive areas of acidic and intermediate intrusive rocks. At the southern periphery of this area, large dolomite and limestone formations occur, accompanied by extensive mineralization along their contact zones. Large areas of the central portion of the Limpopo basin consist of various deposits of consolidated and unconsolidated sedimentary rocks, with important belts of intrusive Greenstone rocks that are heavily mineralised. The north-south trending rhyolites and lavas of the Lebombo Mountains mark the eastern border between South Africa and Mozambique. Elsewhere, harder, silicified sandstones and cherts, as well as syenitic and granitic outcrops, form erosional remnants that protrude above the generally undulating terrain (Du Toit, 1960).

In the western portion of the basin, large areas are covered with deep layers of sedimentary rocks comprising sandstones, siltstones, mudstones and shales. The northern-western areas are also marked by extensive intrusions of Greenstones and schists that contain significant gold, copper and nickel mineralization. Older Karoo System rocks that contain important coal deposits also underlie these areas.

The northern and northeastern portions of the Limpopo basin located in Zimbabwe consist of large expanses of undifferentiated gneisses and granites, with numerous mineralised Greenstone intrusions. The Great Dyke of Zimbabwe intrudes into the northeastern corner of the Limpopo basin.

The eastern (Mozambique) portion of the Limpopo basin consists largely of unconsolidated and consolidated sedimentary rocks with granitic intrusions exposed as erosional remnants in the landscape.

The topography of the Limpopo basin is extremely varied, ranging from sea level in Mozambique to over 2,400 metres in the mountainous region marking the transverse position of the northern extension of the Drakensberg

Mountains. Most of the basin consists of relatively undulating terrain between ranges of hills and mountains. The northward flowing (South African) tributaries of the Limpopo River have incised deep gorges through the hills and mountain ranges that are visible as erosional remnants. Elsewhere, the river valleys are broad and flat-bottomed. The Limpopo River occupies a broad, sandy channel that is incised into the surrounding flat countryside.

Large portions of the central and western parts of the Limpopo basin have very little or poor drainage, and are usually considered to be endorheic (internally draining). These areas are often marked by the formation of saltpans or clay-bottomed pans where rainfall collects and evaporates. These areas are generally subjected to mechanical (physical) weathering processes, in contrast to the predominance of chemical weathering processes in the wetter headwater regions of most tributaries.

The Mozambique portion of the Limpopo basin consists of gently undulating terrain with numerous small tributary streams and pools forming part of the Chagane drainage system. This tributary rises close to the Zimbabwe-Mozambique border, meanders across the Mozambique coastal plain and joins the Limpopo River very close to its mouth on the coast near the town of Xai-Xai.

Soil formations across the Limpopo basin reflect the influence of underlying parent rock material, climatic features and biological activity. The dominant soil types in the basin are moderately deep sandy to sandy-clay loams in the south, grading to shallower, sandy soils in the north and deeper sandy soils in the west and east. The deeper loam soils are extremely important for agricultural activities and support extensive irrigation developments along many of the tributary rivers. A few extensive areas of black vertisols in the southern parts of the basin also support important agricultural developments.

Deep layers of wind-blown Kalahari sands cover large areas of the western portion of the Limpopo basin, whilst the sandy soils of the eastern (Mozambique) portion are derived from old, unconsolidated marine sands. These sandy soils support important hardwood timber resources.

The valley bottom soils along all of the tributary rivers and the Limpopo main channel are generally of colluvial or alluvial origin and support extensive areas of commercial and subsistence agriculture. In contrast, hilly or steeply sloping areas have fragile, shallow, stony soils with little agricultural potential. In the endorheic areas, most soils have a relatively high sodium and clay content and are dispersive.

4.1.2 Climatic features

Because of its geographic position, the climate of Limpopo basin is influenced by prevailing wind systems, including tropical cyclones from the Indian Ocean. The most important of these rain-bearing winds are the southeasterly wind systems that bring rainfalls from the Indian Ocean. In some years, the Inter-Tropical Convergence Zone (ITCZ) moves sufficiently far southwards to influence rainfalls in the northern parts of the basin.

Air temperatures across the Limpopo basin show a marked seasonal cycle, with hottest temperatures recorded during the early Austral Summer months and lowest temperatures during the cool, dry winter months. Rainfalls are also highly seasonal, falling predominantly as intense convective thunderstorms during the warmer summer months. Rainfalls vary from as little as 400 mm per annum in the central parts of the Limpopo valley to over 1,000 mm per annum on the Drakensberg Mountains and close to the mouth of the Limpopo River at Xai-Xai. A sketch map showing the distribution of mean annual rainfall over the Limpopo basin is shown in **Figure 4.1**. This figure also shows the main tributaries of the Limpopo River.

Evaporation rates across the Limpopo basin are both high and variable, ranging from some 3.1 metres per annum in the western and central areas of the basin to some 1.7 metres in the cooler, mountainous regions in the southeastern portion of the basin. In view of these evaporation rates, and the quantity of rainfall received each year, several areas of the Limpopo basin show clear evidence of the dominance of physical weathering processes (Weinert N values greater than 5.0). These areas are located in the western and central portions of the basin and along the middle Limpopo valley. Virtually all of the rest of the Limpopo basin is subject to chemical weathering processes, either seasonally (Weinert N values below 4.0) or continually (Weinert N values below 2.0) (Weinert, 1964).

4.1.3 Population and land use patterns

The total population of the Limpopo basin is approximately 10.5 Million, with almost 60% of Botswana's population located within the basin (**Table 4.2**). The Limpopo basin also contains a large proportion of the population comprising South Africa's Gauteng Province, as well as the population of the Northern Province, and almost all of the agricultural areas, towns and cities, mines and power stations of these two provinces. As a result, the basin includes most of the critically important economic and energy heartland of South Africa.

Table 4.2: Population statistics for the four SADC states comprising the Limpopo basin (excluding the Olifants sub-basin, which is dealt with in **Section 5**). [Data obtained from SARDC (1996), Basson *et al*. (1997), Chenje (2000)].

Country	Total Population of Country (Millions)	Country Population in Basin (Millions)	Proportion of Country Population (%)	Proportion of Basin Population (%)
Botswana	1.639	0.975	59.5	9.3
South Africa	43.421	7.950	18.3	76.1
Mozambique	19.980	1.150	5.8	11.0
Zimbabwe	13.109	0.375	3.0	3.6
Totals:	78.149	10.450	13.4	100.0

In Botswana, the Limpopo catchment supports several important towns and the capital City of Gaborone. The South African sector of the Limpopo Catchment supports several large and medium-sized towns as well as numerous smaller communities. Pietersburg, capital of the Northern Province, is also located here. In addition, *the City of Pretoria and the northern suburbs of the City of Johannesburg and the northern part of the Gauteng province are also located in the basin. Throughout the country portions comprising this catchment, a wide variety of mining operations as well as different forms of agriculture (subsistence and commercial cultivation, game farming, livestock and dairy production) are the economic mainstays of the catchment.*

All Limpopo basin states have skewed population distributions, and experience large-scale migration from rural areas to urban settlements. The Northern province of South Africa comprises mostly extensive rural populations that occupy former Apartheid self-governing "homelands". As a consequence a large proportion of the basin's population is extremely poor and lack access to basic services and amenities such as clean water and adequate sanitation.

Similar to the Zambezi basin, land is a critically important resource throughout the Limpopo basin and the livelihoods of residents and the national economies of all basin states depend (Chenje, 2000). However, the specific types of land use that are practiced are controlled by climatic factors, water availability and, importantly, by land tenure arrangements. A large proportion of the land in the Limpopo basin states is under communal or customary forms of tenure, and land ownership is considered to be one of the major constraints to proper land use and conservation (Chenje, 2000).

Overcrowding and insecure ownership in the smaller communal farming areas (e.g. the Levuvhu and Nzhelele sub-catchments in South Africa) is a primary source of land degradation in the basin. This feature is a critically important driver of poverty within the Limpopo basin and is associated closely with declining indices of per capita agricultural production (Dalal-Clayton, 1997). In many parts of the Limpopo basin, progressive urbanization has been accompanied by the development of peripheral "informal" settlements around the major urban areas.

In comparison to the Zambezi Catchment, the Zimbabwe and Mozambique portions of the Limpopo Catchment are considered to be poor and sparsely settled part, whilst the Botswana and South African sectors have far higher numbers of people and are more densely settled (**Table 4.2**). In the Zimbabwe and Mozambique portions, there are no large cities and the only towns of any size are the Matabeleland South provincial capital of Gwanda in Zimbabwe, and the coastal town of Xai-Xai located close to the mouth of the Limpopo River in Mozambique. The Mozambique sector of the basin has numerous small villages and settlements scattered along the lower reaches of the Limpopo.

4.1.4 Hydrological characteristics, water availability and patterns of water use

The quantity and timing of rainfall received in the Limpopo basin controls the quantity, timing and duration of flows in the different tributary rivers. The uneven distribution of rainfall in the basin is reflected in the very uneven distribution of water resources in the four basin states. In turn, these influence the types of economic activities undertaken by the residents in each country. The uneven distribution of water across the basin has led to tensions and occasional disputes between some of the basin states regarding what can be constituted as a "fair and equitable share" of the available water resources (Ashton, 2000).

The Limpopo and its larger tributaries all exhibit marked seasonal cyclical patterns of high and low flows and many of the smaller tributaries are entirely seasonal or episodic. As mentioned earlier, the Limpopo River shows a very marked pattern of seasonal flows and, in dry years, surface flows cease altogether though water continues to flow in the deeper alluvial deposits. The western and central parts of the basin that receive the lowest rainfalls have mainly seasonal or episodic rivers that have no surface flow during the dry winter months.

Recent studies on the Limpopo River (Boroto & Görgens, 1999) have focussed on the development of an accurate hydrological modelling system that can incorporate the flow contributions of the four basin states. The available information on flows in the Limpopo River is relatively poor and there are significant differences between the flows gauged by different countries. An important hydrological characteristic of the Limpopo River is the very large transmission losses (> 40%) that occur along its length. Whilst a part of the water loss can be accounted for by the large volumes of water transpired by riparian vegetation, there is still uncertainty as to where the remaining losses occur (Boroto & Görgens, 1999). Overall, flows decline along the length of the Limpopo River and very little water discharges to the sea at Xai-Xai.

The demand for water throughout the Limpopo basin is both high and unevenly spread. In particular, water demands by industry, mining and especially the formal (irrigation) agricultural sector account for over 75% of all water used. Coupled with high evaporation losses from the numerous small dams and larger water supply impoundments, flows in the lower reaches of the Limpopo River are usually relatively small, unless they have been "boosted" by the arrival of a tropical cyclone (e.g. the cyclone that arrived in 2000 and flooded large coastal areas of Mozambique).

Several small, though ecologically important, wetlands are found in the Limpopo basin (Midgley *et al*., 1995; Boroto & Görgens, 1999). These wetlands occur predominantly along shallow-gradient reaches of tributary rivers in the South African portion of the basin and the Mozambique coastal plain. The most important wetland areas in the Limpopo basin are the Nylsvley and Mogalakwena floodplains in South Africa, and the mosaic of wetlands on the Chagane floodplain in Mozambique.

The growing water shortage in Botswana prompted the construction of the North-South Carrier, a pipeline system that transports water from the Motloutse River southwards to the City of Gaborone. This has also been supplemented by an inter-basin transfer scheme where water from the Marico Dam in South Africa is transferred over the border to Gaborone in Botswana. Further investigations are underway to determine the feasibility of extending the pipeline northwards to draw water from the Zambezi River at Kazungula. Elsewhere in the South African portion of the basin, numerous inter-basin transfer schemes convey water from one sub-catchment to another to meet growing demands for water. In addition, three inter-basin transfer schemes deliver water from the Vaal system in South Africa into the headwaters of the Crocodile and Olifants rivers to provide domestic water supplies as well as cooling water for several coal-fired thermal power stations. The overall water supply "picture" is made somewhat uncertain by the very real possibility that global climate changes will also have an adverse effect on water availability throughout southern Africa (Ashton, 2000).

Throughout the length of the Limpopo River and its tributaries, water quality is generally good and the water is usually fit for most designated uses. There are water quality problems due to increasing salinity in the central parts of the basin, making the water less suitable for irrigation purposes and for domestic use. In addition, most cities, towns and smaller communities discharge untreated or partially treated domestic and industrial effluent into the various rivers (e.g. the cities and towns of the northern Pretoria – Witwatersrand metropolitan complex in South Africa). As long as there is sufficient dilution, this practice does not have long-term or large-scale detrimental effects. However, with increasing quantities of effluent and declining river flows due to escalating demands for water, water quality problems are occurring more frequently. In some sub-catchments (e.g. the Crocodile-Pienaars in South Africa), it is estimated that treated effluent comprises more than 60% of all flows in this river system. The water quality problems caused effluent discharge become more acute further downstream, as more and more towns contribute their effluent to the total river flow and evaporative concentration accentuates the effects of rising salinity and increasing eutrophication.

In addition to water abstracted for domestic use, large volumes of water are also withdrawn for irrigation; for example: the extensive irrigation areas along all of the tributary rivers and along parts of the Limpopo River. Most small-scale farmers have to rely either on red-fed agriculture or on water drawn from shallow wells or nearby watercourses. Overall, the competition for the limited water resources available is likely to become more intense in future.

Within each of the four basin states, the Limpopo catchment has been divided into a series of sub-catchments for the purposes of this study; these sub-catchments are shown in **Figures 3.3 and 4.2**.

4.1.5 Water management systems and institutions

Each of the basin states has their own water management systems and segments their respective territories into Water Management Units or Water Management Areas. These divisions are normally in the form of sub-catchments, though some of the larger sub-catchments may be further sub-divided. The formal constitution of catchment councils or catchment management agencies has only taken place in Zimbabwe. In the other basin states, water management is undertaken by central Government or is delegated to Provincial Departments. In South Africa, the process of setting up formal Catchment Management Agencies for the nineteen Water Management Areas in the country has started. At this time, the preparatory work for one such agency, the Crocodile West-Marico Catchment Management Agency is now nearing completion. This agency will become the first South African catchment management agency to deal with water resource management in a part of the Limpopo basin.

The SADC Protocol on Shared Watercourse Systems is an important legislative instrument that promotes regional co-operation and collaboration amongst all SADC states. However, unequal institutional and professional capacity within the four member states hampers full expression of this protocol. The four basin states comprising the Limpopo basin have jointly formed a Joint Permanent Technical Commission (JPTC) to deal with matters of common interest relating to the Limpopo River and its tributaries. This Commission deals with matters such as joint flow gauging exercises and inter-basin transfers, as well as dealing with proposed new water development projects by each of the member states.

Each basin state maintains its own system of meteorological and hydrological data collection, primarily for use at the national level. Whilst these systems are at very different levels of coverage in the different states, the data does enable the four basin states to contribute to joint exercises to monitor and predict rainfall and runoff in the Limpopo basin. Recent improvements in weather radar systems and satellite monitoring systems help to expand and improve the regional coverage.

The Botswana Department of Mineral and Energy Affairs is responsible for all water management issues, and operates a good system of flow recording and water quality monitoring on the tributary rivers within its national boundaries.

The South African Department of Water Affairs and forestry maintains a comprehensive system of flow and water quality monitoring on all of the tributary rivers within its area of jurisdiction. Whilst these data are the most comprehensive available for the Limpopo basin, they are not entirely adequate for accurate predictions of flow and water quality in the Limpopo River. Eleven sub-catchments are recognized within the South African sector of the Limpopo basin.

In the Zimbabwean sector of the Limpopo basin, the Zimbabwean National Water Authority (ZINWA) places the Zimbabwean portion of the Limpopo basin under a single Catchment Council: Mzingwane, which corresponds to Hydrological Zone B (ZSG, 1984). Six sub-catchments of the Limpopo basin are recognized in Zimbabwe (**Figure 3.3**). No water quality data are available from ZINWA for the Zimbabwe sector of the Limpopo basin.

In the Mozambican sector of the Limpopo basin, two sub-catchments are recognized: the lower Limpopo and the Chagane. A few flow monitoring data are available from the Mozambique sector but these are not entirely adequate for accurate modelling purposes (Boroto & Görgens, 1999).

4.1.6 Mining and mineral processing operations within the Limpopo basin

There are a large number of mining operations exploiting a wide variety of minerals in the Limpopo basin; the locations of these operations are shown in **Figure 4.2**, whilst the mines located in the South African sector of the Limpopo basin are shown in more detail in **Figure 4.3**. Within Zimbabwe, there are a smaller number and variety of mining and minerals processing operations in the Limpopo Catchment than in the Zambezi catchment, but mining is still widespread (**Figures 3.7 to 3.14**).

Data on the type of mine, size, operational status and location of mining operations are presented in the respective sections on the individual sub-catchment, along with inferences on potential impact. The high/medium/low inference for potential impact was arrived at using the criteria in **Table 1.3** and is discussed sub-catchment by sub-catchment in the following sections. A summarizing overview of the actual and potential impacts on water resources and water quality in each sub-catchment of the Limpopo basin is given in **Section 4.23**.

In the following portions of this sections of the report that contain descriptions of the mining and mineral processing activities in each sub-catchment, it is important to refer to **Figures 4.2 and 4.3**, as well as **Figure 3.2** for the positions of the different sub-catchments within the Limpopo basin.

4.2 The Ngotwane-Bonwapitse sub-catchment

4.2.1 General description

4.2.1.1 Hydrology

The Ngotwane River and its major tributary the Bonwapitse River rise in a range of low sandstone hills at the edge of the Kalahari Desert to the southwest of the Botswana capital, Gaborone, and north of Gaborone, respectively. The Ngotwane River flows in a north-easterly direction to join the Limpopo River some 50 kilometres downstream of the confluence of the Marico and Crocodile rivers, near Steenbokpan. The Bonwapitse River also flows in a north-easterly direction, joining the Limpopo River some 60 kilometres downstream of the Ngotwane-Limpopo confluence.

The Ngotwane River is dammed near Gaborone (Gaborone Dam) and provides the main source of domestic and industrial water for the city. Several small farm dams and numerous boreholes provide water for small-scale irrigation and stock watering in several parts of this sub-catchment.

4.2.1.2 Geology

The rocks of the Kalahari Craton underlie this sub-catchment. Large areas of the sub-catchment have exposures of Gaborone and Mahalapye granites, as well as rocks of the Palapye Suite and Lobatse and Kanye formations. Karoo System rocks in the area contain economic sources of coal.

4.2.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into five groups:

- Moderately shallow, coarse-grained feldspathic sands, derived from the Gaborone and Mahalapye granites;
- Moderately shallow sandy loams, formed from gneisses; and
- Shallow, clay soils with high sodium content in internally draining areas.

The sub-catchment receives low and unreliable rainfalls (under 500 mm per year) with high evaporation rates. Soils are generally shallow and poor to medium quality. Areas with high sodium content pose a salinization risk to irrigation farmers. Soils become progressively sandier towards the northeast of the sub-catchment as rainfalls decline and evaporation rates increase.

Land use in the upper parts of the sub-catchment consist of small- and large-scale commercial farming of drought resistant crops, as well as extensive livestock rearing, particularly of goats and donkeys. The main settlements are the capital city Gaborone, and the important towns Kanye, Thamaga, Tlokweng, Molepolole and Mochudi, Mahalapye and Mmamabula as well as numerous smaller settlements, particularly along the road between Gaborone and Francistown.

4.2.1.4 Surface water users

All towns and settlements rely on whatever surface water they can obtain from local streams and rivers, as well as an extensive system of boreholes. Gaborone obtains a large proportion of its water from the Gaborone dam, supplemented by water transferred from the Marico Dam in South Africa, and the North-South Pipeline that brings water to Gaborone from the Motloutse sub-catchment to the north. Towns located along the route followed by the North-South Pipeline obtain their water from this pipeline and local boreholes. Most irrigation water use is based on water pumped from local boreholes.

4.2.1.5 Water management systems

The Botswana Department of Water Affairs (Gaborone office and Mahalapye office) is responsible for management of all water resources in this sub-catchment. Close liaison is maintained with the South African Department of Water Affairs and Forestry over water transferred from the Marico Dam and regarding flows in the Limpopo River, by means of a Joint Permanent Technical Commission (JPTC). Both countries collaborate in the gauging of river flows and exchange of water quality and flow data. Routine flow gauging is carried out at two stations on the Ngotwane River and at one station on the Bonwapitse River (Boroto & Görgens, 1999).

4.2.1.6 Human impacts on water resources (excluding mining)

The following can be expected to impact on water resources in this sub-catchment:

- Landfills and solid waste disposal sites at Gaborone, Kanye, Thamaga, Tlokweng, Molepolole, Mochudi, Mahalapye and Mmamabula, as well as numerous smaller settlements;
- Disposal of liquid (domestic and some light industrial) effluent at Gaborone, Kanye, Thamaga, Tlokweng, Molepolole, Mochudi, Mahalapye and Mmamabula;
- Non-point domestic effluent via soak-aways in rural areas;
- Non-point impact of irrigation and redistribution of river waters;
- Minor non-point impact from non-intensive commercial or subsistence agriculture; and
- Fuel loss and litter on the roads between Ramotswa, Thamaga, Kanye, Gaborone, Mochudi and Mahalapye.

4.2.2 Mining and mineral processing operations

A single small coal mine is in operation at Mmamabula (**Table 4.3**).

Table 4.3: Mining operations in the Ngotwane-Bonwapitse sub-catchment.

Code Number	Name of Mine	Commodity (ies) Mined	Status	Relative Size	Probable Impact
Bots-1	Mmamabula	Coal	Operating	Small	Low, localized

4.2.3 Alluvial mining

None known.

4.2.4 Monitoring systems

Three flow gauging sites are located on the Ngotwane River (two sites) and the Bonwapitse River (one site). The Botswana Department of Water Affairs conducts regular monitoring of water quality in all the water supply dams, as well as water supplied to towns and smaller communities from the Marico Dam and via the North-South Pipeline. The geohydrology section within the Department of water Affairs also tests borehole water quality at regular intervals.

4.2.5 Water quality data

None obtainable in time for this report, but data are available from the Botswana Department of Water Affairs.

4.2.6 Implications for water quality and quantity management

Very minor impacts can be anticipated from the Mmamabula Colliery, in terms of possible elevated concentrations of suspended solids, total dissolved salts and sulphate. Very small impacts of acid mine drainage can be anticipated.

4.3 The Lotsane sub-catchment

4.3.1 General description

4.3.1.1 Hydrology

The Lotsane River and its minor tributary streams rise in a range of low sandstone hills at the eastern edge of the Kalahari Desert, to the west of the town of Serowe. The Lotsane River flows in an easterly direction to join the Limpopo River some 100 kilometres downstream of the confluence of the Bonwapitse and Limpopo rivers. The river is normally seasonal and only carries surface water during the summer months.

The Lotsane River has a small water supply dam near the town of Palapye and this provides the main source of domestic water for the town, as well as water drawn from the North-South Pipeline. Several small farm dams and boreholes provide water for stock watering in several parts of this dry sub-catchment.

4.3.1.2 Geology

The rocks of the Kalahari Craton underlie this sub-catchment. Large areas of the sub-catchment have exposures of Gaborone and Mahalapye granites, as well as rocks of the Palapye Suite and the Lebung Formation of the Karoo System. The Karoo System rocks in the area contain economic sources of coal.

4.3.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into five groups:

- Moderately shallow, coarse-grained feldspathic to kaolinitic sands, derived from the Gaborone and Mahalapye granites;
- Moderately shallow sandy loams, formed from gneisses; and
- Shallow, clay-rich soils with high sodium content in internally draining areas.

The sub-catchment receives low and unreliable rainfalls (under 500 mm per year) with high evaporation rates. Soils are generally shallow and poor to medium quality. Areas with high sodium content pose a salinization risk for irrigation schemes. Soils become progressively sandier towards the eastern portion of the sub-catchment as rainfalls decline and evaporation rates increase.

Land use in the sub-catchment consists mostly of small-scale commercial and subsistence farming of drought resistant crops, as well as livestock rearing of goats and donkeys. The main settlements are the towns of Serowe, Palapye, Mokoro and Maunatlala, with numerous smaller settlements located along the North-South Pipeline route and along the many roads traversing the sub-catchment.

4.3.1.4 Surface water users

All towns and settlements rely on whatever surface water they can obtain from the seasonal flows in local streams and rivers, as well as an extensive system of boreholes. Larger towns such as Serowe and Palapye obtain most of their water from the North-South Pipeline as well as from local boreholes. Small areas of irrigation rely on local boreholes for their water supplies.

4.3.1.5 Water management systems

The Botswana Department of Water Affairs (Mahalapye and Serowe offices) is responsible for management of all water resources in this sub-catchment. River flows are gauged at one site on the Lotsane River (Boroto & Görgens, 1999).

4.3.1.6 Human impacts on water resources (excluding mining)

The following can be expected to impact on water resources in this sub-catchment:

- Landfills and solid waste disposal sites at Serowe and Palapye, as well as at numerous smaller settlements;
- Disposal of liquid (domestic) effluent at Serowe and Palapye;
- Non-point domestic effluent via soak-aways in rural areas;
- Non-point impact of localized, small-scale irrigation;
- Minor non-point impact from subsistence agriculture; and
- Fuel loss and litter on the roads between Groblers Bridge and Serowe, and between Mahalapye and Francistown, as well as along numerous smaller roads in the sub-catchment.

4.3.2 Mining and mineral processing operations

A single small coal mine is in operation at Morupele-Moijabana (**Table 4.3**).

Table 4.4: Mining operations in the Lotsane sub-catchment.

Code Number	Name of Mine	Commodity (ies) Mined	Status	Relative Size	Probable Impact
Bots-2	Morupele-Moijabana	Coal	Operating	Small	Low

4.3.3 Alluvial mining

None known.

4.3.4 Monitoring systems

One flow-gauging site is located on the Lotsane River downstream of the town of Palapye. The Botswana Department of Water Affairs conducts regular monitoring of water quality in all the water supply dams, as well as water supplied to towns and smaller communities from the North-South Pipeline. The geohydrology section within the Department of water Affairs also tests borehole water quality at regular intervals.

4.3.5 Water quality data

None obtainable in time for this report, but data are available from the Botswana Department of Water Affairs.

4.3.6 Implications for water quality and quantity management

Very minor impacts can be anticipated from the Morupele-Moijabana Colliery, in terms of possible elevated concentrations of suspended solids, total dissolved salts and sulphate. Very small localized impacts of acid mine drainage can be anticipated.

4.4 The Motloutse sub-catchment

4.4.1 General description

4.4.1.1 Hydrology

The Motloutse River and its minor tributary streams rise in a range of low hills at the eastern edge of the Kalahari Desert, to the south-west of Francistown. The Motloutse River flows in an easterly direction to join the Limpopo River some 40 kilometres upstream of the confluence of the Shashe and Limpopo rivers. The river is normally seasonal and only carries surface water during the summer months.

The Motloutse River has a small water supply dam near the town of Selibe-Phikwe and this provides the main source of domestic water for the town and mine, as well as water drawn from the North-South Pipeline. Several small farm dams and boreholes provide water for stock watering in several parts of this dry sub-catchment.

4.4.1.2 Geology

The rocks of the Kalahari Craton underlie this sub-catchment. Large areas of the sub-catchment have exposures of Gaborone and Mahalapye granites, as well as rocks of the Palapye Suite and the Lebung Formation of the Karoo System. The Karoo System rocks in the area contain economic sources of coal. The Selibe-Phikwe copper-nickel mine is located on a contact zone of intense mineralization at the edge of a large Gaborone Granite formation.

4.4.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into five groups:

- Moderately shallow, coarse-grained feldspathic to kaolinitic sands, derived from the Gaborone and Mahalapye granites;
- Moderately shallow sandy loams, formed from gneisses; and

- Shallow, clay-rich soils with high sodium content in internally draining areas.

The sub-catchment receives low and unreliable rainfalls (mostly under 400 mm per year) with high evaporation rates. Soils are generally shallow and poor to medium quality. Areas with high sodium content pose a salinization risk for irrigation schemes. Soils become progressively coarser and sandier towards the eastern portion of the sub-catchment as rainfalls decline and evaporation rates increase.

Land use in the sub-catchment consists mostly of small-scale subsistence farming of drought resistant crops, as well as livestock rearing of goats and donkeys. The main settlements are the towns of Selibe-Phikwe and Serule, with numerous smaller settlements located along the North-South Pipeline route and along the main roads.

4.4.1.4 Surface water users

All towns and settlements rely on whatever surface water they can obtain from the seasonal flows in local streams and rivers, as well as an extensive system of boreholes. Larger towns such as Serule and Selibe-Phikwe obtain most of their water from the North-South Pipeline as well as from local boreholes. Small settlements rely on local boreholes and hand-dug wells for their water supplies.

4.4.1.5 Water management systems

This sub-catchment is located entirely within Botswana and therefore falls under the jurisdiction of the Department of Water Affairs in the Ministry of Mineral and Energy Affairs. Routine flow gauging is carried out at one station on the middle reaches of the Motloutse River, though the flow record is incomplete (Boroto & Görgens, 1999).

4.4.1.6 Human impacts on water resources (excluding mining)

The following can be expected to impact on water resources in this sub-catchment:

- Landfills and solid waste disposal sites at Serule and Selibe-Phikwe, as well as at numerous smaller settlements;
- Disposal of liquid (domestic) effluent at Serule and Selibe-Phikwe;
- Non-point domestic effluent via soak-aways in rural areas;
- Minor non-point impact from subsistence agriculture; and
- Fuel loss and litter on the roads between Martins Drift and Selibe-Phikwe, and along the main road between Serowe and Francistown, as well as along numerous smaller roads in the sub-catchment.

4.4.2 Mining and mineral processing operations

Two mining operations are located in this sub-catchment (**Table 4.5**). The Selibe-Phikwe copper-nickel mine is the largest base metal mine in Botswana.

Table 4.5: Mining operations in the Motloutse sub-catchment.

Code Number	Name of Mine	Commodity (ies) Mined	Status	Relative Size	Probable Impact
Bots-3	Bobonong	Coal	Operating	Medium	Low
Bots-4	Selibe Phikwe	Nickel, Copper	Operating	Large	Medium

4.4.3 Alluvial mining

None known.

4.4.4 Monitoring systems

One flow-gauging site is located on the Motloutse River upstream of the town of Selibe-Phikwe. The Botswana Department of Water Affairs conducts regular monitoring of water quality in all the water supply dams, as well as water supplied to towns, mines and smaller communities from the North-South Pipeline. The geohydrology section within the Department of water Affairs also tests borehole water quality at regular intervals.

4.4.5 Water quality data

None obtainable in time for this report, but data are available from the Botswana Department of Water Affairs.

4.4.6 Implications for water quality and quantity management

Medium-scale impacts can be anticipated from the Selibe-Phikwe copper-nickel mine and its smelter, in terms of elevated concentrations of suspended solids, total dissolved salts, copper, nickel and sulphate. Very small localized impacts of acid mine drainage can also be anticipated. Impacts from the Bobonong Colliery are expected to be very small and localized in extent.

4.5 The Shashe-Tuli (Botswana and Zimbabwe) sub-catchment

4.5.1 General description

4.5.1.1 Hydrology

The Zimbabwe portion of this sub-catchment is Zones S1-S6, T1-T5, M and R of Area B (ZSG, 1984). The major tributaries of the perennial Shashe (Shashi) River are the Thuli (Tuli) (Zones T1-T5 and M), Shashani (Zones S2 and S3) Simukwe (Zones S4 and S5) and Ramakwebana (Ramaquebane) (ZSG, 1984). The Shashani is dammed at Gulameta, the Chavezi, a tributary of the Thuli, is dammed near Silobi, and the Ingwezi, a tributary of the Ramakwebana, is dammed near Domborefu.

In Botswana, small water supply dams on the Shashe River provide water for local communities and mining operations, as well as small-scale irrigation farms.

4.5.1.2 Geology

See **Figure 3.6** (ZGS, 1999). The Zimbabwe Craton underlies most of the sub-catchment, including the Botswana portion. Important formations include: Gwanda Greenstone Belt, Lower Gwanda Greenstone Belt, Mphoengs Greenstone Belt and granitic terrain. The south is underlain by Limpopo Belt gneisses, and the far south (Thuli Village area) by Karoo basalts. In the western (Botswana) portion of the sub-catchment, Archaean granites and gneisses are intruded by numerous Greenstone belts, with associated Karoo System rocks and silicified sandstones.

4.5.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into five groups:

- Moderately shallow, coarse-grained kaolinitic sands, derived from the granites;
- Very shallow to moderately shallow sandy loams, formed from gneisses;
- Very shallow to moderately shallow clays, formed from the Greenstone Belts;
- Shallow, clay soils with high sodium content in internally draining areas; and
- Very shallow sands, derived from the basalts (DRSS, 1979).

From Kezi northwards in Zimbabwe, the sub-catchment is in Natural Region IV, with low (under 650mm) and unreliable rainfall, and poor soils. South of Kezi is in Region V, with poor soils, rainfall under 600mm and in places under 450mm (ZSG, 1997). In the Botswana sector of the sub-catchment, rainfalls decline steadily towards the west and south, reaching some 350-400 mm per annum at the Sashe-Limpopo junction.

North of Kezi, land use is commercial farming, private and resettlement land (ZSG, 1998), mainly livestock rearing with some drought resistant crops. The south is Communal Lands, and agriculture limited mainly to livestock, especially goats. The main settlements are Kezi and Maphisa Villages.

In the Botswana sector of the sub-catchment, land use is primarily some commercial farming of livestock and small irrigation areas along the rivers, with game ranching in drier areas. Most livestock are goats and donkeys. Several settlements and towns are located in this area, as well as a number of mining operations.

4.5.1.4 Surface water users

Maphisa draws water from Gulameta Dam on the Shashani. Irrigation by commercial agriculture uses water from Ingwezi Dam in the west.

4.5.1.5 Water management systems

In Zimbabwe, the sub-catchment falls under the Mzingwane Catchment Council of ZINWA. In Botswana, the sub-catchment falls under the jurisdiction of the Department of Water in the Ministry of Mineral and Energy Affairs. Routine flow gauging is carried out at one station on the Shashe River in Botswana, though the flow record is incomplete.

4.5.1.6 Human impacts on water resources (excluding mining)

The following could be expected to have an impact on water resources:

- Landfills, Kezi and Maphisa in Zimbabwe, and Francistown, Sebina and Tonotha-Shashe in Botswana;
- Disposal of liquid effluent, Kezi and Maphisa in Zimbabwe, and Francistown, Tonotha-Shashe in Botswana;
- Non-point domestic effluent in rural areas;
- Non-point impact of irrigation and redistribution of river waters in the west;
- Minor non-point impact from non-intensive commercial or subsistence agriculture; and
- Fuel loss and litter on the roads to Ngwesi, Maphisa and St Joseph's in Zimbabwe, and between the border at Plumtree and Francistown in Botswana.

4.5.2 Mining and mineral processing operations

In Botswana, most mining is associated with the mineralised Greenstone belts, with copper, gold and nickel the most important commodities mined (**Table 4.6**).

The Zimbabwe portion of the sub-catchment falls mainly under the Bulawayo Mining District (ZGS, 1995). The main mining activity is gold mining in the western part of the Gwanda Greenstone Belt (**Table 4.7**) and previously in the Lower Gwanda Greenstone Belt. Asbestos, copper, nickel, pyrite and tungsten have also been mined (Tyndale-Biscoe, 1940). Several centuries ago, extensive gold mining took place in the Gwanda Greenstone Belt, in places over 70m deep (Tyndale-Biscoe, 1940), although the exact date has not been determined.

Table 4.6: Mining operations in the Shashe (Botswana) sub-catchment.

Code Number	Name of Mine	Commodity (ies) Mined	Status	Relative Size	Probable Impact
Bots-7	Matsitama	Copper	Operating	Small	Very low
Bots-8	Tati	Gold	Operating	Small	Low–Medium (As)
Bots-9	Selkirk	Copper, Nickel	Operating	Small	Low

Table 4.7: Mining operations in the Shashe (Zimbabwe) Sub-catchment.

Name	Commodity	Status	Total produced /t	Potential Impact
Champion	Arsenic	Closed 1924	1022.7	High
Hydra	Arsenic	Closed 1946	553.3	High
Vubachikwe	Arsenic	Closed 1949	110.1	High
Antelope	Gold	Closed	9.2	Medium
Blanket	Gold	In operation	27.0	High: Arsenic possible
Freda	Gold	In operation	10.5	High: Arsenic possible
Horn	Gold	Dump retreatment	5.0	High: Arsenic & bismuth possible
Vubachikwe Black Jack	Gold	In operation	25.1	High: Size & Arsenic possible
Noel	Nickel	Closed 1963	4651.9	High: Arsenic possible
Hampden Iron	Pyrite	Closed 1942	1492.0	High

See ZGS (1988a) and ZGS (1988b) for locations.

A copper smelter was operated at Valley, west of West Nicholson, during the first half of the twentieth century (Tyndale-Biscoe, 1940).

In Zimbabwe, there is exploration for diamond, arsenic, nickel, gold, copper and lead (ZGS, 2001).

4.5.3 Alluvial mining

Alluvial mining of gold takes place in the Thuli River in Zimbabwe (**Figure 3.14**; Chiyanike, 1997). There appears to be no alluvial mining taking place in the Botswana sector of the sub-catchment.

4.5.4 Monitoring systems

ZINWA is currently setting one up and the Botswana Department of Water plans to expand its current monitoring programme.

4.5.5 Water quality data

None available.

4.5.6 Implications for water quality and quantity management

In Zimbabwe, the major impacts to be expected are from arseniferous gold and nickel mines and arsenic mines in the western Gwanda and the Lower Gwanda Greenstone Belt: acid mine drainage and release of toxic metals, such as arsenic and bismuth are possible. There are minor impacts from alluvial gold mining in the Thuli River.

In Botswana, minor impacts are anticipated from arseniferous gold, nickel and copper mines, with minor acid mine drainage.

4.6 The Pazhi sub-catchment

4.6.1 General description

4.6.1.1 Hydrology

This is Zone L1 of Area B (ZSG, 1984). The area consists of the catchments of several small rivers, which flow directly into the Limpopo. The two largest are the Pazhi and the Mutshilashokwe.

4.6.1.2 Geology

Karoo basalts underlie most of the sub-catchment, whilst Limpopo Belt gneisses underlie the east (**Figure 3.6**; ZGS, 1999).

4.6.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into two groups:

- Very shallow to moderately shallow sandy loams, formed from gneisses; and
- Very shallow sands, derived from the basalts (DRSS, 1979).

The sub-catchment is entirely in Natural Region V, with poor soils rainfall under 600mm and in places under 450mm (ZSG, 1997). Land use is mainly Communal Lands, with subsistence agriculture: mainly livestock production. The southeast corner is commercial farming land with livestock production.

4.6.1.4 Surface water users

There is limited extraction of water for rural domestic use and for subsistence agriculture.

4.6.1.5 Water management systems

The sub-catchment falls under the Mzingwane Catchment Council of ZINWA.

4.6.1.6 Human impacts on water resources (excluding mining)

The following could be expected to have an impact on water resources:

- Non-point domestic effluent; and
- Minor non-point impact from non-intensive commercial or subsistence agriculture.

4.6.2 Mining and mineral processing operations

The catchment falls mainly under the Masvingo Mining District (ZGS, 1995). The main mining activity is diamond production from River Ranch, although this mine is currently not in production and is kept on a care and maintenance basis.

Table 4.8: Mining operations in the Pazhi Sub-catchment.

Name	Commodity	Status	Total produced /t	Potential Impact
River Ranch	Diamond	Care and maintenance		Low

See ZGS (1988a) for location.

Currently, there are no legal exploration activities (ZGS, 2001).

4.6.3 Alluvial mining

Neither known nor likely.

4.6.4 Monitoring systems

None.

4.6.5 Water quality data

None available.

4.6.6 Implications for water quality and quantity management

The impact of River Ranch, the only mining operation in the area (now closed), is likely to be restricted to a minor contribution to siltation.

4.7 The Mzingwane sub-catchment

4.7.1 General description

4.7.1.1 Hydrology

This sub-catchment comprises Zones UZ1-UZ4, IN1-IN2, IK and NC of Area B (ZSG, 1984). The Mzingwane (Umzingwani) River rises near Bulawayo and flows south to the Limpopo. Its major tributary is the Insiza (Zones IN1-IN2). The Mzingwane, Ncema, Inyakuni and Insiza are all dammed in the Esigodini area (Zones UZ1, NC, IK and IN1 respectively). The lower Insiza is dammed at Silabiuhwa (Zone IN2). The lower Mzingwane is dammed at Zhove, near Mazunga in Zone UZ1.

4.7.1.2 Geology

See **Figure 3.6** (ZZGS, 1999). The northern half of the sub-catchment is underlain by the Zimbabwe Craton: Bulawayo Greenstone Belt, Gwanda Greenstone Belt, Filabusi Greenstone Belt and granitic terrain. The southern half is underlain by Limpopo Belt gneisses, except for the area around Mazunga, which is underlain by Karoo basalts.

4.7.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into four groups:

- Moderately shallow, coarse-grained kaolinitic sands, derived from the granites;
- Very shallow to moderately shallow sandy loams, formed from gneisses;
- Very shallow to moderately shallow clays, formed from the Greenstone Belts; and
- Very shallow sands, derived from the basalts (DRSS, 1979).

From Gwanda northwards, the sub-catchment is in Natural Region IV, with low (under 650mm) and unreliable rainfall, and poor soils. South of Gwanda is in Region V, with poor soils, rainfall under 600mm and in places under 450mm (ZSG, 1997).

North of Kezi, land use is commercial farming, private and resettlement land (ZSG, 1998), mainly livestock rearing with some drought resistant crops. The south is Communal Lands, and agriculture limited mainly to livestock, especially goats.

The main settlements are Gwanda Town and Esibomvu, Esigodini, West Nicholson and Colleen Bawn Villages.

4.7.1.4 Surface water users

The City of Bulawayo draws much of its water supply from the Esigodini area dams: Insiza, Inyankuni, Mzingwane and Ncema. Commercial agriculture is a major water user, especially north of Gwanda, where crop production takes place.

4.7.1.5 Water management systems

The sub-catchment falls under the Mzingwane Catchment Council of ZINWA.

4.7.1.6 Human impacts on water resources (excluding mining)

The following could be expected to have an impact on water resources:

- Landfills, Gwanda, Esibomvu, Esigodini, West Nicholson and Colleen Bawn;
- Disposal of liquid effluent, Gwanda, Esibomvu, Esigodini, West Nicholson and Colleen Bawn;
- Urban run off, Gwanda, Esibomvu, Esigodini, West Nicholson and Colleen Bawn;
- Non-point domestic effluent, rural areas;
- Minor non-point impact from non-intensive commercial or subsistence agriculture;
- Runoff from Gwanda airport; and
- Fuel loss and litter on the main Bulawayo – Beitbridge road and railway link.

4.7.2 Mining and mineral processing operations

The catchment falls under the Bulawayo and Masvingo Mining Districts (ZGS, 1995). The main mining activity is gold mining in the eastern part of the Gwanda Greenstone Belt and the Filabusi Greenstone Belt. Historically, asbestos and tungsten have been mined in the Bulawayo and Filabusi Greenstone Belts.

There is exploration for nickel, gold, copper, lead, tungsten, cobalt, silver, diamond, platinum, and arsenic (ZGS, 2001).

Table 4.9: Mining operations in the Mzingwane Sub-catchment.

Name	Commodity	Status	Total produced /t	Potential Impact
Beta	Asbestos	Closed 1972	3291.5	Low
Croft	Asbestos	Closed 1968	24674.5	Low
Kudu	Asbestos	Closed 1980	6377.6	Low
Lenninhurst	Asbestos	Closed 1967	5893.5	Low
Pangani	Asbestos	Closed 1981	123135.9	Low
Recompense	Asbestos	Closed 1961	1129.2	Low
Thornwood	Asbestos	Closed 1981	59683.0	Low
Wynnes	Asbestos	Closed 1976	25005.0	Low
Greenhill	Aventurine	Closed 1975	160.4	Low
Jopempe	Aventurine	Closed 1984	191.5	Low
Dick Mick	Barytes	Closed 1963	580.6	Low
Cement	Clay	Closed 1977	696139.0	Medium
Korbut	Clay	Closed 1984	471926.0	Low
Willsgrove	Clay	Closed 1984	4000000.0	Medium
Epoch	Cobalt	Closed 1999	94.0	High: AMD possible
Coen's Luck	Emerald	Closed 1977	0.00542	Low
Felspar	Feldspar	Closed 1951	4667.0	Low
Finact	Flintclay	Closed 1984	1400.0	Low
Red Mite	Garnet industrial	Closed 1976	16.9	Low
Bushtick	Gold	Closed	15.0	Medium
Fred	Gold	In operation	17.8	High: Arsenic possible
Geelong	Gold		5.4	Medium
How	Gold	In operation	25.5	High: As possible
Jessie	Gold		13.7	Medium
Colleen Bawn	Limestone	In operation	11797070	Medium
Epoch	Nickel	Closed 1999	15124.0	High: AMD possible
Fernando / Fred	Tungsten	Closed 1980	66.21	Low
Fit	Tungsten	Closed 1982	86	Low
Good Hope	Tungsten	Closed 1971	138.3	Low
Hope	Tungsten	Closed 1968	78.0	Low
Killarney	Tungsten	Closed 1981	106.3	Low
Lioness Group	Tungsten	Closed 1982	426.0	Low
Mustard	Tungsten	Closed 1979	74.1	Low
Richardson Group	Tungsten	Closed 1970	200.9	Low
Sapphire Blue	Tungsten	Closed 1973	71.7	Low
Sydkom	Tungsten	Closed 1984	635.9	Low
Union Jack	Tungsten	Closed 1971	59.5	Low

See ZGS (1988a) and ZGS (1988b) for locations.

4.7.3 Alluvial

Alluvial mining of gold takes place in the Mzingwane and Insiza Rivers (Chiyanike, 1997), and more generally throughout the Filabusi Greenstone Belt (**Figure 3.14**).

4.7.4 Monitoring systems

ZINWA is currently setting one up.

4.7.5 Water quality data

None available.

4.7.6 Implications for water quality and quantity management

Impact is to be expected from three sources:

- Epoch nickel and cobalt mine, with potential acid mine drainage;
- The arseniferous How and Fred gold mines, with potential acid mine drainage; and
- Alluvial gold mining.

All three of these are associated with the greenstone belts, as is the medium level impact of numerous smaller gold mines. The Mzingwane sub-catchment is the most intensely mined in the Limpopo Catchment in Zimbabwe.

4.8 The Diti sub-catchment

4.8.1 General description

4.8.1.1 Hydrology

This is Zone L2 of Area B (ZSG, 1984). The area consists of the catchments of several small rivers, which flow directly into the Limpopo. The two largest are the Diti and the Shashashi.

4.8.1.2 Geology

See **Figure 3.6** (ZGS, 1999). Limpopo Belt gneisses underlie most of the sub-catchment, with some Karoo sediments in the southeast.

4.8.1.3 Pedology, agriculture and land use

Soils in the sub-catchment are generally very shallow to moderately shallow sandy loams, formed from gneisses (DRSS, 1979).

The sub-catchment is entirely in Natural Region V, with poor soils rainfall under 600mm and in places under 450mm (ZSG, 1997). Land use is mainly Communal Lands, with subsistence agriculture: mainly livestock production.

4.8.1.4 Surface water users

There is limited extraction of water for rural domestic use and for subsistence agriculture. Beitbridge extracts water from the Limpopo River, mainly for domestic use.

4.8.1.5 Water management systems

The sub-catchment falls under the Mzingwane Catchment Council of ZINWA.

4.8.1.6 Human impacts of water resources (excluding mining)

The following could be expected to have an impact on water resources:

- Landfills, Beitbridge;
- Disposal of liquid effluent, Beitbridge;
- Urban run off, urban areas of Beitbridge;
- Non-point domestic effluent;
- Minor non-point impact from non-intensive commercial or subsistence agriculture; and
- Runoff from Beitbridge airport.

4.8.2 Mining and mineral processing operations

The catchment falls mainly under the Masvingo Mining District (ZGS, 1995). Historically, magnesite and corundum have been produced, but no commodities are currently in production.

Table 4.10: Mining operations in the Diti Sub-catchment.

Name	Commodity	Status	Total produced /t	Potential Impact
Pande	Magnesite	Closed 1984	836308	Medium

See ZGS (1988a) for locations.

There is exploration for diamonds (ZGS, 2001).

4.8.3 Alluvial mining

Neither known nor likely.

4.8.4 Monitoring systems

None.

4.8.5 Water quality data

None available.

4.8.6 Implications for water quality and quantity management

The Pande mine is situated on two large serpentine bodies (Light and Broderick, 1998), so it is possible that its operations may have been associated with some alkaline mine drainage. It is also possible that the Pande quarry had some impact in terms of siltation in the area.

4.9 The Bubye sub-catchment

4.9.1 General description

4.9.1.1 Hydrology

This is Zones B1-B3 and L3 of Area B (ZSG, 1984). The Bubye flows from the Masase area to the Limpopo near Crook's Corner. There are wetlands along the Kwaluzi River in Zone B2 and at the Bubye – Limpopo confluence, Zones B1 and L3. The Bubye is dammed at Ripple Creek in Zone B3.

4.9.1.2 Geology

See **Figure 3.6** (ZGS, 1999). Most of the sub-catchment is underlain by Limpopo Belt gneises, except for Karoo basalts in the Gongwe area, post Karoo granites in the Mateke Hills and Karoo sediments in the Selungwe area.

4.9.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into four groups:

- Moderately shallow, coarse-grained kaolinitic sands, derived from the granites;
- Very shallow to moderately shallow sandy loams, formed from gneisses and Karoo sediments;
- Very shallow to moderately shallow clays, formed from the Greenstone Belts; and
- Very shallow sands, derived from the basalts (DRSS, 1979).

The Masase area in the far north is in Natural Region IV, with low (under 650mm) and unreliable rainfall, and poor soils. The remainder of the sub-catchment is in Region V, with poor soils, rainfall under 600mm and in places under 450mm (ZSG, 1997).

Land use is mainly commercial farming, private and resettlement land (ZSG, 1998), mainly livestock rearing with some drought resistant crops. The far south is Communal Lands, and agriculture limited mainly to livestock, especially goats.

4.9.1.4 Surface water users

Commercial agriculture is a major water user, including drawing water from Ripple Creek dam.

Water is pumped from the Limpopo near Crook's Corner to the border post at Sango – Chicualacuala, some 50km to the northeast.

4.9.1.5 Water management systems

The sub-catchment falls under the Mzingwane Catchment Council of ZINWA.

4.9.1.6 Human impacts of water resources (excluding mining)

The following could be expected to have an impact on water resources:

- Non-point domestic effluent, rural areas;
- Minor non-point impact from non-intensive commercial or subsistence agriculture; and
- Fuel loss and litter on the Masvingo – Beitbridge road and railway link.

4.9.2 Mining and mineral processing operations

The catchment falls mainly under the Masvingo Mining District (ZGS, 1995). A small quantity of magnesite was produced from Freedom Mine on the southern end of the Great Dyke, up until 1943. Otherwise, mineral resources, such as coal, in the sub-catchment have not been exploited.

There is exploration, mainly for diamond, as well as gold, silver, PGEs, copper and nickel (ZGS, 2001).

4.9.3 Alluvial mining

Neither known nor likely.

4.9.4 Monitoring systems

ZINWA is currently setting one up.

4.9.5 Water quality data

None available.

4.9.6 Implications for water quality and quantity management

Until such time as any exploration activities prove fruitful, there will be no significant impact of mining in the sub-catchment.

4.10 The Mwenezi sub-catchment

4.10.1 General description

4.10.1.1 Hydrology

This is Zones N1-N3 of Area B (ZSG, 1984). The Mwenezi rises west of Mberengwa and flows into the Limpopo in Mozambique. The Mwenezi is dammed at Manyuchi in Zone N2.

4.10.1.2 Geology

See **Figure 3.6** (ZGS, 1999). The Zimbabwe Craton underlies the northwest: granites and the Filabusi, Belingwe and Mweza Greenstone Belts. The Great Dyke passes through the northwest of the sub-catchment. The central area is underlain by Limpopo Belt gneises. Karoo basalts underlie the southeast and rhyolites, post Karoo granites in the Mateke Hills and post Karoo sediments in the east.

4.10.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into six groups:

- Moderately shallow, coarse-grained kaolinitic sands, derived from the Zimbabwe Craton granites;
- Very shallow to moderately shallow sandy loams, formed from gneisses and post Karoo sediments;
- Shallow to moderately shallow clays, with toxic levels of Ni and/or Cr in some areas, formed from the Filabusi and Belingwe Greenstone Belts;
- Very shallow sands formed from the Mateke Hills granites and the Mweza Greenstone Belt;
- Moderately deep to very shallow sands, derived from the basalts; and
- Deep sands formed from post Karoo sediments in the Guluene-Chefu area (DRSS, 1979).

Northwest of Manyuchi Dam is in Natural Region IV, with low (under 650mm) and unreliable rainfall, and poor soils. The remainder of the sub-catchment is in Region V, with poor soils, rainfall under 600mm and in places under 450mm (ZSG, 1997).

Land use is mixed commercial farming, private and resettlement land (ZSG, 1998) and Communal Lands, with the area east of the Mwenezi River in the south forming part of Gonarezhou National Park. Agriculture is mainly livestock rearing with some cash and fodder crops, principally in the northwest.

The main settlements are Mwenezi, Rutenga and Mataga Villages.

4.10.1.4 Surface water users

Agriculture is a major water user, including drawing water from Manyuchi Dam. Permanent pools on the Mwenezi River are the main source of water for game animals in western Gonarezhou National Park during the dry season, and are used as game viewing sites by tourists.

4.10.1.5 Water management systems

The sub-catchment falls under the Mzingwane Catchment Council of ZINWA.

4.10.1.6 Human impacts of water resources (excluding mining)

The following could be expected to have an impact on water resources:

- Non-point domestic effluent, rural areas;
- Minor non point impact from commercial or subsistence agriculture; and
- Fuel loss and litter on the Masvingo – Beitbridge and Rutenga – Sango road and railway links.

4.10.2 Mining and mineral processing operations

The catchment falls under the Masvingo Mining District (ZGS, 1995). The major mining activities are production of chrome at Inyala and Rhonda, gold in the eastern part of the Filabusi Greenstone Belt and emeralds at Sandawana.

Table 4.11: Mining operations in the Mwenezi Sub-catchment.

Name	Commodity	Status	Total produced /t	Potential Impact
Bend	Asbestos	Closed 1973	28652.0	Low
Peak	Asbestos	Closed 1970	2306.1	Low
Vanguard	Asbestos	Open in 1984	414265.0	Low
Inyala	Chromium	In operation	562034.0	Low
Rhonda	Chromium	In operation	182653	Low
Belingwe	Corundum	Closed 1959	2948.8	Low
Haybert	Emerald	Closed 1983	0.06820	Low
Sandawana Group	Emerald	In operation	0.02229	Low
Sihande	Emerald	Closed 1984	0.15130	Low
Umtasa	Emerald	Closed 1979	0.02163	Low
Vidan East	Emerald	Closed 1983	0.00626	Low
Calac	Magnesite	Closed 1970	13739	Low

See ZGS (1988a) for locations.

There are extensive small-scale chrome workings in the Rhonda area (**Figure 3.14**).

There is exploration, mainly for diamonds, as well as nickel, copper, PGEs and gold (ZGS, 2001).

4.10.3 Alluvial mining

Neither known nor likely.

4.10.4 Monitoring systems

ZINWA is currently setting one up.

4.10.5 Water quality data

None available.

4.10.6 Implications for water quality and quantity management

Available evidence does not suggest any high impacts of mining on the Mwenezi Sub-catchment. Such impacts as occur will relate to the extensive chrome and emerald workings in the south of Mberengwa District.

4.11 The Mkgadikgadi catchment

4.11.1 General description

4.11.1.1 Hydrology

This is Zones K, T and N of Area A (ZSG, 1984). The Nata (Manzamnyama) River, and its main tributaries, the Tegwani and the Maitengwe, flows from the Bulawayo – Plumtree area northwestwards into the Kalahari Desert, where they ultimately flow into the Mkgadikgadi Pans. The Gwabazabuya or Dzivanini River, which flows occasionally from the area west of Tsholotsho, joins the Nata in Botswana. Although the Mkgadikgadi Pans normally form a closed drainage system, during very infrequent times of flood, they overflow into the headwaters of the Motloutse River, a tributary of the Limpopo. For this reason, the Mkgadikgadi Catchment is discussed under the Limpopo Catchment.

4.11.1.2 Geology

See **Figure 3.6** (ZGS, 1999). Most of the catchment is underlain Kalahari Sands. South of Stanley, granites and gneisses of the Zimbabwe Craton underlie the catchment. Between the Kalahari Sands and the Craton, there is a small area of Karoo basalts and sediments.

4.11.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into four groups:

- Very deep Kalahari Sands,
- Moderately shallow, coarse-grained kaolinitic sands, derived from the granites;
- Moderately shallow to moderately deep, medium grained loamy sands and sandy loams, derived from the Karoo sediments; and
- Very shallow sands, derived from the basalts (DRSS, 1979).

The catchment is in Natural Region IV, with low (under 650mm) and unreliable rainfall, and poor soils (ZSG, 1997). Land use is mainly Communal Lands and the northern third of the catchment falling under the immense

Hwange National Park (ZSG, 1998). Agriculture is mainly subsistence livestock rearing with some drought resistant crops. The south is Communal Lands, and agriculture limited mainly to livestock, especially goats.

The main settlement is Plumtree Town.

4.11.1.4 Surface water resources

Plumtree draws water from Questeds Dam on the upper Tegwani.

4.11.1.5 Water management systems

The catchment falls under the Sanyati Catchment Council of ZINWA.

4.11.1.6 Human impacts on water resources (excluding mining)

The following could be expected to have an impact on water resources:

- Landfills, Plumtree;
- Disposal of liquid effluent, Plumtree;
- Non-point domestic effluent, rural areas; and
- Minor non-point impact from non-intensive agriculture.

4.11.2 Mining and mineral processing operations

The catchment falls under the Bulawayo Mining District (ZGS, 1995). There have not, to date, been any mining activities in the catchment, although some exploration is taking place. There is exploration for gold, copper, zinc and nickel (ZGS, 2001).

4.11.3 Alluvial mining

Neither known nor likely.

4.11.4 Monitoring systems

None.

4.11.5 Water quality data

None available.

4.11.6 Implications for water quality and quantity management

Unless a mine is opened as result of current exploration activities, there is and will be neither mining nor any impacts of mining taking place.

4.12 The Lower Limpopo and Chagane (Mozambique) sub-catchment

4.12.1 General description

4.12.1.1 Hydrology

This sub-catchment consists of the main stem of the Limpopo River, from the border with South Africa and Zimbabwe, to the coast at Xai-Xai (**Figure 4.2**). The Mwenezi River from Zimbabwe joins the Limpopo River, some 70 kilometres downstream of Pafuri, whilst the Olifants River flows into the Limpopo River a further 120 kilometres downstream. Shortly before the Limpopo River reaches its mouth at the coast, the Chagane River joins it. The Chagane River drains a very large area of coastal plain and consists almost entirely of seasonal or episodic streams and pools (**Figure 4.2**). The Limpopo River downstream of its confluence with the Olifants River supports a very large irrigation scheme at Chokwe. The Chokwe Irrigation Scheme is estimated to consist of some 290 km^2 of demarcated irrigation area, though not all of this appears to be utilized (Boroto & Görgens, 1999).

The Olifants River basin is dealt with separately in this report (**Section 5**) and is not included here under the Limpopo basin.

Dry season (June 1998) flows in the Limpopo River at Crooks Corner close to Pafuri, where the borders of South Africa, Mozambique and Zimbabwe meet, consist almost entirely of flows contributed by the Mutale-Levuvhu river system (P.J. Ashton, personal observations). The Limpopo River upstream of Crooks Corner is usually dry for several months during winter each year (Boroto & Görgens, 1999).

4.12.1.2 Geology

Most of this sub-catchment is underlain by extensive Quaternary deposits of semi-consolidated sandstones and mudstones, with slightly older deposits of Tertiary age from the Mazamba, Jofane and Cheringoma formations. In addition, there are also areas of the Grunja and Sena post-Karoo complexes, consisting predominantly of alkaline dolerites and shales, with minor evidence of non-economic coal measures in small outliers of the Stormberg Series along the western portion of the sub-catchment close to the Lebombo Mountains. Recent alluvial deposits and discrete flood terraces characterize the valley bottom along the Limpopo River.

4.12.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into four groups:

- Relatively deep, unconsolidated sands of marine origin covering much of the Chagane sub-catchment;
- Moderately shallow, coarse-grained sands derived from the Rhyolites of the Lebombo Mountains;
- Moderately shallow to moderately deep, medium-grained loamy sands and silty sands along river channels and flood terraces; and
- Shallow, coarse-grained sandy soils derived from Karoo Series basalts.

Soils in the Chokwe Irrigation Scheme located downstream of the Limpopo-Olifants confluence consist predominantly of silty or loamy sands derived from earlier flood events. Crops produced consist of Cotton, Sorghum and Maize, with some cultivation of fruit trees (Mangoes and Cashew Nuts).

Land use outside of the Chokwe Irrigation Scheme consists predominantly of subsistence agriculture and minor livestock rearing, with small-scale tourism activities along the coastline at Xai-Xai.

4.12.1.4 Surface water users

The largest water users in this sub-catchment are the Chokwe Irrigation Scheme (Boroto & Görgens, 1999) and the town of Xai-Xai. The Chokwe Irrigation Scheme covers a potential area of 29,000 hectares (290 km^2) and its water demand has been estimated at over 500 million cubic metres per year (Boroto & Görgens, 1999). It can be anticipated that some of this water will return to the Limpopo River as seepage contaminated by whatever agro-chemicals are used in these sandy soils.

Elsewhere in the sub-catchment, water users consist of a large number of small settlements along the Limpopo River and in the Chagane sub-catchment. Where perennial surface water is absent, these users rely on hand-dug wells for all their water requirements.

4.12.1.5 Water management systems

The Mozambique Department of Water Affairs is responsible for the management of all water resources within this sub-catchment and monitors flows irregularly at three points along the Limpopo River. These data are apparently insufficient for accurate modelling purposes (Boroto & Görgens, 1999).

4.12.1.6 Human impacts on water resources (excluding mining)

Impacts on water resources in this sub-catchment are expected to consist of:

- Contaminated return flows seeping from the Chokwe Irrigation Scheme;

- Landfills at Xai-Xai;
- Disposal of liquid effluent, Xai-Xai (probably discharged to sea);
- Non-point domestic effluent from soak aways in rural areas; and
- Minor non-point impact from non-intensive agriculture.

4.12.2 Mining and mineral processing operations

An extensive source of heavy mineral sands (containing titanium, illmenite and zirconium) is under prospecting licence close to the town of Xai-Xai at the mouth of the Limpopo River (**Table 4.12**).

Table 4.12: Mining operations in the Lower Limpopo (Mozambique) sub-catchment.

Code Number	Name of Mine	Commodity (ies) Mined	Status	Relative Size	Probable Impact
Moz-1	Rio Limpopo	Titanium, Illmenite	Prospecting	Large	Very low

4.12.3 Alluvial mining

None known or anticipated.

4.12.4 Monitoring systems

The Mozambique Department of Water Affairs monitors flows in the Limpopo River at three flow gauging stations (Boroto & Görgens, 1999). No details are available of any water quality monitoring of water supplies provided to towns and settlements.

4.12.5 Water quality data

None available.

4.12.6 Implications for water quality and quantity management

No impacts on water resources are anticipated from the prospecting activities located close to the mouth of the Limpopo River.

4.13 The Marico sub-catchment

4.13.1 General description

4.13.1.1 Hydrology

*This sub-catchment consists of the area drained by the Marico River, from its headwaters in the dolomitic aquifers between the towns of Zeerust and Lichtenburg, to its confluence with the Ngotwane River to form the Limpopo River (**Figure 4.2**). There are four relatively large water supply dams located in this sub-catchment, of which the Marico Dam also supplies water to the City of Gaborone in Botswana. The main stem of the Marico River is perennial, but most of its tributaries have seasonal or episodic flows. In addition to the larger water supply dams, the sub-catchment also contains a large number of smaller farm dams used to trap runoff in seasonal channels and supply this water either for livestock watering or for small-scale irrigation schemes.*

Extensive areas of the lower reaches of this sub-catchment are internally draining and provide little or no runoff to flows in the Marico River.

4.13.1.2 Geology

In the upper reaches of this sub-catchment, the geological features are characterized by the presence of extensive dolomite and limestone formations. Extensive areas of unconsolidated and semi-consolidated sedimentary rocks of the Transvaal Supergroup underlie the northern areas of the catchment. These are intruded by wide belts of basic or mafic lavas in the south, with intrusions of basic, mafic and ultramafic rocks in the north. Virtually the entire northern portion of the sub-catchment is underlain by wide expanses of acid and intermediate intrusive rocks, with intercalated assemblages of compact sedimentary and intrusive rocks. The limestone and dolomite formations contain very large volumes of water that provide perennial flows to the Marico River.

4.13.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into four main groups:

- Moderate to deep clayey loam soils on flat and undulating terrain overlying dolomite and limestone in the upper reaches of the catchment;
- Moderate to deep clay loam soils over much of the middle portions of the sub-catchment, overlying the more porous unconsolidated sedimentary material;
- Moderately shallow to moderately deep, clayey loam to clay-rich, fine-grained soils over most of the lower reaches of the sub-catchment; and
- Coarser-grained sandy soils long river channels and flood terraces.

Most of the clayey loam soils would be suitable for commercial agriculture if sufficient water were available. However, most of the land use is given over to small-scale irrigation along river courses, and the raising of small and large livestock and game animals. All irrigation water use occurs within Government Water Control Areas situated along the main river channels. The main crops produced consist of Cotton, Sorghum and Maize, with some cultivation of citrus and soft fruits.

Several small towns with some light industry and mining operations are present.

4.13.1.4 Surface water users

All towns and settlements in the sub-catchment rely on water supplied from the larger impoundments, or from run-of-river abstraction points and, occasionally, from local boreholes. Most of the water used in the sub-catchment is consumed by the numerous irrigation schemes in the Government Water Control Areas along the Marico River and the South African bank of the Limpopo River.

4.13.1.5 Water management systems

The South African Department of Water Affairs and Forestry is responsible for the management of all water supply and water use in the sub-catchment. Close liaison is maintained between the Department and their Botswana colleagues for the supply of water to Gaborone from the Marico Dam.

The Department of Water Affairs and Forestry (DWAF) operates a comprehensive system of flow gauging at all dams in the sub-catchment and particular attention is paid to monitoring the quantity of water supplied to irrigation schemes and towns, as well as some attention to the quality of agricultural return flows and effluent discharges to the Marico River. The quality of dolomite springs is monitored regularly.

This sub-catchment (and its eastern neighbour, the Elands-Crocodile-Pienaarsrivier sub-catchment) are likely to become the first official Catchment Management Agency that will take over responsibility for al aspects of water resource management and water supply. The preliminary documentation is being finalized and catchment studies are either in progress or have been completed.

4.13.1.6 Human impacts on water resources (excluding mining)

The following activities can be expected to have an impact on water resources in the sub-catchment:

- Landfills and solid waste disposal sites at Zeerust, Groot Marico, Swartruggens and Derdepoort;
- Disposal of liquid (domestic and some light industrial) effluent at Zeerust, Groot Marico, Swartruggens and Derdepoort;
- Minor volumes of run off from urban areas;
- Non-point domestic effluent from numerous small settlements and farms;
- Minor non-point impact from non-intensive commercial or subsistence agriculture;

- Major non-point impact of agricultural return flows from intensive irrigation areas; and
- Litter and domestic garbage alongside roads traversing the sub-catchment.

4.13.2 Mining and mineral processing operations

The positions of the mining operations in the Marico sub-catchment are shown in **Figures 4.2 and 4.3**. Details of each operation are given in **Table 4.13**.

Table 4.13: Mining operations in the Marico sub-catchment.

Code Number	Name of Mine	Commodity (ies) Mined	Status	Relative Size	Probable Impact
C6-4	Kameelboom	Vanadium	Prospecting	Small	Very low
C6-6	Hightop Manganese	Manganese	Prospecting	Small	Very low
C6-7	Dwaalboom	Dolomite/Limestone	Operating	Medium	Very low
C6-26	Marico Fibre	Chrysotile asbestos	Prospecting	Small	Very low
C6-27	Marico Andalusite A	Andalusite	Prospecting	Small	Very low
D6-1	Zeerust	Chrome	Operating	Medium	Low – Medium
D6-2	Marico	Chrome	Operating	Medium	Low – Medium
D6-3	Nietverdiend	Chrome	Operating	Medium	Low – Medium
D6-16	Androfax	Andalusite	Operating	Medium	Low
D6-17	Helam	Diamond - kimberlite	Operating	Medium	Low
D6-27	Witkop Marico	Fluorspar	Operating	Medium	Low – Medium
D6-47	Autumn Slate	Dimension stone	Operating	Small	Low
D6-49	Rosmincol	Dimension stone	Operating	Medium	Low
D6-50	Marico Prospect A	Lead	Prospecting	Small	Very low
D6-51	Marico Prospect B	Lead	Prospecting	Small	Very low
D6-52	Witkop Mangaan A	Manganese	Prospecting	Small	Very low
D6-53	Witkop Mangaan B	Manganese	Prospecting	Small	Very low
D6-54	Marico Andalusite B	Vanadium, Andalusite	Prospecting	Small	Very low

4.13.3 Alluvial mining

None known or anticipated.

4.13.4 Monitoring systems

The Department of Water Affairs and Forestry have provided data for the Malmanie Eye and the Rhenosterfontein Eye, both of which are dolomitic springs in the headwaters of the sub-catchment. No specific details of monitoring of agricultural return flows or effluent discharges could be obtained in time for this report.

4.13.5 *Water quality data*

The available water quality data refer only to the water quality in two dolomitic springs located at the headwaters of the sub-catchment. As such, the data provide little insight into the general water quality of the sub-catchment. Future studies should seek to obtain details of all effluents discharged to the sub-catchment, as well as information on agricultural return flows. These data will help decision-makers to appreciate the implications of deteriorating water quality for irrigation water users.

4.13.6 *Implications for water quality and quantity management*

Most of the mining operations in this sub-catchment are relatively small or are still under prospecting permits. Minor contamination can be anticipated from the operating chrome mines in the form of possible toxic hexavalent chrome. Minor acid mine drainage impacts can also be expected but, since this is a relatively dry area, this is unlikely to be significant. Some increase in suspended solids can be anticipated in the rivers and streams located close to mining and quarrying (dimension stone) operations.

4.14 The Crocodile-Elands-Pienaarsrivier sub-catchment

4.14.1 *General description*

4.14.1.1 Hydrology

*This sub-catchment consists of the area drained by the Crocodile River and its two main tributaries, the Elands and Pienaars Rivers, from the area immediately to the north of the City of Johannesburg, to its confluence with the Limpopo River (**Figure 4.2**). Elands River drains the area to the northwest of Johannesburg, whilst the Pienaars River drains the area from Pretoria northwards to the Waterberg Mountains near the town of Warmbaths. All these rivers are perennial and their flows are supplemented by substantial discharges of treated domestic and industrial effluent. Flows in these rivers are also enhanced by water imported from the Vaal River system to the south of Johannesburg, which is used principally for domestic and industrial water supplies prior to treatment and discharge.*

There are sixteen relatively large water supply dams located in this sub-catchment, all of which supply water for domestic and industrial use as well as for irrigation activities. In addition to the larger water supply dams, the sub-catchment also contains a very large number (> 850) of smaller farm dams that are used to trap runoff in seasonal channels and supply this water either for livestock watering or for small-scale irrigation schemes.

Extensive areas of the lower reaches of this sub-catchment are internally draining and provide little or no runoff to flows in the Limpopo River.

Several thermal springs are located in the area around the Waterberg Mountains; most of these are used as medicinal spas.

4.14.1.2 Geology

In the upper reaches of the Crocodile River, the geological features are characterized by the presence of extensive dolomite and limestone formations surrounding a central core of acidic and intermediate intrusive rocks. The Elands River rises in an area characterized by unconsolidated sedimentary strata and mafic and ultramafic intrusive rocks. In contrast, the headwaters of the Pienaars River are located in an area underlain by formations of acid and intermediate lavas, arenaceous and argillaceous strata, and basic and acidic rocks of the Bushveld Complex and the granites of the Waterberg Formation.

Extensive areas of unconsolidated and semi-consolidated sedimentary rocks of the Transvaal Supergroup underlie the northern areas of the catchment. These are intruded by wide belts of basic or mafic lavas in the south, with intrusions of basic, mafic and ultramafic rocks in the north. Virtually the entire northern portion of the sub-catchment is underlain by wide expanses of acid and intermediate intrusive rocks, with intercalated assemblages of compact sedimentary and intrusive rocks.

4.14.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into four main groups:

- Moderate to deep sandy loam soils on flat and undulating terrain overlying dolomite, limestone and sandstones in the upper reaches of the catchment;
- Moderate to deep sandy loam soils lining long stretches of the Crocodile River valley in its middle reaches;
- Moderate to deep clay loam soils over much of the middle portions of the sub-catchment (located away from the river channels), overlying the more porous unconsolidated sedimentary material; and
- Moderately shallow to moderately deep, clayey loam to clay-rich, fine-grained soils over most of the lower reaches of the sub-catchment.

Most of the clayey loam soils are highly suitable for commercial agriculture when sufficient water is provided. Virtually all of the suitable soils are contained within the jurisdiction of formal irrigation boards or Government Water Control Areas. Further away from the main river channels, most of the land use is given over to small-scale irrigation from farm dams as well as the raising of small and large livestock and game animals. A very wide variety of crops are produced, ranging from intensive vegetable production to Tobacco, Maize, Cotton, Citrus and Sub-tropical Fruits, Sorghum, Sunflowers and Soya bean. Minor areas of plantation forestry (mostly Eucalyptus, with some Pine) are also located in the wetter portions of the sub-catchment. The timber is used primarily for fencing poles and house construction.

Several large cities and numerous smaller towns are present in the upper reaches of the sub-catchment. The number and density of population declines with increasing distance from the upper reaches. A wide variation of both light and heavy industry is present in the cities and larger towns, with many industries geared specifically to meeting the needs of the extensive mining sector.

4.14.1.4 Surface water users

All cities, towns and settlements in the sub-catchment rely on water supplied from the larger water supply impoundments, or from run-of-river abstraction points and, occasionally (in the lower reaches), from local boreholes. Most of the water used in the sub-catchment is consumed by the extensive urban areas that are spread across the headwaters of the sub-catchment, whilst the numerous irrigation schemes in the Government Water Control Areas along the Crocodile River and its major tributaries also require very large volumes of water. Water supplies are supplemented by water imported from the Vaal River system to the south of Johannesburg; this water is used primarily for domestic and industrial use. Extensive informal settlements have sprung up around the periphery of the major urban centres. These settlements lack access to basic services such as clean water supplies and suitable sanitation systems.

The extensive mining developments in the mineral-rich Bushveld Igneous Complex compete with irrigation agriculture in the sharing of the relatively meagre water resources that are available (Midgley *et al*., 1995). Historically, irrigation development preceded the more recent emphasis on mining of chrome, platinum-group minerals, iron ore, phosphates, fluorspar and coal. Unless the water supplies to large areas under irrigation can be "cannibalised", additional supplies of water will need to be imported into this sub-catchment to meet the rapidly rising demands for water that result from continued mining development and the possible construction and operation of future coal-fired power stations (Midgley *et al*., 1995).

4.14.1.5 Water management systems

The South African Department of Water Affairs and Forestry (DWAF) is responsible for the management of all aspects of water supply and water use in the sub-catchment. The Department operates a comprehensive system of flow gauging at all dams in the sub-catchment and particular attention is paid to monitoring the quantity of water supplied to irrigation schemes and towns, as well as increasing attention to the quality of agricultural return flows and effluent discharges to the Crocodile River.

This sub-catchment (and its western neighbour, the Marico River sub-catchment) are likely to become the first official Catchment Management Agency that will take over responsibility for al aspects of water resource management and water supply. The preliminary documentation is being finalized and catchment studies are either in progress or have already been completed.

4.14.1.6 Human impacts on water resources (excluding mining)

The following activities can be expected to have an impact on water resources in the sub-catchment:

- Landfills and solid waste disposal sites at all cities and towns;

- Disposal of large volumes of liquid (domestic, light industrial and heavy industrial) effluent at all cities and towns;
- Large volumes of runoff from cities and the larger towns, as well as all other urban areas;
- Seepage from two hazardous waste dumps located in the sub-catchment;
- Discharge of radionuclides in effluent from the Pelindaba experimental reactors;
- Non-point domestic effluent from numerous small settlements and farms;
- Minor non-point impact from non-intensive commercial or subsistence agriculture;
- Major non-point impact of agricultural return flows from intensive irrigation areas; and
- Large volumes of litter and domestic garbage alongside the many roads and highways that traverse the sub-catchment.

4.14.2 Mining and mineral processing operations

The positions of the mining operations in the Marico sub-catchment are shown in **Figures 4.2 and 4.3**. Details of each operation are given in **Table 4.14**.

Table 4.14: Mining operations in the Crocodile-Elands-Pienaars sub-catchment.

Code Number	Name of Mine	Commodity (ies) Mined	Status	Relative Size	Probable Impact
C6-1	Rhino Lead	Lead	Prospecting	Small	Very low
C6-2	Thabazimbi	Iron	Operating	Large	Low – Medium
C6-3	Rhino Andalusite	Andalusite	Operating	Large	Low
C6-8	Zwartkop	Chrome	Operating	Medium	Low
C6-9	Amandebult	Platinum	Operating	Very large	Medium
C6-10	Vlaknek	Vanadium	Prospecting	Very small	Very low
C6-11	Koppie Aleen	Vanadium	Prospecting	Very small	Very low
C6-12	Northam	Platinum	Operating	Medium	Low
C6-13	Union	Platinum	Operating	Medium	Low
C6-14	Latilla	Dolomite / Limestone	Operating	Medium	Low
C6-15	Brakspruit	Vanadium	Prospecting	Small	Very low
C6-16	Kransberg	Vanadium	Prospecting	Small	Very low
C6-17	Witfontein	Fluorspar	Prospecting	Small	Very low
C6-18	Rooiberg	Copper	Closed	Small	Very low
C6-19	Witfontein B	Fluorspar	Closed	Small	Very low
C6-20	Rooiberg B	Gold	Closed	Small	Very low
C6-21	Kwarriehoek	Gold	Closed	Very small	Very low
C6-22	Sterkfontein	Fluorspar	Closed	Very small	Very low
C6-23	Knoppieskraal	Fluorspar	Closed	Very small	Very low
C6-24	Doornfontein	Fluorspar	Closed	Small	Very low
D6-4	Rooderand	Chrome	Operating	Medium	Medium
D6-5	Rustenburg Minerals	Chrome	Operating	Large	Medium
D6-6	Ruighoek	Chrome	Operating	Very large	Medium – High
D6-7	Ntuane	Chrome	Operating	Medium	Medium

D6-8	Beestekraal	Dolomite / Limestone	Operating	Large	Very low
D6-9	Bafokeng	Platinum	Operating	Large	Medium
D6-10	Impala	Platinum	Operating	Medium	Medium
D6-11	Boshoek	Chrome	Operating	Medium	Medium
D6-12	Wildebeestfontein	Platinum	Operating	Large	Medium
D6-13	Boekenhoutfontein	Chrome	Operating	Medium	Medium
D6-14	Rustenburg Granite	Dimension stone	Operating	Small	Very low
D6-15	Bospoort	Dimension stone	Operating	Small	Very low
D6-18	Impala – W'beestfontein	Platinum	Operating	Large	Medium
D6-19	Ba-Magopa	Vanadium	Operating	Medium	Low – Medium
D6-20	Marikana - Geluk	Dimension stone	Operating	Small	Very low
D6-21	Marikana Granite	Dimension stone	Operating	Small	Very low
D6-22	Paardekraal	Platinum	Operating	Medium	Medium
D6-23	Maroela	Chrome	Operating	Medium	Medium
D6-24	Noordwes	Chrome	Operating	Medium	Medium
D6-25	Rustenburg – Waterval	Platinum	Operating	Medium	Medium
D6-26	Crocodile River	Platinum	Operating	Medium	Medium
D6-28	Keeley Slate	Dimension stone	Operating	Medium	Very low
D6-29	Mazista Slate	Dimension stone	Operating	Medium	Very low
D6-30	Miusell	Chrome	Operating	Medium	Medium
D6-31/32	Harmse – Waterkloof	Chrome	Operating	Medium	Medium
D6-33	Karee	Platinum	Operating	Medium	Medium
D6-34	Western Platinum	Platinum	Operating	Large	Medium – High
D6-35	Eastern Platinum	Platinum	Operating	Large	Medium – High
D6-36	Kroondal	Platinum	Operating	Large	Medium – High
D6-37	Marikana	Platinum	Operating	Large	Medium – High
D6-38	Kroondal B	Chrome	Operating	Medium	Medium
D6-39	Rustenburg	Chrome	Operating	Medium	Medium
D6-40	Wonderkop	Chrome	Operating	Medium	Medium
D6-41	Kafferskraal	Chrome	Operating	Medium	Medium
D6-42	Elandsdrift	Chrome	Operating	Medium	Medium
D6-43/44	Elandskraal – Mooinooi	Chrome	Operating	Medium	Medium
D6-45	Western Buffelsfontein	Chrome	Operating	Medium	Medium
D6-46	De Rust	Glass sand	Operating	Large	Low
D6-48	Beau Rivage	Dimension stone	Operating	Medium	Low
D6-55	Silver Hills	Lead, Silver	Closed	Small	Very low
D6-56	Buffelspoort	Fluorspar	Closed	Small	Very low
D6-57	Ruigtesloo	Fluorspar	Closed	Small	Very low
E6-1	Reef Quarries	Limestone / Dolomite	Operating	Medium	Low
C7-16	Buffalo Fluorspar	Fluorspar	Operating	Medium	Low – Medium
D7-3	Sabrix	Clay minerals	Operating	Small	Very low
D7-6	Roodepoort 1	Clay minerals	Operating	Large	Low

D7-13	Premier	Diamond – kimberlite	Operating	Large	Medium
D7-14	Kameeldrift	Clay minerals	Operating	Small	Very low
D7-15	Boekenhoutkloof	Clay minerals	Operating	Medium	Low
D7-17	Fortsig	Chrysotile asbestos	Operating	Small	Very low
D7-19	Donkerhoek	Glass sand	Operating	Small	Very low
D7-20	Mooiplaas	Limestone / Dolomite	Operating	Medium	Low
D7-21	Puntlyk	Glass sand	Operating	Small	Very low
D7-22	Samancor Lyttleton	Limestone / Dolomite	Operating	Medium	Low
D7-23	Noel Lancaster	Glass sand	Operating	Small	Very low
D7-25	Grootfontein	Clay minerals	Operating	Medium	Low
D7-31	Hippo Olifantsfontein	Limestone / Dolomite	Operating	Medium	Low
D7-37	Bourke	Fluorspar	Closed	Small	Very low
D7-38	Rust de Winter	Fluorspar	Closed	Small	Very low

4.14.3 Alluvial mining

None known or anticipated.

4.14.4 Monitoring systems

The Department of Water Affairs and Forestry (DWAF) operate a comprehensive monitoring system of flow measurements and water quality measurements in the sub-catchment. In addition, DWAF also regulate the quantity and quality of all effluent discharges through a system of effluent discharge permits or licences. Each licensed effluent discharger is required to carry out a routine monitoring programme of the flow and quality of their effluent and supply this to DWAF. The Department then conducts a randomised series of audit samples to check the veracity of the effluent returns submitted by each discharger.

4.14.5 Water quality data

The Department of Water Affairs and Forestry have provided data for the main stem of the Crocodile River at three points along its length (**Table 4.15**). These data reveal that the water quality in the Crocodile River is very poor in the upper reaches due to contamination from effluents and seepage. There is a minor improvement in orthophosphate (PO_4-P) concentrations in Hartbeespoort Dam, but further deterioration occurs downstream, probably as a result of irrigation return flows and discharges containing fertilizers. Concentrations of total dissolved salts and pH values increase downstream, indicating progressive salinization. No details of specific agricultural return flows or effluent discharges could be obtained in time for this report. This information is also regarded as very sensitive and normally has to be dealt with confidentially.

Table 4.15: Water quality data for three sampling stations along the Crocodile River (Annual averages, in mg/litre, provided by Department of Water Affairs and Forestry).

Station	pH	TDS	PO_4-P
A2H12	7.6	485	1.4
A2H52	7.7	510	0.7
A2H60	7.9	535	2.0

4.14.6 Implications for water quality and quantity management

There are a very large number of mining operations of differing sizes in this sub-catchment, and a wide variety of mineral commodities are exploited. In addition to the mining operations listed in **Table 4.14**, there are also a relatively large number of mining operations that have either been closed or abandoned (C.J. Vorster, personal communication). Some prospecting permits have also been issued but no details were available for this report.

Perhaps the most significant impacts associated with mining in this sub-catchment are those linked to chrome mining and refining. The defunct African Chrome Smelter at Brits, currently being evaluated for refurbishment, has previously contaminated local ground water resources with toxic hexavalent chrome (Cr^{6+}). Minor contamination by hexavalent chrome can also be anticipated from the operating chrome mines located near to the town of Rustenburg. Another contaminant that can pose significant problems is Vanadium, which is known to be toxic to plants and animals when present in high concentrations. The vanadium mines near Rustenburg, and those mines where vanadium is a secondary product (**Table 4.14**) all have the potential to pose vanadium toxicity problems.

Some minor problems associated with elevated metal concentrations can also be expected from the platinum mines and the now-closed base metal mines (lead, silver, tin, zinc, copper). All of these mines have sulphide orebodies and minor acid mine drainage can be anticipated from these mines. The large iron ore mines at Thabazimbi are likely to contribute elevated concentrations of iron and manganese to local waterbodies via wind-blown dusts. Minor contamination by elevated fluoride concentrations can be anticipated in the middle reaches of this sub-catchment, where local streams drain fluoride-rich areas being mined in the western side of the Waterberg Plateau.

The lower reaches of the sub-catchment are relatively dry, with high Weinert N weathering indices indicating that mechanical weathering processes dominate. Consequently, any contaminants emitted by mines in this area would not normally be expected to be very mobile. This contrasts with the lower Weinert N weathering indices of the upper reaches of the sub-catchment, where chemical weathering processes will dominate and contaminants would be more mobile.

All of the metal mining operations and those quarrying operations that extract dimension stone (predominantly granite) as well as dolomite and limestone can be expected to contribute elevated levels of suspended solids to local waterways.

4.15 The Matlabas-Mokolo sub-catchment

4.15.1 General description

4.15.1.1 Hydrology

*This sub-catchment consists of the area drained by the Matlabas and Mokolo rivers and their main tributary streams. These two small river systems flow northwards or north-westwards from the area to the east of the town of Thabazimbi, joining the Limpopo River (**Figure 4.2**). The flow patterns in these two rivers is very variable as a result of the prevailing low and unpredictable rainfalls (average 450 mm) and the rivers normally only contain surface water during the summer months. Most of their tributary streams are episodic and only flow for short periods of time after local rainfalls in their vicinity. The two rivers contain four small dams and numerous smaller farm dams that are used to supply water for domestic and irrigation purposes, as well as livestock watering (Boroto & Görgens, 1999).*

4.15.1.2 Geology

The geological features of this sub-catchment are relatively simple. Porous consolidated and partially consolidated sedimentary strata, predominantly sandstones, underlie the upper two-thirds of the sub-catchment. This is succeeded by a broad band of intercalated arenaceous and argillaceous strata and undifferentiated sedimentary extrusive and intrusive rocks, mainly granites and gneisses, together with coal-bearing rocks of the Karoo Supergroup, in the lowest reaches alongside the Limpopo River (Midgley *et al*., 1994).

4.15.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into three main groups:

- Moderate to deep sandy loam soils on the sloping and undulating terrain in the upper reaches of the sub-catchment;
- Moderately deep sandy loam soils lining long stretches of the valley bottoms in the middle reaches of the sub-catchment; and
- Shallow to moderately deep sandy soils in flat and undulating terrain in the lower reaches of the sub-catchment.

Most of the clayey loam soils are highly suitable for commercial agriculture when sufficient water is provided. Virtually all of the suitable soils along the Mokolo River are contained within the jurisdiction of formal irrigation boards or Government Water Control Areas. Further away from the main river channels, most of the land use is given over to small-scale livestock farming as well as the raising of game animals. Virtually no irrigation takes place along the Matlabas River due to the scarcity of water. In the Mokolo irrigation schemes, a very wide variety of drought-tolerant crops are produced, ranging from Cotton, Citrus and Sub-tropical Fruits, to Sorghum, Sunflowers and Soya bean.

A few small towns and several small settlements are present in the upper reaches of the sub-catchment, though population densities decline with increasing distance downstream. The north-eastern portions of this sub-catchment support large numbers of small-scale subsistence farmers in areas that were previously part of the Apartheid system of “self-governing homelands”.

4.15.1.4 Surface water users

All of the towns and settlements in the sub-catchment rely on water supplied from the water supply impoundments, or from run-of-river abstraction points and, occasionally (in the lower reaches), from local boreholes. Most of the water used in the sub-catchment is consumed by the extensive formal irrigation along the Mokolo River. The sub-catchment has very unreliable supplies of water and there seems to be little opportunity for expansion of the irrigated areas without the importation of additional water supplies (Midgley *et al*., 1999). The Matimba Power Station located close to the Groot Geluk Colliery also uses large volumes of cooling water.

A few informal settlements have sprung up around the periphery of the minor towns in the sub-catchment. These settlements lack access to basic services such as clean water supplies and suitable sanitation systems. In addition, the large numbers of subsistence farmers in the north-eastern portion of the sub-catchment have to rely on boreholes and hand-dug wells for their meagre water supplies. The Department of Water Affairs and Forestry is undertaking a concerted campaign to provide water supplies to these and other nearby areas in the Laphalala and Mogalakwena sub-catchments in an attempt to alleviate the hardships experienced by these residents.

4.15.1.5 Water management systems

The South African Department of Water Affairs and Forestry (DWAF) is responsible for the management of all aspects of water supply and water use in the sub-catchment. The Department operates a routine system of flow gauging at all dams in the sub-catchment and particular attention is paid to monitoring the quantity of water supplied to irrigation schemes and towns, as well as increasing attention to the quality of agricultural return flows and any effluent discharges to the Mokolo River.

4.15.1.6 Human impacts on water resources (excluding mining)

The following activities can be expected to have an impact on water resources in the sub-catchment:

- Landfills and solid waste disposal sites at towns;
- Disposal of liquid (domestic) effluent at all towns;
- Minor volumes of urban runoff from towns;
- Seepage / discharge of cooling water from Matimba Power station;
- Non-point domestic effluent from numerous small settlements and farms;
- Minor non-point impact from non-intensive commercial or subsistence agriculture;
- Non-point impacts of agricultural return flows from intensive irrigation areas; and
- Litter and domestic garbage discarded alongside the roads.

4.15.2 *Mining and mineral processing operations*

There are only two small mining concerns in this sub-catchment (**Table 4.16**).

Table 4.16: Mining operations in the Matlabas-Mokolo sub-catchment.

Code Number	Name of Mine	Commodity (ies) Mined	Status	Relative Size	Probable Impact
B6-1	Grootgeluk	Coal	Operating	Very large	Medium
B6-2	Steenbokpan	Phosphate	Prospecting	Very small	Very low

4.15.3 *Alluvial mining*

None known or anticipated.

4.15.4 *Monitoring systems*

The Department of Water Affairs and Forestry (DWAF) conduct routine monitoring of river flows and water quality at a few sites in this sub-catchment. In addition, in accordance with their statutory responsibility, DWAF also regulate the quantity and quality of all effluent discharges through a system of effluent discharge permits or licences. Each licensed effluent discharger is required to carry out a routine monitoring programme of the flow and quality of their effluent and supply this to DWAF. The Department then conducts a randomised series of audit samples to check the veracity of the effluent returns submitted by each discharger.

4.15.5 *Water quality data*

No specific water quality data for this sub-catchment could be obtained in time for this report. In view of the very limited mining activity, this deficiency is not considered to be important.

4.15.6 *Implications for water quality and quantity management*

The available evidence suggests that the only likely source of any impact on local water resources and water quality would be the large Groot Geluk Colliery and its coking plant. These impacts would most likely be localized and consist almost entirely of minor acid mine drainage linked to the oxidation of pyrite in the coal.

4.16 The Laphalala sub-catchment

4.16.1 General description

4.16.1.1 Hydrology

*This sub-catchment consists of the area drained by the Laphalala River and its tributary streams. This river system flow northwards or north-westwards from the area to the west of the town of Nylstroom, joining the Limpopo River downstream of the Mokolo River (**Figure 4.2**). The flow pattern in this river is very variable as a result of the prevailing low and unpredictable rainfalls (average 450 mm) and the long stretches of the river normally only contain surface water during the summer months. Most of their tributary streams are episodic and only flow for short periods of time after local rainfalls in their vicinity. The Laphalala River contains several small dams and numerous off-channel farm dams that are used to supply water for domestic and irrigation purposes, as well as livestock watering (Boroto & Görgens, 1999).*

4.16.1.2 Geology

The geological features of the Laphalala sub-catchment are relatively complex since they consist of several different formations of widely differing ages. Most of the upper reaches of the sub-catchment are underlain by a variety of porous consolidated and partially consolidated sedimentary strata, predominantly sandstones, quartzites and felsites of the Waterberg and Soutpansberg Groups. These have been variously intruded by acidic and basic granites and lavas of the Bushveld Complex, which in turn overlie the crystalline gneissic rocks of the Basement Complex.

Further downstream, the sub-catchment is underlain by a sequence of sandstones and quartzites, followed by carbon-rich mudstones and shales, and then basalts, of the Karoo Sequence. The sandstones are silicified and resistant to weathering, remaining as harder protruding rock formations that stand well clear of the surrounding undulating terrain to form local mountains or ranges of hills. The erosion-resistant rocks of the Waterberg Group show a similar tendency, standing well clear of the surrounding countryside.

Large areas of the central parts of the sub-catchment are overlain by recent (Quaternary) deposits of unconsolidated or poorly consolidated sandy material.

4.16.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into three main groups:

- Moderate to deep sandy-clay loam soils on the sloping and undulating terrain in the upper reaches of the sub-catchment;
- Moderately deep sandy loam soils lining long stretches of the valley bottoms in the middle reaches of the sub-catchment; and
- Shallow to moderately deep sandy soils in flat and undulating terrain in the lower reaches of the sub-catchment.

Most of the clayey loam soils in the upper parts of the sub-catchment are suitable for irrigation when sufficient water is available. There are two small portions of formal irrigation board control areas in the upper part of the sub-catchment, with two more small irrigation areas in the central reaches. The area along the banks of the Limpopo River is part of a formal irrigation area, and uses water that is pumped either from the bed of the Limpopo River or from boreholes sunk next to the riverbed. Further away from the main river channel, the land use consists almost entirely of small-scale livestock farming as well as the raising of game animals.

A few small towns and several small settlements are present in the upper reaches of the sub-catchment, though population densities decline with increasing distance downstream. The northern and eastern portions of this sub-catchment support large numbers of small-scale subsistence farmers.

4.16.1.4 Surface water users

All of the towns and settlements in the sub-catchment rely on water supplied from numerous small water supply impoundments, or from run-of-river abstraction points and, occasionally (in the lower reaches), from local boreholes. Most of the water used in the sub-catchment is consumed by the extensive formal irrigation along the Laphalala River. The sub-catchment has very unreliable supplies of water and there is little opportunity to expand the irrigated areas without importing additional water supplies (Midgley *et al*., 1999).

The large numbers of subsistence farmers in the northern and eastern portion of the sub-catchment rely on boreholes and hand-dug wells for their water supplies. The Department of Water Affairs and Forestry is undertaking a concerted campaign to provide water supplies to these and other nearby areas in the Mokolo and Mogalakwena sub-catchments in an attempt to alleviate the hardships experienced by these residents.

4.16.1.5 Water management systems

The South African Department of Water Affairs and Forestry (DWAF) is responsible for the management of all aspects of water supply and water use in the sub-catchment. The Department operates a routine system of flow gauging at all water supply dams in the sub-catchment and particular attention is paid to monitoring the quantity of water supplied to irrigation schemes and towns, as well as increasing attention to the quality of agricultural return flows and any effluent discharges to the Laphalala River. Irrigation Boards are locally responsible for providing allocations of water to their members, though they are not responsible for the quality of the water supplied or for the quality of any irrigation return flows that seep back to nearby watercourses.

4.16.1.6 Human impacts on water resources (excluding mining)

The following activities can be expected to have an impact on water resources in the Laphalala sub-catchment:

- Minor seepage from small landfill sites and solid waste disposal sites at towns;
- Disposal of liquid (domestic) effluent at towns;
- Minor volumes of urban runoff from towns;
- Non-point domestic effluent from numerous small settlements and farms;

- Minor non-point impact from non-intensive commercial or subsistence agriculture;
- Non-point impacts of agricultural return flows from intensive irrigation areas; and
- Litter and domestic garbage discarded alongside the roads.

4.16.2 Mining and mineral processing operations

Three mining operations are of interest in this sub-catchment (**Figures 4.2 and 4.3**; **Table 4.17**).

Table 4.17: Mining operations in the Laphalala sub-catchment.

Code Number	Name of Mine	Commodity (ies) Mined	Status	Relative Size	Probable Impact
B7-6	Abbot's Poort	Phosphate	Prospecting	Small	Very low
C7-1	Dorset	Lead	Prospecting	Small	Very low
C7-25	Mooihoek	Tin	Closed	Small	Very low

4.16.3 Alluvial mining

None known or anticipated.

4.16.4 Monitoring systems

The Department of Water Affairs and Forestry (DWAF) conduct routine monitoring of river flows and water quality at a few sites in this sub-catchment. In addition, in accordance with their statutory responsibility, DWAF also regulate the quantity and quality of all effluent discharges through a system of effluent discharge permits or licences. Each licensed effluent discharger is required to carry out a routine monitoring programme of the flow and quality of their effluent and supply this to DWAF. The Department then conducts a randomised series of audit samples to check the veracity of the effluent returns submitted by each discharger.

4.16.5 Water quality data

No specific water quality data for the Laphalala sub-catchment could be obtained in time for this report. In view of the very limited mining activity, this deficiency is not considered to be important.

4.16.6 Implications for water quality and quantity management

The available evidence suggests that the very limited mining activities in this sub-catchment are unlikely to have had any significant impact on either the local water resources or on water quality in the area.

4.17 The Theuniskloof sub-catchment

4.17.1 General description

4.17.1.1 Hydrology

*This sub-catchment consists of the area drained by two small seasonal – episodic streams, and is located between the Laphalala and Mogalakwena sub-catchments (**Figures 4.2 and 4.3**). These two stream systems flow northwards to join the Limpopo River downstream of the Laphalala River (**Figure 4.2**). Flow patterns are very variable as a result of the prevailing low and unpredictable rainfalls (average 380 mm) and the streams normally only contain surface water immediately after rainfalls during the summer months. The sub-catchment contains a few very small farm dams that provide water to livestock (Boroto & Görgens, 1999).*

4.17.1.2 Geology

This small sub-catchment is underlain by a sequence of silicified sandstones and quartzites, accompanied by minor carbon-rich mudstones and shales, and then basalts, of the Karoo Sequence. The sandstones are resistant to weathering and remain as harder outcropping rock formations that stand clear of the surrounding terrain to form small ranges of hills. Quaternary deposits of unconsolidated or poorly consolidated sandy material overlie large areas of the sub-catchment. A few intrusive, diamondiferous kimberlite pipes have been discovered in the area.

4.17.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into two main groups:

- Moderately deep sandy loam soils on the sloping and undulating terrain in the upper reaches of the sub-catchment; and
- Relatively shallow sandy soils in flat and undulating terrain in the lower reaches of the sub-catchment.

The area along the banks of the Limpopo River is part of a formal irrigation area, and uses water that is pumped either from the bed of the Limpopo River or from boreholes sunk next to the riverbed. Further away from the main river channel, the land use consists of small-scale livestock farming and the raising of game animals.

A few small settlements are present in the sub-catchment, though population densities are very low.

4.17.1.4 Surface water users

All of the settlements in the sub-catchment rely on water supplied from local boreholes or run-of-river abstraction points in the bed of the Limpopo River. Most of the water used in the sub-catchment is consumed by irrigation along the banks of the Limpopo River (Midgley *et al*., 1999). The Department of Water Affairs and Forestry is evaluating the need for provision of additional water supplies to the sub-catchment.

4.17.1.5 Water management systems

The South African Department of Water Affairs and Forestry (DWAF) is responsible for the management of all aspects of water supply and water use in the sub-catchment. Due to the absence of surface water supplies in the sub-catchment, the Department does not have any flow gauging or water quality monitoring points in this sub-catchment.

Irrigation Boards are locally responsible for providing allocations of water to their members, though they are not responsible for the quality of the water supplied or for the quality of any irrigation return flows that seep back to nearby watercourses.

4.17.1.6 Human impacts on water resources (excluding mining)

The following activities can be expected to have an impact on water resources in the Theuniskloof sub-catchment:

- Non-point domestic effluent from small settlements and farms;
- Minor non-point impact from subsistence agriculture;
- Non-point impacts of agricultural return flows from irrigation areas; and
- Litter and domestic garbage discarded alongside the roads.

4.17.2 Mining and mineral processing operations

Two mining operations are of interest in this sub-catchment (**Figures 4.2 and 4.3**; **Table 4.18**).

Table 4.18: Mining operations in the Theuniskloof sub-catchment.

Code Number	Name of Mine	Commodity (ies) Mined	Status	Relative Size	Probable Impact
A7-7	The Oaks	Diamond – kimberlite	Operating	Small	Very low
B7-4	Rooikoppie	Iron	Prospecting	Small	Very low

4.17.3 Alluvial mining

None known or anticipated, though alluvial diamonds may be present downstream of The Oaks Diamond Mine.

4.17.4 Monitoring systems

The Department of Water Affairs and Forestry (DWAF) do not carry out any monitoring of river flows or water quality in this sub-catchment because of the scarcity of surface water. However, the department does occasionally monitor the quality of water in local boreholes as part of its national ground water monitoring system.

4.17.5 Water quality data

No water quality data were available for this sub-catchment. In view of the very limited mining activity, this deficiency is not considered to be important.

4.17.6 Implications for water quality and quantity management

The available evidence suggests that the very limited mining activities in this sub-catchment are unlikely to have had any significant impact on either the local water resources or on water quality in the area. Any impact would be likely to consist of a minor increase in suspended solids concentrations during periods of high flow.

4.18 The Mogalakwena sub-catchment

4.18.1 General description

4.18.1.1 Hydrology

*This sub-catchment consists of the area drained by the Mogalakwena River and its tributary streams, notably the Nyl River in the upper reaches. This river system flows northwards from the area around the town of Nylstroom and joins the Limpopo River downstream of the Laphalala River (**Figure 4.2**). The flow pattern in this river is variable as a result of the prevailing low and unpredictable rainfalls (average 540 mm) though the river is normally perennial and only dries up during severe droughts. Summer rainfalls cause a dramatic increase in the flows of this river, though most of the tributary streams are highly seasonal and tend to flow only during the summer months. The Nylsvley wetland is an extremely important wetland in the upper reaches of the catchment and attenuates the flows contributed by the Nyl River to the Mogalakwena River.*

The Mogalakwena sub-catchment contains several hundred small farm dams that are used to supply water for domestic and irrigation purposes, as well as livestock watering (Boroto & Görgens, 1999). These farm dams are responsible for most of the reduced flows that now characterize the Mogalakwena River.

Additional water supplies are piped into the catchment by the Magalies Water Board to meet the growing demand for potable and industrial water in this sub-catchment.

4.18.1.2 Geology

Like the Laphalala sub-catchment, the geological features of the Mogalakwena sub-catchment are relatively complex and consist of several different formations of widely differing ages. Most of the upper reaches of the sub-catchment are underlain by a variety of porous consolidated and partially consolidated sedimentary strata, predominantly sandstones, quartzites and felsites of the Waterberg and Soutpansberg Groups. These have been variously intruded by acidic and basic granites and lavas of the Bushveld Igneous Complex and the Transvaal Sequence, which in turn overlie the crystalline rocks of the Basement Complex.

Further downstream, the sub-catchment is underlain by sequences of silicified sandstones and quartzites, followed by carbon-rich mudstones and shales, and then basalts, of the Karoo Sequence. The sandstones are highly resistant to weathering and stand well above the surrounding undulating terrain to form local mountains or ranges of hills (e.g. Wolkberg Mountain). Erosion-resistant rocks of the Waterberg Group show a similar tendency, standing well clear of the surrounding countryside to form distinctive landscape features.

Large areas of the central parts of the sub-catchment are overlain by recent (Quaternary) deposits of unconsolidated or poorly consolidated sandy material.

4.18.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into four main groups:

- Moderate to deep sandy-clay loam soils on the sloping and undulating terrain in the upper reaches of the sub-catchment;
- Shallow to moderately deep sandy loam soils lining the valley bottoms in the middle reaches of the sub-catchment;
- Shallow to moderately deep sandy soils in flat and undulating terrain in the lower reaches of the sub-catchment; and
- Black to mottled, clay-rich, blocky vertisols (often overlying leached sands) in wetland areas subjected to continuous or seasonal inundation (e.g. Nylsvley).

Most of the clayey loam soils in the upper parts of the sub-catchment are very suitable for irrigation when sufficient water is available. Large stretches of the upper and lower reaches of the Mogalakwena River are under the jurisdiction of formal irrigation boards. In addition, the area along the banks of the Limpopo River is also part of a formal irrigation area, and uses water that is pumped either from the bed of the Limpopo River or from boreholes sunk next to the riverbed. Further away from the main channel of the Mogalakwena River, land use consists almost entirely of small-scale livestock farming as well as game farming.

Several towns and numerous small settlements are located in the upper and middle reaches of the sub-catchment, though population densities are much lower as the Limpopo River is approached. The central and eastern portions of this sub-catchment support very large numbers of small-scale subsistence farmers.

4.18.1.4 Surface water users

All of the towns and settlements in the sub-catchment rely on water supplied from numerous small water supply impoundments, or from run-of-river abstraction points and, occasionally (in the lower reaches), from local boreholes. The extensive areas of irrigation along the Mogalakwena River consume most of the water used in the upper and central reaches of the sub-catchment. The sub-catchment has very unreliable supplies of water and the Magalies Water Board provides additional water supplies via a pipeline from Pretoria.

The large numbers of subsistence farmers in the central and eastern portion of the sub-catchment rely on boreholes and hand-dug wells for their water supplies. The Department of Water Affairs and Forestry is undertaking a concerted campaign to provide water supplies to these and other nearby areas in the Mokolo and Laphalala sub-catchments in an attempt to improve the reliability of their water supplies.

4.18.1.5 Water management systems

The South African Department of Water Affairs and Forestry (DWAF) is responsible for the management of all aspects of water supply and water use in the sub-catchment. The Department operates a routine system of flow gauging at all major water supply dams in the sub-catchment and particular attention is paid to monitoring the quantity of water supplied to irrigation schemes and towns, as well as increasing attention to the quality of agricultural return flows and any effluent discharges to the Mogalakwena River. Extensive surveys of the sub-catchment's ground water potential have been carried out by DWAF so as to facilitate selection of appropriate locations for water supply boreholes.

Irrigation Boards are locally responsible for providing allocations of water to their members, though they are not responsible for the quality of the water supplied or for the quality of any irrigation return flows that seep back to nearby watercourses.

4.18.1.6 Human impacts on water resources (excluding mining)

The following activities can be expected to have an impact on water resources in the Mogalakwena sub-catchment:

- Minor seepage from small landfill sites and solid waste disposal sites at several of the larger towns;
- Disposal of liquid (domestic and some light industrial) effluent at all towns;
- Minor volumes of urban runoff from the larger towns;
- Non-point domestic effluent from numerous small settlements and farms;
- Minor non-point impact from non-intensive subsistence agriculture;
- Non-point impacts of agricultural return flows from intensive irrigation areas; and
- Litter and domestic garbage discarded alongside the extensive road system that traverses the sub-catchment.

4.18.2 *Mining and mineral processing operations*

The following mining operations are of interest in this sub-catchment (**Figures 4.2 and 4.3**; **Table 4.19**).

Table 4.19: Mining operations in the Mogalakwena sub-catchment.

Code Number	Name of Mine	Commodity (ies) Mined	Status	Relative Size	Probable Impact
A7-6	Tolwe	Copper	Prospecting	Very small	Very low
B7-3	Buffelshoek	Lead	Prospecting	Very small	Very low
B7-5	Baltimore	Phosphate	Prospecting	Very small	Very low
B7-14	Potgietersrus Platinum	Platinum	Operating	Medium	Low
B7-15	Bakenberg	Vanadium	Prospecting	Small	Very low
B7-16	Lebowa Granite	Dimension stone	Operating	Medium	Very low
B7-17	Zandrivier	Gold	Operating	Small	Low
C7-2	Vaalkop	Vanadium	Prospecting	Small	Very low
C7-3	Zebediela	Clay minerals	Operating	Small	Very low
C7-9	Naboomspruit Quarry	Dimension stone	Operating	Small	Very low
C7-15	Hartbeesfontein	Fluorspar	Closed	Small	Very low
C7-22	Sterkrivier	Vanadium, Chrome	Prospecting	Small	Very low
C7-26	Union Tin	Tin	Closed	Small	Very low

4.18.3 *Alluvial mining*

None known or anticipated.

4.18.4 *Monitoring systems*

The Department of Water Affairs and Forestry (DWAF) conduct routine monitoring of river flows and water quality at several sites in the Mogalakwena sub-catchment. In addition, in accordance with their statutory responsibility, DWAF also regulate the quantity and quality of all effluent discharges through a system of effluent discharge permits or licences. Each licensed effluent discharger is required to carry out a routine monitoring programme of the flow and quality of their effluent and supply this to DWAF. The Department then conducts a randomised series of audit samples to check the veracity of the effluent returns submitted by each discharger.

4.18.5 *Water quality data*

Water quality data for three sites along the Mogalakwena River (upper, middle and lower reaches of the sub-catchment) were obtained from the Department of water Affairs and Forestry. These data are presented in **Table 4.20**, below.

Table 4.20: Average values for selected water quality constituents in the upper, middle and lower reaches of the Mogalakwena River. (All data presented as mg/litre, except electrical conductivity (milliSiemens/metre) and pH values).

Parameter	**River Reach**		
	Upper	**Middle**	**Lower**
Electrical Conductivity	34.5	26.3	32.0
pH	7.5	7.6	7.9
Total Dissolved Salts	266	216	261
Ca	23	28	25.1
Na	33	14	32.1
K	5.8	2.6	6.4
F	0.3	0.3	0.3
Cl	30	9.6	48.4
SO_4	8.7	4.0	3.4

4.18.6 Implications for water quality and quantity management

The available evidence suggests that the only likely source of any impact on local water resources and water quality would be the Potgietersrus Platinum Mine and its associated processing plants and tailings dams. These impacts would most likely consist of localized acid mine drainage linked to the oxidation of sulphide minerals. In addition, the Rustenburg Platinum Mine and the other operating and closed or abandoned mining operations can be expected to contribute increased quantities of suspended solids to local streams and rivers during and after rainfalls.

4.19 The Setoka-Soutsloot sub-catchment

4.19.1 General description

4.19.1.1 Hydrology

*This sub-catchment consists of the area drained by several small seasonal and episodic streams, and is located between the Mogalakwena and Sand sub-catchments (**Figures 4.2 and 4.3**). These stream systems all flow* *northwards to join the Limpopo River downstream of the Mogalakwena River (**Figure 4.2**). Flow patterns are very variable as a result of the prevailing low and unpredictable rainfalls (average 375 mm) and the streams normally only contain surface water immediately after rainfalls during the summer months. The sub-catchment contains one water supply dam for the Vinetia Diamond Mine and a few very small farm dams that provide water to livestock (Boroto & Görgens, 1999).*

4.19.1.2 Geology

This small sub-catchment is underlain by a sequence of silicified sandstones and quartzites, accompanied by minor carbon-rich mudstones and shales, and then basalts, of the Karoo Sequence. The sandstones are resistant to weathering and remain as harder outcropping rock formations that stand clear of the surrounding terrain to form small, steep-sided ranges of hills. Quaternary deposits of unconsolidated or poorly consolidated sandy material overlie large areas of the sub-catchment. An important diamondiferous kimberlite pipe is located in the area and is being worked (Vinetia Diamond Mine).

4.19.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into two main groups:

- Moderately deep sandy soils on the sloping and undulating terrain in the upper reaches of the sub-catchment; and
- Relatively shallow, coarse-grained sandy soils and silt deposits in flat and undulating terrain in the lower reaches of the sub-catchment, particularly along the flood terraces of streams.

The area along the banks of the Limpopo River is part of a formal irrigation area, and uses water that is pumped either from the bed of the Limpopo River or from boreholes sunk next to the riverbed. Further away from the main river channel, the land use consists of small-scale livestock farming and the raising of game animals. A few small settlements are present, though population densities are very low.

4.19.1.4 Surface water users

All of the farmsteads and settlements in the sub-catchment rely on water supplied from local boreholes or run-of-river abstraction points in the bed of the Limpopo River. Most of the water used in the sub-catchment is consumed by irrigation along the banks of the Limpopo River, though the Vinetia Diamond Mine is also an important water user (Midgley *et al*., 1999).

4.19.1.5 Water management systems

The South African Department of Water Affairs and Forestry (DWAF) is responsible for the management of all aspects of water supply and water use in the sub-catchment. Due to the absence of significant surface water supplies in the sub-catchment, the Department does not have any flow gauging or water quality monitoring points in this sub-catchment. The Vinetia Diamond Mine monitors the quantity and quality of water in their water supply impoundment (water is supplied from boreholes in the bed of the Limpopo River).

Irrigation Boards are locally responsible for providing allocations of water to their members, though they are not responsible for the quality of the water supplied or for the quality of any irrigation return flows that seep back to the Limpopo River.

4.19.1.6 Human impacts on water resources (excluding mining)

The following activities can be expected to have an impact on water resources in the Setoka-Soutsloot sub-catchment:

- Non-point domestic effluent from small settlements and farms;
- Minor non-point impact from subsistence agriculture;
- Non-point impacts of agricultural return flows from irrigation areas; and
- Litter and domestic garbage discarded alongside the roads.

4.19.2 Mining and mineral processing operations

The following mining operations are of interest in this sub-catchment (**Figures 4.2 and 4.3**; **Table 4.21**).

Table 4.21: Mining operations in the Setoka-Soutsloot sub-catchment.

Code Number	Name of Mine	Commodity (ies) Mined	Status	Relative Size	Probable Impact
A7-1	Limpopo Alluvial	Diamond - alluvial	Closed	Very small	Very low
A7-2	Skutwater	Coal	Prospecting	Small	Very low
A7-3	Venetia Alluvial	Diamond – alluvial	Closed	Very small	Very low
A7-4	Venetia	Diamond – kimberlite	Operating	Medium	Low

4.19.3 Alluvial mining

Small-scale alluvial diamond mining activities have been carried out downstream of the Vinetia Diamond Mine in the past.

4.19.4 Monitoring systems

The Department of Water Affairs and Forestry (DWAF) do not carry out any monitoring of river flows or water quality in this sub-catchment because of the scarcity of surface water. However, the Department does occasionally monitor the quality of water in local boreholes as part of its national ground water monitoring system. In addition, the Vinetia Diamond Mine is required to submit regular returns to the Department showing the quantity and quality of water abstracted from the bed of the Limpopo River and the results of seepage control monitoring.

4.19.5 Water quality data

No specific water quality data for the Setoka-Soutsloot sub-catchment could be obtained in time for this report.

4.19.6 Implications for water quality and quantity management

The available evidence suggests that the very limited mining activities in this sub-catchment are unlikely to have had any significant impact on either the local water resources or on water quality in the area. Any impact would be likely to consist of a minor increase in suspended solids concentrations during periods of high flow.

4.20 Mining operations in the Sand sub-catchment

4.20.1 General description

4.20.1.1 Hydrology

*This sub-catchment consists of the area drained by the Sand River and its tributary streams, notably the Brak, Hout, Dwars and Dorp rivers in the upper and middle reaches. As the names of some tributaries imply, they usually contain little or no water. This river system flows northwards from the area around the town of Pietersburg and joins the Limpopo River close to the town of Messina (**Figure 4.2**). The flow pattern in this river is highly variable as a result of the prevailing low and unpredictable rainfalls (average 480-500 mm) and the river is not normally perennial. During drought periods, the Sand River may remain without surface water for periods of several consecutive months. Summer rainfalls cause a dramatic increase in the flows of this river, though most of the tributary streams are highly seasonal.*

The Sand sub-catchment contains over 700 small farm dams that are used to supply water mainly for livestock watering purposes (Boroto & Görgens, 1999). These farm dams are responsible for most of the reduced and episodic flows that now characterize the Sand River and its tributaries.

The Department of Water Affairs and Forestry has completed the feasibility studies aimed at transferring water to the Sand sub-catchment from the middle reaches of the Olifants River to the southeast, and from the upper reaches of the Levuvhu River located to the east of the Sand River (**Figure 4.2**).

4.20.1.2 Geology

Like the Mogalakwena sub-catchment, the geological features of the Sand sub-catchment are relatively complex and consist of several different formations of widely differing ages. A variety of acidic, intrusive granites and gneisses of the Sand River Formation underlie most of the upper reaches of the sub-catchment. Younger consolidated and silicified sedimentary strata, predominantly sandstones and quartzites of the Soutpansberg Group have in turn intruded these.

Further downstream, the sub-catchment is underlain by sequences of silicified sandstones and quartzites of the Soutpansberg Group, followed by carbon-rich mudstones and shales, and then basalts, of the Karoo Sequence. The sandstones are highly resistant to weathering and stand well above the surrounding undulating terrain to form local mountains or ranges of hills (e.g. the Soutpansberg Mountains). Erosion-resistant rocks of the Soutpansberg Group tend to stand well clear of the surrounding countryside to form distinctive landscape features.

Large areas of the central parts of the sub-catchment are overlain by recent (Quaternary) deposits of unconsolidated or poorly consolidated sandy material.

4.20.1.3 Pedology, agriculture and land use

The soils in the Sand sub-catchment can be divided into four main groups:

- Moderately shallow to deep sandy-clay loam soils on the sloping and undulating terrain in the upper reaches of the sub-catchment;
- Shallow to moderately deep sandy loam soils lining the valley bottoms in the middle reaches of the sub-catchment;
- Shallow sandy soils in foothill areas and on flat and undulating terrain in the lower reaches of the sub-catchment; and
- Clay-rich, blackish soils with a high sodium content lining internal drainage areas and with dispersive characteristics.

Most of the clayey loam soils in the upper parts of the sub-catchment would be suitable for irrigation if sufficient water were available. Two relatively small areas in the upper and lower portions of the Sand River sub-catchment are under the jurisdiction of formal water control boards or irrigation boards. In addition, the area along the banks of the Limpopo River is also part of a formal irrigation area, and uses water that is pumped either from the bed of the Limpopo River or from boreholes sunk next to the riverbed. Further away from the main channel of the Sand River, land use consists almost entirely of subsistence rain-fed cultivation of drought-resistant crops, small-scale livestock farming and game farming.

Several large towns and numerous small settlements are located in the upper and middle reaches of the sub-catchment, including the City of Pietersburg, capital of the Northern Province. However, population densities decline rapidly in the area to the north of the town of Louis Trichardt and the Soutpansberg Mountains, until the town of Messina is reached close to the Limpopo River. The upper and central portions of this sub-catchment support very large numbers of small-scale subsistence farmers.

4.20.1.4 Surface water users

All of the cities, towns and settlements in the Sand sub-catchment rely on water supplied from numerous small water supply impoundments, or from run-of-river abstraction points and, occasionally (in the lower reaches), from local boreholes. These water supplies are supplemented by water transferred into the sub-catchment from the Olifants River and from the headwaters of the Levuvhu River. The relatively small areas of irrigation consume a significant proportion of the water used in the upper and lower-central reaches of the sub-catchment.

Most of the large numbers of subsistence farmers in the upper and central portions of the sub-catchment rely on boreholes and hand-dug wells for their water supplies. The Department of Water Affairs and Forestry is undertaking a concerted campaign to provide water supplies (usually ground water via boreholes) to these residents in an attempt to improve the reliability of their water supplies.

4.20.1.5 Water management systems

The South African Department of Water Affairs and Forestry (DWAF), through its Provincial office in Pietersburg, is responsible for the management of all aspects of water supply and water use in the sub-catchment. The Department operates a routine system of flow gauging at all major water supply dams in the sub-catchment and particular attention is paid to monitoring the quantity of water supplied to irrigation schemes and towns, as well as increasing attention to the quality of agricultural return flows and any effluent discharges to the Sand River. Extensive surveys of the sub-catchment's ground water potential have been carried out by DWAF so as to facilitate selection of appropriate locations for water supply boreholes.

Irrigation Boards are locally responsible for providing allocations of water to their members, though they are not responsible for the quality of the water supplied or for the quality of any irrigation return flows that seep back to nearby watercourses.

4.20.1.6 Human impacts on water resources (excluding mining)

The following activities can be expected to have an impact on water resources in the Sand sub-catchment:

- Minor seepage from landfill sites and solid waste disposal sites at several of the larger towns and cities;
- Disposal of liquid (domestic and some light industrial) effluent at all towns;
- Minor volumes of urban runoff from the larger towns;
- Non-point domestic effluent from numerous small settlements and farms;

- Minor non-point impact from non-intensive subsistence agriculture;
- Non-point impacts of agricultural return flows from intensive irrigation areas; and
- Litter and domestic garbage discarded alongside the extensive road system that traverses the sub-catchment.

4.20.2 Mining and mineral processing operations

The following mining operations are of interest in this sub-catchment (**Figures 4.2 and 4.3**; **Table 4.22**).

Table 4.22: Mining operations in the Sand sub-catchment.

Code Number	Name of Mine	Commodity (ies) Mined	Status	Relative Size	Probable Impact
A8-5	Messina Copper	Copper	Closed	Medium	Low-Medium
A8-6	Baobab Vermiculite	Vermiculite	Operating	Small	Very low
A7-5	Soutpansberg Salt	Salt	Operating	Medium	Low-Medium
B7-1	Goetgedacht	Vermiculite	Prospecting	Small	Very low
B7-2	Potgietersrand	Tin	Prospecting	Very small	Very low
B7-7	Bandelierkop	Corundum	Operating	Very small	Very low
B7-9	Mangata alluvial	Gold	Artisan (few)	Very small	Low, some As
B7-10	Kolkbank alluvial	Gold	Artisan (few)	Very small	Low, some As
B7-11	Fort Klipdam	Silicon	Operating	Small	Very low
B7-12	Witkop Silica	Silicon	Operating	Medium	Very low

4.20.3 Alluvial mining

A few small-scale alluvial gold mining activities occur in this sub-catchment.

4.20.4 Monitoring systems

The Department of Water Affairs and Forestry (DWAF) Regional office in Pietersburg carries out routine monitoring of river flows and water quality in this sub-catchment, as well as other sub-catchments in the Northern Province. In addition, the Department also monitors the quality of water in local boreholes as part of its national ground water monitoring system. All industries are required to submit regular returns to the Department showing the quantity and quality of water used and the results of all effluent discharge and seepage control monitoring.

4.20.5 Water quality data

Water quality data for three sites along the Sand River (middle, lower-middle and lower reaches of the sub-catchment) were obtained from the Department of water Affairs and Forestry. These data are presented in **Table 4.23**, below.

Table 4.23: Water quality data (median and 95th percentile values) for three sites along the Sand River. All values are in mg/litre except and electrical conductivity (milliSiemens/metre), and pH.

Parameter	River Reach		
	Middle	**Lower-Middle**	**Lower**
pH	7.67 - 8.48	7.05 - 8.03	7.65 - 8.30
Electrical Conductivity	59.1 - 115.2	9.5 - 39.1	59.0 - 79.3
Ca	28.2 - 62	6.2 - 22	31.2 - 41.8
Mg	21.2 - 54	3.4 - 12.9	20.2 - 27.2
Na	46.5 - 125.3	5.3 - 32.8	55.1 - 81.4
K	4.2 - 7.1	0.9 - 4.2	4.5 - 5.5
Total alkalinity ($CaCO_3$)	172 - 345	26.7 - 117.2	159.9 - 192.4
Cl	54.6 - 178.1	10.3 - 33.9	66.5 - 112.7
F	0.23 - 0.43	0.08 - 0.26	0.27 - 0.43
Si	9.4 - 13.3	7.7 - 9.9	9.73 - 12.08
SO_4	12.5 - 40.9	3.6 - 10.7	14.7 - 34.3
NH_4-N	0.06 - 0.21	0.05 - 0.12	0.05 - 0.21
NO_3-N	0.02 - 0.45	0.06 - 0.35	0.02 - 0.35
PO_4-P	0.03 - 0.11	0.01 - 0.05	0.03 - 0.08

These data (**Table 4.23**) show that the Sand River water is moderately mineralised and is subject to enrichment by plant nutrients (nitrogen and phosphorus), probably as a result of agricultural return flows and discharges of treated sewage effluent. The concentration ranges of the normal water quality parameters indicate that the water is generally of a good quality and fit for most uses except irrigation on sensitive soils.

4.20.6 Implications for water quality and quantity management

The available evidence suggests that the very limited mining activities in this sub-catchment are unlikely to have any significant impact on either the local water resources or on water quality in the area. Most impacts would be likely to consist of a minor increase in suspended solids concentrations during periods of high flow following rainfalls. The possible exceptions to this statement would be a possibility of minor acid mine drainage from the abandoned pits and adits of the Messina Copper Mine and the presence of small quantities of arsenic associated with alluvial gold diggings. If these alluvial miners use mercury to separate out the gold, then there is also a risk of mercury contamination.

The Soutpansberg Salt Works extract salt from evaporite deposits located to the south of the town of Louis Trichardt. There is a minor risk of localized ground water contamination in this area.

4.21 The Nzhelele sub-catchment

4.21.1 General description

4.21.1.1 Hydrology

*This sub-catchment consists of the area drained by the Nzhelele and Tshipise rivers and their small tributary streams. These two small rivers flows almost due northwards from the northern slopes of the Soutpansberg Mountains to the Limpopo River, downstream of the town of Messina (**Figure 4.2**). The flow patterns in these rivers are highly variable as a result of the prevailing low and unpredictable rainfalls (average 350-400 mm) and the rivers are not normally perennial. During drought periods, both rivers may remain without surface water for periods of several consecutive months. Summer rainfalls cause a dramatic increase in flows, though the tributary streams are episodic and only contain water after rainfalls.*

The Nzhelele sub-catchment contains two large dams and over 80 smaller dams that are used to supply water mainly for domestic use and livestock watering purposes (Boroto & Görgens, 1999). These dams are responsible for most of the reduced and episodic flows in the lower reaches of the Nzhelele and Tshipise rivers.

A strongly flowing thermal spring is located at Tshipise and forms the centre of a resort development there.

4.21.1.2 Geology

Similar to the northern parts of the Sand River sub-catchment, the geological features of the Nzhelele sub-catchment consist of several different formations of widely differing ages. A variety of acidic, intrusive granites and gneisses of the Sand River Formation underlie the uppermost reaches of the sub-catchment, whilst younger consolidated and silicified sedimentary strata, predominantly sandstones and quartzites of the Soutpansberg Group have in turn intruded these to form the spectacular, steep-sided hills and mountains of the eastern limb of the Soutpansberg Mountains.

Further downstream, the sub-catchment is underlain by sequences of silicified sandstones and quartzites of the Soutpansberg Group, followed by carbon-rich mudstones and shales, and then basalts, of the Karoo Sequence. Compact sedimentary extrusive and intrusive rocks of the Beit Bridge Complex mark the position of the Limpopo Mobile Belt, underlying the northern part of the catchment closest to the Limpopo River.

Large areas of the central and northern parts of the sub-catchment are overlain by recent (Quaternary) deposits of poorly consolidated sandy material.

4.21.1.3 Pedology, agriculture and land use

The soils in the Nzhelele sub-catchment can be divided into three main groups:

- Moderately deep sandy-clay loam soils on the tops of the hill slopes and undulating terrain in the uppermost reaches of the sub-catchment;
- Shallow to moderately deep sandy soils lining the valley bottoms in the middle reaches of the sub-catchment; and
- Small areas of clay-rich soils with a high sodium content lining internal drainage areas close to the Limpopo River, and having dispersive characteristics.

Most of the sandy-clay loam soils in the upper parts of the sub-catchment fall within a zone of higher rainfall and support extensive plantation forestry activities. The sub-catchment is under the jurisdiction of a formal water control a board board that is responsible for irrigation water allocations from the two storage reservoirs. In addition, the area along the banks of the Limpopo River is also part of a formal irrigation area, and uses water that is pumped either from the bed of the Limpopo River or from boreholes sunk next to the riverbed. Several areas of intensive (irrigated) cultivation of drought-resistant crops such as cotton are located within the irrigation areas. Further away from the main channel of the Nzhelele and Tshipise rivers, land use consists almost entirely of subsistence rain-fed cultivation of drought-resistant crops, small-scale livestock farming and game farming.

Several large and small settlements are located in the upper and middle reaches of the sub-catchment. The central portion of this sub-catchment also supports large numbers of small-scale subsistence farmers.

4.21.1.4 Surface water users

Most of the water used in the sub-catchment is consumed by irrigation in the central and lower reaches of this sub-catchment (Midgley *et al*., 1999). Most farms and settlements in the sub-catchment rely heavily on water supplied from local boreholes and small farm dams. The hot spring resort at Tshipise uses water obtained directly from the thermal spring and other (cooler) springs in the area.

4.21.1.5 Water management systems

The South African Department of Water Affairs and Forestry (DWAF), through its Provincial office in Pietersburg, is responsible for the management of all aspects of water supply and water use in the sub-catchment. The Department operates a routine system of flow gauging at the two major water supply dams in the sub-catchment and particular attention is paid to monitoring the quantity of water supplied to irrigation schemes and towns, as well as increasing attention to the quality of agricultural return flows to the Nzhelele and Tshipise rivers. Some surveys of the sub-catchment's ground water potential have been carried out by DWAF so as to facilitate selection of appropriate locations for water supply boreholes.

Irrigation Boards are locally responsible for providing allocations of water to their members, though they are not responsible for the quality of the water supplied or for the quality of any irrigation return flows that seep back to nearby watercourses.

4.21.1.6 Human impacts on water resources (excluding mining)

The following activities can be expected to have an impact on water resources in the Nzhelele sub-catchment:

- Minor seepage from solid waste disposal sites at several of the larger settlements;
- Non-point domestic effluent from numerous small settlements and farms;
- Minor non-point impact from non-intensive subsistence agriculture;
- Non-point impacts of agricultural return flows from intensive irrigation areas; and
- Litter and domestic garbage along the roads that traverse the sub-catchment.

4.21.2 Mining and mineral processing operations

The following mining operations are of interest in this sub-catchment (**Figures 4.2 and 4.3**; **Table 4.24**).

Table 4.24: Mining operations in the Nzhelele sub-catchment.

Code Number	**Name of Mine**	**Commodity (ies) Mined**	**Status**	**Relative Size**	**Probable Impact**
A8-1	Limpopo	Nickel, Lead	Closed	Very small	Very low
A8-7	Shangani	Coal	Prospecting	Very small	Very low

4.21.3 Alluvial mining

None known or anticipated.

4.21.4 Monitoring systems

The Department of Water Affairs and Forestry (DWAF) Regional office in Pietersburg carries out irregular monitoring of river flows and water quality in this sub-catchment, as well as some borehole monitoring.

4.21.5 Water quality data

No specific water quality data for this sub-catchment could be obtained in time for this report.

4.21.6 Implications for water quality and quantity management

The available evidence suggests that the very limited mining activities in this sub-catchment are unlikely to have had any significant impact on either the local water resources or on water quality in the area. Any impact would be likely to consist of a minor increase in suspended solids concentrations during periods of high flow following rainfalls.

4.22 Mining operations in the Levuvhu sub-catchment

4.22.1 General description

4.22.1.1 Hydrology

*This sub-catchment consists of the area drained by the Levuvhu River and its main tributary the Mutale River, together with a variety of smaller tributary streams. The Levuvhu and Mutale rivers flows north-eastwards from the north-eastern slopes of the Soutpansberg Mountains to the Limpopo River, joining the Limpopo River at Crooks Corner where the borders of South Africa, Mozambique and Zimbabwe meet (**Figure 4.2**). The flow patterns in these two rivers are fairly variable as a result of the prevailing unpredictable rainfalls, though the upper reaches of the sub-catchment receive over 1,000 mm of rainfall per year. There is an extremely steep gradient in rainfall from the upper reaches of the sub-catchment to the Limpopo River where annual rainfalls average some 250 mm per year. Both the Mutale and the Levuvhu rivers are normally perennial, though the Levuvhu River has been extensively exploited and now contains very little water. During drought periods, the lower reaches of both rivers may stop flowing for periods of several months. Summer rainfalls cause a dramatic increase in flows, though the tributary streams are episodic and only contain water after rainfalls.*

The Levuvhu sub-catchment contains four large dams and over 180 smaller dams that are used to supply water mainly for domestic use and livestock watering purposes (Boroto & Görgens, 1999), as well as some water that is transferred out of this sub-catchment into the Sand sub-catchment. In addition, the Venda sacred lake, Lake Fundudzi, is located on the upper reaches of the Mutale River.

4.22.1.2 Geology

The geological characteristics of the Levuvhu sub-catchment share several similarities with neighbouring sub-catchments to the west. A variety of acidic, intrusive granites and gneisses of the Sand River Formation underlie the uppermost reaches of the sub-catchment, whilst younger consolidated and silicified sedimentary strata, predominantly sandstones and quartzites of the Soutpansberg Group have in turn intruded and overlain these to form the spectacular, steep-sided hills and mountains of the eastern limb of the Soutpansberg Mountains, located in the headwaters of this sub-catchment.

Further downstream, the sub-catchment is underlain by sequences of silicified sandstones and quartzites of the Soutpansberg Group, followed by carbon-rich mudstones, shales and basalts, of the Karoo Sequence. Compact sedimentary extrusive and intrusive rocks of the Beit Bridge Complex mark the position of the highly mineralised Limpopo Mobile Belt, underlying the northern part of the catchment closest to the Limpopo River.

Recent (Quaternary) deposits of semi consolidated sandy material overlie large areas of the central and northern parts of the sub-catchment.

4.22.1.3 Pedology, agriculture and land use

The soils in the Levuvhu sub-catchment can be divided into three main groups:

- Moderately deep, red-coloured sandy-clay loam soils on the tops of the hill slopes and undulating terrain in the uppermost reaches of the sub-catchment;
- Shallow to moderately deep, reddish to tan coloured sandy soils lining the valley bottoms in the middle reaches of the sub-catchment; and
- Small areas of clay-rich, blackish or mottled soils with a high organic content covering flood terraces close to the lower reaches of the Levuvhu River and the Limpopo River; in some parts (e.g. the Pafuri Floodplain, these soils have a high sodium content and dispersive characteristics).

Most of the sandy-clay loam soils in the upper parts of the sub-catchment fall within a zone of higher rainfall and support extensive plantation forestry activities. The sub-catchment is under the jurisdiction of a formal water control a board that is responsible for irrigation water allocations from the four storage reservoirs. Further away from the main channels of the Mutale and Levuvhu rivers, land use consists almost entirely of subsistence rain-fed cultivation of drought-resistant crops and small-scale livestock farming.

The overall pattern of land use in the Levuvhu sub-catchment is relatively complex, and includes towns, collected or grouped (but not collective) villages and settlements, traditional family units, commercial and subsistence cropping of cultivated lands, natural forests and forest plantations, Nature Reserves and National Parks (the northern portion of the Kruger National Park).

Land use in the upper reaches of the sub-catchment comprises mainly commercial framing and large plantation forestry estates, with natural forests on the watershed dividing the Mutale and Levuvhu catchments. The town of Louis Trichardt located on the sub-catchment boundary to the west is the main service and industrial centre for the upper portion of the sub-catchment.

In the central reaches of the sub-catchment, the predominant land use consists of groups of villages serving nearby collected (but not collective) agricultural plots. This development hinges around the rapidly expanding urban centre of Thohoyandou, which is located close to the Levuvhu River. The central portion of the sub-catchment is also used extensively for small and large livestock rearing. Further to the east, there is a transition in land use from villages and agricultural plots to traditional single-family subsistence agriculture. In the lowermost reaches of the sub-catchment, land use is entirely devoted to conservation in Nature Reserves and the Kruger National Park.

The Tshikondeni Colliery is located close to the lower reaches of the Levuvhu River, whilst several closed and abandoned mines, as well as alluvial diamond prospecting areas, are located closer to the Limpopo River.

4.22.1.4 Surface water users

Most of the water used in the sub-catchment is consumed by formal (large-scale) and small-scale irrigation in the central reaches of the Levuvhu River and Mutale River (Midgley *et al*., 1999). Most farms and settlements that are locate away from river channels in the sub-catchment rely heavily on water supplied from local boreholes and small farm dams. Livestock are watered at small natural springs on the hill slopes or at watering points along the river channels.

The large urban centre of Thohoyandou is one of the largest water users in the sub-catchment, with water being supplied to domestic users as well as a wide variety of light industries. A relatively small volume of water is transferred from this sub-catchment to the Sand sub-catchment to supplement water supplies to the town of Louis Trichardt.

4.22.1.5 Water management systems

The South African Department of Water Affairs and Forestry (DWAF), through its office in Thohoyandou, is responsible for the management of all aspects of water supply and water use in the Levuvhu sub-catchment. The Department operates a routine system of flow gauging at the four major water supply dams in the sub-catchment and particular attention is paid to monitoring the quantity of water supplied to irrigation schemes, towns and the Tshikondeni Colliery. Some surveys of the sub-catchment's ground water potential have been carried out by DWAF so as to facilitate selection of appropriate locations for water supply boreholes.

Irrigation Boards are locally responsible for providing allocations of water for irrigation, though they are not responsible for the quality of the water supplied or for the quality of any irrigation return flows that seep back to nearby watercourses.

4.22.1.6 Human impacts on water resources (excluding mining)

The following activities can be expected to impact on water resources in the Levuvhu sub-catchment:

- Minor seepage from solid waste disposal sites (rubbish dumps) at the towns and most larger settlements;
- Discharge of effluent (domestic and light industrial) from Thohoyandou;
- Non-point domestic effluent from numerous small settlements and farms;
- Minor non-point impact from non-intensive subsistence agriculture;
- Non-point impacts of agricultural return flows from intensive irrigation areas; and
- Litter and domestic garbage along the roads that traverse the sub-catchment.

4.22.2 Mining and mineral processing operations

The following mining operations are of interest in this sub-catchment (**Figures 4.2 and 4.3**; **Table 4.25**).

Table 4.25: Mining operations in the Levuvhu sub-catchment.

Code Number	Name of Mine	Commodity (ies) Mined	Status	Relative Size	Probable Impact
A8-2	Mutale	Pegmatite minerals	Abandoned	Small	Very low
A8-3	Pafuri	Graphite	Abandoned	Very small	Very low
A8-4	Tshikondeni	Coal	Operating	Medium	Low-Medium
A8-8	Nyala	Magnesite	Operating	Small	Very low

4.22.3 Alluvial mining

None known, though alluvial diamond deposits are understood to be present along the lower reaches of the Limpopo River adjacent to this sub-catchment.

4.22.4 Monitoring systems

The Department of Water Affairs and Forestry (DWAF) Regional office in Pietersburg carries out irregular monitoring of river flows and water quality in this sub-catchment, as well as limited monitoring of a few boreholes.

4.22.5 Water quality data

Water quality data for two sites along the Mutale River (middle and lower reaches) and one site of the Levuvhu River (lower reaches) were obtained from the Department of water Affairs and Forestry. These data are presented in **Table 4.26**.

Table 4.26: Average annual values of a range of water quality characteristics at three DWAF sampling sites on the Mutale and Levuvhu rivers, Levuvhu sub-catchment. (Data derived from DWAF water quality records; all values are given in mg/litre unless otherwise stated).

Water Quality Constituent	Sampling Site		
	Middle Mutale (A9H004)	Lower Mutale (A9H008)	Lower Levuvhu (A9H010)
PH (log units)	6.85	7.90	7.78
Electrical conductivity (mS/m)	7.4	12.9	15.8
Total Dissolved Salts	48	95	99
Ca	4.6	10.1	10.3
Mg	2.7	5.4	5.7
Na	5.2	7.6	10.5
K	0.26	2.12	1.17
Total Alkalinity (mg $CaCO_3$)	19.4	46.6	41.1
Cl	8.4	8.8	18.3

SO_4	3.5	4.2	3.8
F	0.05	0.12	0.11
Si	5.03	6.94	4.81
NH_4-N	0.05	0.05	0.07
NO_3-N	0.14	0.40	0.08
PO_4-P	0.011	0.017	0.016

These water quality data (**Table 4.26**) indicate that water quality in both the Mutale and Levuvhu rivers is relatively good, though that of the Levuvhu River can be considered to be marginally poorer. This is a reflection of the intensive and extensive patterns of land use along the banks of the Levuvhu River.

4.22.6 Implications for water quality and quantity management

The available evidence suggests that the very limited mining activities in this sub-catchment are unlikely to have had any significant impact on either the local water resources or on water quality in the area. Any impact would be likely to consist of a minor increase in suspended solids concentrations during periods of high flow and, possibly, minor acid mine drainage with lower pH values and higher dissolved salts concentrations from the Tshikondeni Colliery.

4.23 Summary of impacts of mining operations on water resources and water quality in the Limpopo basin

The wide variety of mining operations and mineral processing activities located within the Limpopo basin have differing degrees of impact on both the water resources available to other users and on the water quality of these resources. From the available data, it seems clear that those mining operations that are located within low rainfall regions of the basin (where physical weathering processes predominate) have relatively low and/or localized impacts on the water resources. In contrast, mining operations located in the wetter regions of the basin where chemical weathering processes predominate tend to have far more extensive impacts. This seems to be due to the presence of ample moisture within the soil profile that enables continual chemical changes to take place and allows the water available to mobilize and transport the different contaminants that become available.

A summarized overview of the actual and anticipated impacts of mining operations and mineral processing plants in each sub-catchment of the Limpopo basin is given in **Table 4.27**. This information provides a useful impression that could be used to focus water resource management plans and water quality management plans in the different component areas of the Limpopo basin.

5. THE OLIFANTS CATCHMENT

In order to provide a suitable background for subsequent descriptions of the impacts of mining on water resources in the Olifants basin, this section starts with a brief overview of the catchment characteristics. This is then followed by condensed descriptions of the information relating to mining activities and their impacts in each sub-catchment.

The Olifants basin is actually a sub-catchment of the Limpopo basin but has been treated separately in this report. As a result, the figures used in this report for the catchment area, runoff, and population of the Limpopo basin exclude the relevant details for the Olifants basin that are given here.

5.1 Introduction

The Olifants River is a very important river in southern Africa and its basin comprises portions of two SADC states (Mozambique and South Africa; **Table 5.1**; **Figure 1.1**), and forming the largest sub-basin of the Limpopo system (**Figures 4.2 and 4.3**). The Olifants basin is located between 22.5 ° and 26.5 ° South latitude and between 28.5 ° and 324.8 ° East longitude, with a total area of approximately 87,000 km^2, comprising roughly 4.3% of the total area of the two basin states. The area contributed to the basin by each state varies between 1.6% (Mozambique) and 6.1% (South Africa; **Table 5.1**).

Table 5.1: Area statistics for the two SADC states comprising the Olifants basin [Data obtained from Midgley *et al*. (1995) and Boroto & Görgens (1999)].

Country	Total Area of Country (km^2)	Country Area in Basin (km^2)	Proportion of Country Area (%)	Proportion of Basin Area (%)
Mozambique	801,590	12,600	1.6	14.5
South Africa	1,219,912	74,400	6.1	85.5
Totals:	2,021,502	87,000	4.3	100.0

The Olifants River has a relatively dense network of tributary streams and rivers, though most of the tributaries in the lower reaches of the catchment only have either seasonal or episodic flows. In historical times, the Olifants River was considered to be a strong-flowing perennial river but is now regarded as a weakly perennial river where flows frequently cease and, during drought periods, flows may be hardly discernable over large stretches of the lower reaches of the river.

The Olifants basin encompasses an important ecological transition zone that marks the junction of four separate bio-climatic regions. The area is considered to be very important in terms of the diversity of its fauna and flora and also contains several important conservation areas. In addition, the Olifants basin supports a very large population, including some of the region's poorest rural communities, as well as numerous urban areas and farming communities and important forestry areas.

5.1.1 Geology, topography and soils

The Olifants basin is located over the eastern lobe of the Kalahari Craton, forming the largest sub-basin of the Limpopo basin. The Archaean Craton rocks comprise predominantly crystalline granitic and gneissic rocks, intruded by various Greenstone belts as well as dolerite dykes and sills, and silicified sedimentary formations. Karoo System rocks overlie large areas of the southwestern portion of the basin and these are also associated with younger sedimentary and crystalline rocks consisting predominantly of sandstones, carbon-rich mudstones, conglomerates and shales. Recent sedimentary deposits line most of the river valleys and provide important farming areas (Du Toit, 1960).

In the western (South African) portion of the Olifants basin, the Bushveld Igneous Complex forms an extremely important feature and contains a very large proportion of the region's mineral wealth. The geological features of this area consist mostly of basic mafic and ultramafic intrusive rocks, accompanied by extensive areas of acidic and intermediate intrusive rocks. At the southern and eastern periphery of this area, large dolomite and limestone formations occur, accompanied by extensive mineralization along their contact zones. Several areas of the northern portion of the Olifants basin consist of various deposits of consolidated and unconsolidated sedimentary rocks, with important belts of intrusive Greenstone rocks that are heavily mineralised.

The north-south trending rhyolites and lavas of the Lebombo Mountains mark the eastern border between South Africa and Mozambique, and separate the South African and Mozambican portions of the basin. The eastern (Mozambique) portion of the Olifants basin consists largely of unconsolidated and consolidated sedimentary rocks with granitic intrusions exposed as erosional remnants in the landscape

In the southern portion of the basin, the extensive, carbon-rich sedimentary rocks of the Karoo System contain enormous economic reserves of coal and are the site of intensive coal mining activities. Elsewhere, and particularly prominent in the northern and eastern parts of the basin, harder, silicified sandstones and cherts, as well as syenitic and granitic outcrops, form stack-like erosional remnants that protrude above the generally undulating terrain (Du Toit, 1960).

The topography of the Olifants basin is extremely varied, ranging from approximately 150 metres above sea level where it joins the Limpopo River in Mozambique, to over 2,000 metres in the mountainous region marking the transverse position of the northern extension of the Drakensberg Mountains. Most of the basin consists of relatively undulating terrain separated by ranges of steep-sided hills and mountains. The northeastward flowing Olifants River and its major tributaries have incised deep gorges through the hills and mountain ranges that form spectacular landscape units. Generally, the river valleys tend to be broad and flat-bottomed, with river channels that are slightly or moderately incised into the surrounding parent material.

Several small sections of the northeastern parts of the Olifants basin (especially in the Shingwedzi and Letaba sub-catchments) have very little or poor drainage, and are usually considered to be endorheic (internally draining). These areas are often marked by the formation of clay-bottomed pans where rainfall collects and evaporates to leave small deposits of salts. The drier northern and eastern portions of the Olifants basin are generally subjected to mechanical (physical) weathering processes, in contrast to the predominance of chemical weathering processes in the wetter headwater regions of most tributaries.

Soil formations across the Olifants basin reflect the strong influence of underlying parent rock material, climatic features and biological activity. The dominant soil types in the basin are moderately deep sandy to sandy-clay loams in the west and south, grading to shallower, sandy or gravely soils in the north and east. The deeper loam soils are extremely important for agricultural activities and support extensive irrigation developments along the Olifants River as well as many of its tributaries. A few areas of black vertisols in the southern and western parts of the basin also support important agricultural developments.

The valley bottom soils along all of the tributary rivers and the Olifants main channel are generally of colluvial or alluvial origin and support extensive areas of commercial and subsistence agriculture. In contrast, hilly or steeply sloping areas tend to have fragile, shallow, stonier soils with less agricultural potential. In the endorheic areas, most soils have a relatively high sodium and clay content and are dispersive.

5.1.2 Climatic features

Because of its geographic position, the prevailing wind systems, including tropical cyclones from the Indian Ocean, have a strong influence on the climate of the Olifants basin. The most important of the rain-bearing winds are the southeasterly wind systems that bring rainfalls from the Indian Ocean. In some years, unusual southward movements of the Inter-Tropical Convergence Zone (ITCZ) have been sufficient to influence rainfalls in the northern parts of the Olifants basin for short periods of time.

Air temperatures across the Olifants basin show a marked seasonal cycle, with hottest temperatures recorded during the early Austral Summer months and lowest temperatures during the cool, dry winter months. Rainfalls are also highly seasonal, falling predominantly as intense convective thunderstorms during the warmer summer months. Rainfalls vary from as little as 400 mm per annum in the eastern parts of the Olifants basin, along the border with Mozambique, to over 1,000 mm per annum on the Drakensberg Mountains. A sketch map showing the distribution of mean annual rainfall over the Olifants and Limpopo basins is shown in **Figure 4.1**; this map also shows the main tributaries of the Olifants River.

Evaporation rates across the Olifants basin are both high and variable, ranging from some 2.4-2.6 metres per annum in the eastern areas of the basin to some 1.7 metres in the cooler, mountainous regions in the southwestern portion of the basin. In view of these evaporation rates, and the quantity of rainfall received each year, several portions of the Olifants basin show clear evidence of the dominance of physical weathering processes (with Weinert N values greater than 5.0). These areas are located predominantly in the eastern and northeastern portions of the basin and along the lower reaches of the Olifants valley. Virtually all of the rest of the Limpopo basin is subject to chemical weathering processes, either seasonally (Weinert N values below 4.0) or continually (Weinert N values below 2.0) (Weinert, 1964).

5.1.3 Population and land use patterns

The total population of the Olifants basin is estimated to be approximately 10.5 Million, with South Africans comprising some 85% of the basin population (**Table 5.2**). The Olifants basin also contains a large proportion of the population of South Africa's Gauteng Province, as well as parts of the populations of the Northern and Mpumalanga Provinces. The Olifants basin contains virtually all of the important coalmines and thermal power stations, as well as critically important agricultural areas, towns and cities. Consequently, the Olifants basin is correctly considered to house the energy heartland of South Africa.

Table 5.2: Population statistics for the two SADC states comprising the Olifants basin. [Data obtained from SARDC (1996) and Basson *et al*. (1997)].

Country	**Total Population of Country (Millions)**	**Country Population in Basin (Millions)**	**Proportion of Country Population (%)**	**Proportion of Basin Population (%)**
Mozambique	19.980	275,000	1.4	87.1
South Africa	43.421	1,850,000	4.3	12.9
Totals:	63.401	2,125,000	3.4	100.0

In Mozambique, the Olifants basin supports several scattered communities and small to moderate-sized settlements, but no towns or cities; the Mozambican population of the Olifants basin is essentially rural in character.

In contrast, the much larger South Africans sector of the Olifants basin supports several large and medium-sized towns as well as numerous smaller communities and subsistence farmers. Throughout the South African portions of the Olifants basin, a wide variety of mining operations as well as different forms of agriculture (subsistence and commercial cultivation, game farming, livestock and dairy production) provide the economic cornerstone for development in the basin.

Both South Africa and Mozambique have "skewed" population distributions, and experience large-scale migration from rural areas to urban settlements. The Olifants basin in South Africa contains areas of extensive rural and peri-urban populations that occupy former Apartheid self-governing "homelands". As a consequence of past iniquities, a large proportion of the basin's population is extremely poor and lack access to basic services and amenities such as clean water and adequate sanitation.

Similar to other parts of southern Africa, land is a critically important resource throughout the Olifants basin and the livelihoods of residents and the national economies of both basin states depend on access to land (Chenje, 2000). However, the specific types of land use that are practiced in the basin are controlled by climatic factors, water availability and, importantly, by land tenure arrangements. A large proportion of the land in the Olifants basin is under communal or customary forms of tenure, and land ownership is considered to be one of the major constraints to proper land use and conservation (Chenje, 2000).

Overcrowding and insecure ownership in the smaller communal farming areas (e.g. the Shingwedzi, Selati, and Middle Olifants sub-catchments in the Olifants basin) is a primary source of land degradation in the basin. This feature is a critically important driver of poverty within the Olifants basin and is associated closely with declining indices of per capita agricultural production (Dalal-Clayton, 1997). In many parts of the Olifants basin, progressive urbanization has been accompanied by the development of peripheral "informal" settlements around the major urban areas.

In stark comparison to the Zambezi Catchment, the South African and Mozambique portions of the Olifants Catchment are relatively densely settled (**Table 5.2**). Whilst the Olifants basin does not contain any very large cities, there are numerous medium- and small-sized towns and villages. In the Mozambique portion of the basin, the population is more evenly spread and the only sizeable groups of people are those associated with irrigation activities near the Massingir Dam and the nearby Chokwe Irrigation Scheme (which is located just outside the Olifants basin).

5.1.4 Hydrological characteristics, water availability and patterns of water use

The quantity and timing of rainfall received in the Olifants basin controls the quantity, timing and duration of flows in the different tributary rivers. The uneven distribution of rainfall in the basin is reflected in the very uneven distribution of water resources in the different sub-catchments. In turn, these influence the types of economic activities undertaken by the residents in each area. The uneven distribution of water across the basin, coupled with increasing competition for the available water resources, has led to tensions and occasional disputes between individuals and communities as to what can be considered as a "fair and equitable share" of the available water resources (Ashton, 2000).

The Olifants River and its larger tributaries all exhibit marked seasonal cyclical patterns of high and low flows and many of the smaller tributaries are entirely seasonal or episodic. In some, drier years, surface flows cease in several tributaries though some water continues to flow in the deeper alluvial deposits. The northern and eastern parts of the basin that receive the lowest rainfalls have many seasonal or episodic rivers that have no surface flow during the dry winter months.

The demand for water throughout the Olifants basin is both high and unevenly spread. In particular, water demands by industry, mining and especially the formal (irrigation) agricultural sector account for over 75% of all water used. Coupled with high evaporation losses from the numerous small dams and larger water supply impoundments, flows in the lower reaches of the Olifants River are usually relatively small, unless they have been "boosted" by the arrival of a tropical cyclone (e.g. the cyclone that arrived in 2000 and flooded large coastal areas of Mozambique).

The escalating competition for water and the continued water shortage in the upper reaches of the Olifants basin prompted the importation of additional water supplies from the Vaal and Komati basins to the south. These water supplies are seen to be essential for continued operation of the many thermal (coal-fired) power stations and their satellite collieries. The overall water supply "picture" is made even more uncertain by the very real possibility that global climate changes will also have an adverse effect on water availability throughout southern Africa (Ashton, 2000).

Throughout the length of the Olifants River and its tributaries, water quality is considered to be generally good and the water is usually fit for most designated uses. However, several areas in the central and lower reaches of the basin experience serious water quality problems due to increasing salinity, making the water less suitable for irrigation purposes and for domestic use. In addition, most cities, towns and smaller communities discharge untreated or partially treated domestic and industrial effluent into the various rivers (e.g. the cities and towns of the Mpumalanga Highveld). As long as the waste material is innocuous and there is sufficient dilution, this practice does not have long-term or large-scale detrimental effects. However, with increasing quantities of effluent and declining river flows due to escalating demands for water, water quality problems now occur more frequently. Water quality problems caused by seepages and effluent discharge tend to become more acute further downstream, as more and more towns contribute their effluent to the total river flow and evaporative concentration accentuates the effects of rising salinity and increasing eutrophication. Seepage losses or discharges of effluent containing potentially toxic compounds compound these problems.

In some sub-catchments where the rivers are normally seasonal and only flow during the wet summer months, effluent discharges and seepage from mining operations have transformed the river into a perennially flowing system. In the case of a river such as the Selati, effluent discharges and seepage now comprises the entire dry season flow of this river and often equal the flow in the lower Olifants River itself.

In addition to water abstracted for domestic use, large volumes of water are also withdrawn for irrigation; for example: the extensive irrigation areas along the main stem of the Olifants River and many of its major perennial tributaries. Most small-scale farmers have to rely either on red-fed agriculture or on water drawn from shallow wells or nearby watercourses. Overall, the competition for the limited water resources available is likely to become more intense in future.

The Olifants basin has been divided into a series of sub-catchments for the purposes of this study; these sub-catchments are shown in **Figures 4.2 and 4.3**.

5.1.5 Water management systems and institutions

Both South Africa and Mozambique have their own water management systems and segments their respective territories into Water Management Units or Water Management Areas. These divisions are normally in the form of sub-catchments, though some of the larger sub-catchments may be further sub-divided.

In the South African sector of the Olifants basin, the South African Department of Water Affairs and Forestry (DWAF) is the authority responsible for all aspects of water resource and water quality management. The Department delegates the responsibility of water supply to communities and industries to Local Authorities or Water Utilities wherever possible. In future, the Department will constitute formal Catchment Management Agencies to deal with all aspects of water resource management and water supply. In Mozambique, the equivalent functions are fulfilled by the Mozambique Department of Water.

The SADC Protocol on Shared Watercourse Systems provides an important legislative instrument that promotes regional co-operation and collaboration amongst all SADC states. However, unequal institutional and professional capacity within the member states hampers full expression of this protocol. Since the Olifants basin is considered to be a sub-basin of the Limpopo basin, South Africa and Mozambique are part of a larger group of four basin states with have jointly formed a Joint Permanent Technical Commission (JPTC) to deal with matters of common interest relating to the Limpopo River and all its tributaries. This Commission deals with matters such as joint flow gauging exercises and inter-basin transfers, as well as dealing with proposed new water development projects by each of the member states. This institutional arrangement appears to work well at an operational level.

Both South Africa and Mozambique maintain their own system of meteorological and hydrological data collection, primarily for use at the national level. Whilst these systems are at very different levels of coverage, the data does enable the basin states to collaborate on monitoring programmes and predict rainfall and runoff in the Olifants basin. Recent improvements in weather radar systems and satellite monitoring systems help to expand and improve the regional coverage.

Nine sub-catchments have been recognized in the South African sector of the Olifants basin, with one additional sub-catchment located in Mozambique. Both flow and water quality data for the South African sector of the Olifants basin are obtainable from the Department of Water Affairs and Forestry (DWAF). No water quality or flow data are available for the Mozambique sector of the Olifants basin.

5.1.6 Mining and mineral processing operations within the Olifants basin

There are a large number of mining operations exploiting a wide variety of minerals in the Olifants basin; the locations of these operations are shown in **Figure 4.2**, whilst the mines located in the South African sector of the Olifants basin are shown in more detail in **Figure 4.3**. In Mozambique, there are no mining operations located within the Olifants basin.

Data on the type of mine, size, operational status and location of mining operations are presented in the respective sections for each sub-catchment, along with inferences on potential impact. The high/medium/low inference for potential impact was arrived at using the criteria in **Table 1.3** and is discussed sub-catchment by sub-catchment in the following sections. A summarizing overview of the actual and potential impacts on water resources and water quality in each sub-catchment of the Olifants basin is given in **Section 5.11**.

In the following portions of this sections of the report that contain descriptions of the mining and mineral processing activities in each sub-catchment, it is important to refer to **Figures 4.2 and 4.3** for the positions of the different sub-catchments within the Olifants basin.

5.2 The Wilge sub-catchment

5.2.1 General description

5.2.1.1 Hydrology

*This sub-catchment consists of the area drained by the Wilge River and its tributary stream, down to the point where the Wilge River joins the Olifants River immediately upstream of the Loskop Dam (**Figure 4.2**). The*

Wilge River drains a relatively small area to the east of Pretoria and, primarily due to the continual release of water from the dolomite and limestone formations, the streams and rivers are all perennial. Minor discharges of treated domestic effluent from Bronkhorstspruit and Cullinan supplement flows in the Wilge River.

The sub-catchment contains one relatively large water supply dam (Bronkhorstspruit Dam), which supplies domestic and industrial water to the town of Bronkhorstspruit, as well as irrigation water to the extensive areas of irrigation downstream of the dam. In addition, the sub-catchment has numerous small farm dams that are used to trap runoff in seasonal channels and supply this water for livestock watering.

There are also a very large number of small wetlands located along almost every stream and river in this sub-catchment (Marneweck et al.*, 2001). These are formed at the uphill side of protruding dolerite formations (typically dykes and sills) that dip gently to the south. These dolerite formations act as impermeable barriers and water collects on their uphill sides, saturating the soils. The downstream end of each wetland is usually marked by a dolerite exposure where the water reaches the ground surface and flows over the dolerite barrier. This system of inter-connected wetlands provides an extremely important attenuation mechanism that ensures water is released throughout the year, thereby maintaining perennial stream and river flows in this sub-catchment.*

5.2.1.2 Geology

In the upper reaches of the Wilge River, the geological features are characterized by the presence of extensive dolomite and limestone formations surrounding and a small area of Karoo Supergroup rocks consisting of consolidated layers of carbon-rich shales and intercalated arenaceous strata. Further downstream, centering on the Bronkhorstspruit Dam, the sub-catchment is underlain by large areas of porous unconsolidated and semi-consolidated sedimentary strata, principally quartzitic sandstones, and an area of Dwyka tillite. Close to the confluence of the Wilge and Olifants rivers, a small area of acidic and intermediate intrusive granites of the Waterberg Group underlies the northern portion of this sub-catchment.

The dolomite and limestone formations provide excellent aquifer characteristics and overly thick layers of carbon-rich dolerites and shales of the Karoo Supergroup.

5.2.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into five main groups:

- Moderate to deep sandy loam soils on flat and undulating terrain overlying dolomite and limestone in the upper reaches of the catchment;
- Moderate to deep sandy loam soils lining long stretches of the Wilge River valley in its middle reaches;
- Moderate to deep clay loam soils over much of the middle portions of the sub-catchment (located away from the river channels), overlying the more porous unconsolidated sedimentary material; and
- Moderately shallow to moderately deep, clayey loam to clay-rich, fine-grained soils over most of the lower reaches of the sub-catchment; and

- Dark grey to blackish, mottled vertisols located along low-gradient reaches of most streams and river sections, forming characteristic wetland soils.

Most of the clayey loam soils are highly suitable for commercial agriculture when sufficient water is available. Virtually all of the areas with suitable soils, particularly the area downstream of the Bronkhorstspruit Dam, are contained within the jurisdiction of formal irrigation boards or Government Water Control Areas. Further away from the main river channels, most of the land use is given over to small- and medium-scale livestock farming operations. A relative small variety of crops are produced on the irrigated and rain-fed areas, primarily maize, Lucerne, potatoes and sunflowers. Minor areas of plantation forestry (principally Wattle) are also located in the wetter portions of the sub-catchment.

Several small towns (e.g. Bronkhorstspruit and Cullinan) and numerous smaller settlements and farming communities are present in the upper reaches of the sub-catchment. Population numbers and density decline with increasing distance from the upper reaches. Some light and heavy industry is present in the town of Bronkhorstspruit, with many industries geared specifically to meeting the needs of the extensive mining sector in the region.

5.2.1.4 Surface water users

All towns in the sub-catchment rely on water supplied from water supply reservoirs, principally the Bronkhorstspruit Dam and, in the case of Cullinan, from the Rand water reticulation system. The larger settlements are also being supplied with water to varying degrees by the Rand Water reticulation system. Smaller settlements and farmsteads rely on boreholes for their water requirements. The Wilge and Kendal thermal power stations are also supplied with water drawn from local water supplies.

The extensive irrigation areas downstream of the Bronkhorstspruit Dam consume most of the water used in the sub-catchment. Extensive informal settlements have sprung up around the periphery of the urban centres; these settlements lack access to basic services such as clean water supplies and suitable sanitation systems.

5.2.1.5 Water management systems

The South African Department of Water Affairs and Forestry (DWAF) is responsible for the management of all aspects of water supply and water use in the sub-catchment. The Department operates a system of routine flow gauging at the Bronkhorstspruit Dam and pays particular attention to monitoring the quantity of water supplied to irrigation schemes and towns, as well as increasing attention to the quality of agricultural return flows and effluent discharges to the Wilge River. The local irrigation board is responsible for the day-to-day management of water allocations for irrigation.

5.2.1.6 Human impacts on water resources (excluding mining)

The following activities can be expected to have an impact on water resources in the Wilge sub-catchment:

- Landfills and solid waste disposal sites at all towns;
- Disposal of liquid (domestic and light industrial) effluent at all towns;
- Disposal or seepage of high salinity power station cooling water;
- Moderate volumes of runoff from towns, as well as all other urbanized areas;
- Non-point domestic effluent from numerous small settlements and farms;
- Minor non-point impact from non-intensive commercial or subsistence agriculture;
- Minor non-point impact of agricultural return flows from intensive irrigation areas; and
- Litter and domestic garbage discarded alongside the many roads and highways that traverse the sub-catchment.

5.2.2 Mining and mineral processing operations

The following mining operations are of interest in the Wilge sub-catchment (**Figures 4.2 and 4.3**; **Table 5.3**).

Table 5.3: Mining operations in the Wilge sub-catchment.

Code Number	Name of Mine	Commodity (ies) Mined	Status	Relative Size	Probable Impact
C7-19	Marble Hall	Limestone / Dolomite	Operating	Medium	Low
D7-2	Pienarsrivier	Limestone / Dolomite	Operating	Small	Very low
D7-4	Vergenoeg	Fluorspar	Operating	Large	Low – Medium
D7-6	Nooitgedacht	Clay minerals	Operating	Large	Low
D7-8	Cullinan	Clay minerals	Operating	Large	Low
D7-10	Belfast	Clay minerals	Operating	Small	Very low
D7-11	Rietfontein	Clay minerals	Operating	Small	Very low
D7-39	Enkeldoring	Gold	Closed	Small	Very low

5.2.3 Alluvial mining

None known or anticipated.

5.2.4 Monitoring systems

The Department of Water Affairs and Forestry (DWAF) regularly monitor flows and water quality at the Bronkhorstspruit Dam, as well as two other sites further downstream. In addition, DWAF also regulate the quantity and quality of all effluent discharges through a system of effluent discharge permits or licences. Each licensed effluent discharger is required to carry out a routine monitoring programme of the flow and quality of their effluent and supply this to DWAF. The Department then conducts a randomised series of audit samples to check the veracity of the effluent returns submitted by each discharger.

5.2.5 Water quality data

No specific water quality data for this sub-catchment could be obtained in time for this report. In view of the very limited mining activity, this deficiency is not considered to be important.

5.2.6 Implications for water quality and quantity management

The available evidence suggests that the limited mining and quarrying activities carried out in this catchment would be likely to have very minor, localized impacts on the water resources of the sub-catchment. These impacts would be likely to consist of very slight instances of acid mine drainage and an increase in suspended sediment loads in nearby streams and rivers as soil is eroded from exposed areas. There is also a likelihood that seepage of high salinity power station cooling water and seepage from coal ash dumps at the two thermal power stations.

5.3 The Little Olifants - Riet sub-catchment

5.3.1 General description

5.3.1.1 Hydrology

*The hydrological features of this sub-catchment are very similar to those of its eastern neighbour, the Wilge sub-catchment. The Little Olifants - Riet sub-catchment consists of the area drained by the upper reaches of the Olifants, Little Olifants and Riet rivers and their tributary streams, down to the point where the Olifants River joins the Wilge River at the Loskop Dam (***Figure 4.2***). The Olifants, Little Olifants and Riet rivers drain a relatively small area that includes the coal-mining towns of Witbank and Middelburg located to the east of Pretoria. The sub-catchment receives additional water via three inter-basin transfer schemes from the Vaal, Usutu and Komati systems, whilst relatively large discharges of treated domestic and industrial effluent from Witbank and Middelburg supplement flows in the Olifants and Little Olifants rivers. All rivers and streams in this sub-catchment are perennial.*

The sub-catchment contains four water supply dams, one of which (Loskop Dam) also supplies water for the extensive irrigation agriculture areas downstream of this sub-catchment. The other dams all supply domestic and industrial water to the towns of Witbank and Middelburg as well as the numerous collieries and smaller settlements in the sub-catchment. In addition, the sub-catchment has numerous small farm dams that trap runoff in seasonal channels and supply this water for limited livestock watering.

The sub-catchment also contains an enormous number of small wetlands located every stream and river (Marneweck et al.*, 2001). These are formed at the uphill side of protruding dolerite formations (typically dykes and sills) that dip gently to the south. These dolerite formations act as impermeable barriers and water collects on their uphill sides, saturating the soils. The downstream end of each wetland is usually marked by a dolerite exposure where the water reaches the ground surface and flows over the dolerite barrier. This system of inter-*

connected wetlands provides an extremely important attenuation mechanism that ensures water is released throughout the year, thereby maintaining perennial stream and river flows in this sub-catchment. However, mining activities (blasting, ground clearing, overburden stripping, acid mine drainage) have damaged or broken several of these dolerite formations in recent years. This has resulted in increased summer flows, reduced attenuation and therefore lower winter flows, and a steady decline in water quality in downstream reaches (Toerien et al.*, 1980; Johnson & Du Toit, 1997; Hodgson & Krantz, 1999; Marneweck* et al.*, 2001).*

5.3.1.2 Geology

In the upper reaches of the Little Olifants, Riet and Olifants rivers, the geological features consist almost entirely of rocks of the Ecca Group and Dwyka Formation of the Karoo Supergroup. The Ecca Group rocks consist of consolidated layers of silicified sandstone, shale and coal, together with interbedded mudstones, siltstones and shales. The important Witbank and Highveld coal deposits located near to the town of Witbank form the centre of this group. Rocks of the Dwyka Formation, principally tillite, shale and siltstones, underlie the Ecca Group rocks. Extensive dolerite dykes and sills have intruded both of these formations.

The northern part of this sub-catchment is underlain by acid and intermediate intrusive formations of the Waterberg Group, as well as by mafic and ultramafic intrusive formations. Small areas of dolomite and limestone, as well as silicified sandstone are also found in the northern reaches of this sub-catchment.

5.3.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into five main groups:

- Shallow to moderately deep sandy-clay loam soils on flat and undulating terrain overlying rocks of the Ecca Group, principally shales and silicified sandstones, in the upper reaches of the catchment;
- Moderate to deep sandy loam soils lining long stretches of the Olifants River valley in its middle reaches;
- Moderate to deep clay loam soils over much of the lower portions of the sub-catchment (located away from the river channels), overlying the more porous unconsolidated sedimentary material;
- Moderately shallow to moderately deep, clayey loam to clay-rich, fine-grained soils over granitic areas in the lower reaches of the sub-catchment; and
- Dark grey to blackish, mottled vertisols located along low-gradient reaches of streams and river sections in the upper reaches of the sub-catchment, forming characteristic wetland soils.

Most of the soils are highly suitable for commercial agriculture when sufficient water is available. Virtually all of the areas with suitable soils, particularly the area downstream of the Loskop Dam, are contained within the jurisdiction of formal irrigation boards or Government Water Control Areas. Further away from the main river channels, and downstream of the coal mining operations in the upper parts of the sub-catchment, land use is given over to small- and medium-scale livestock farming operations. A relative small variety of crops are produced on the irrigated and rain-fed areas, primarily maize, lucerne, potatoes and sunflowers.

Several towns (e.g. Witbank and Middelburg) and numerous smaller settlements and farming communities are present in the upper reaches of the sub-catchment. Population numbers and density initially decline with increasing distance from the upper reaches, and then increase again in the intensively farmed irrigation areas. Light and heavy industry is present in the towns of Witbank and Middelburg, with many industries geared specifically to meeting the needs of the extensive coal-mining sector in the region.

5.3.1.4 Surface water users

All towns, mines, power stations and industries in the sub-catchment rely on water supplied from water supply reservoirs. Additional water is brought into the sub-catchment via inter-basin transfer schemes from the Komati, Usutu and Vaal systems, principally to meet the large volumes requirements of the eight power stations located in this sub-catchment. Smaller settlements and farmsteads, particularly those in the lower reaches of the sub-catchment, rely on boreholes for their water requirements.

The extensive irrigation areas downstream of the Loskop Dam consume most of the water used in the lower reaches of this sub-catchment. Extensive informal settlements have sprung up around the periphery of the urban centres (e.g. Witbank and Middelburg). These settlements lack access to basic services such as clean water supplies and suitable sanitation systems.

5.3.1.5 Water management systems

The South African Department of Water Affairs and Forestry (DWAF) is responsible for the management of all aspects of water supply and water use in the sub-catchment. The Department operates a system of routine flow gauging at the Loskop Dam, and other water supply dams, and pays particular attention to monitoring the quantity of water supplied to irrigation schemes and towns, as well as increasing attention to the quality of agricultural return flows and effluent discharges to the Wilge River. The irrigation boards are responsible for the day-to-day management of water allocations for irrigation.

Each coalmine and thermal power station also collaborates in the management of their water supplies and in the disposal of their wastes and effluents. At present, no cost-effective cure is available for the problems associated with the extensive acid mine drainage that characterizes seepage and discharges from the collieries in the Witbank and Highveld coal-mining areas. All of the mining companies who are active in this area collaborate actively in joint research programmes to devise solutions for this perennial problem. At the present time, a very ambitious project, named "COALTECH 2020" has been launched to discover alternative ways of dealing with the variety of problems faced by collieries in this area, and to extend the economic lifespan of the mines (Beukes, 2000). This programme involves representatives from 15 international and 15 national organizations, including all the major mining houses, the Department of Water Affairs and Forestry, the Department of Mineral and Energy Affairs, The Department of Environmental Affairs and Tourism, the CSIR and academia (three South African universities). This concerted, collaborative approach has already led to improvements in both the understanding of the various problems and in the management of some of the water problem areas.

5.3.1.6 Human impacts on water resources (excluding mining)

The following activities can be expected to have an impact on water resources in the Little Olifants - Riet sub-catchment:

- Landfills and solid waste disposal sites at all towns;
- Disposal of liquid (domestic, light and heavy industrial) effluent at all towns;
- Seepage from power station ash dumps;
- Disposal or seepage of high salinity power station cooling water;
- Moderate volumes of runoff from towns, as well as all other urbanized areas;
- Non-point domestic effluent from numerous small settlements and farms;
- Minor non-point impact from non-intensive commercial or subsistence agriculture;
- Non-point impact of agricultural return flows from intensive irrigation areas; and
- Litter and domestic garbage discarded alongside the many roads and highways that traverse the sub-catchment.

Examples of the types of effluents that are discharged into this sub-catchment are shown in **Table 5.4**, which list the water quality characteristics of four sewage treatment plant effluents.

Table 5.4: Representative water chemistry data for four major sewage treatment works in the Little Olifants – Riet sub-catchment. (Data taken from Hodgson & Krantz, 1999).

Parameter	**Sewage Works Name**			
	Middelburg	**Naauwpoort**	**Ferrobank**	**Riverview**
PH	7.7	7.9	7.8	7.9
Total Dissolved salts	385	562	618	628
Suspended Solids	1.0	6.4	13.2	11.6
Electrical Conductivity	76	93	96	99
C.O.D.	3.0	53	55	64
Na	-	88	108	96
K	-	15	13	22
SO_4	250	182	249	192
Cl	62	45	54	79
Total Alkalinity	130	182	124	210
NH_4-N	0.6	4.8	9.6	21
NO_3+NO_2-N	4.8	0.1	6.3	0.4
PO_4-N	4.3	2.1	5.8	7.8

These treated sewage effluents will result in eutrophication of the receiving waters and will probably render the water unfit for domestic consumption and irrigation on sensitive soils.

5.3.2 Mining and mineral processing operations

The following mining operations are of interest in the Little Olifants and Riet sub-catchment (**Figures 4.2 and 4.3**; **Table 5.5**).

Table 5.5: Mining operations in the Riet and Little Olifants sub-catchments.

Code Number	Name of Mine	Commodity (ies) Mined	Status	Relative Size	Probable Impact
C7-18	Black Wattle	Copper	Operating	Medium	Low
D7-18	Vaalbank	Coal	Operating	Small	Low - Medium
D7-26	Rondebult	Coal	Operating	Small	Low – Medium
D7-27	Elandsfontein	Coal	Operating	Small	Low – Medium
D7-28	Landau	Coal	Operating	Medium	Medium – High
D7-29	Arnot	Coal	Operating	Medium	Medium – High
D7-30	Strathrae	Coal	Operating	Small	Low – Medium
D7-32	Greenside	Coal	Operating	Medium	Medium – High
D7-33	Middelburg	Coal	Operating	Large	High
D7-34	Duvha	Coal	Operating	Medium	Medium – High
D7-35	Douglas	Coal	Operating	Medium	Medium – High
D7-36	Arnot Optimum	Coal	Operating	Large	High
D7-41	Rooikraal	Copper	Closed	Small	Very low
D7-42	Kruisrivier	Copper	Closed	Small	Very low
D7-43	Kameeldoring	Copper	Closed	Very small	Very low
E7-1	Waterpan	Coal	Operating	Small	Low - Medium
E7-2	Bank	Coal	Operating	Medium	Medium – High
E7-3	Kleinkoppie	Coal	Operating	Medium	Medium – High
E7-5	Tweefontein	Coal	Operating	Medium	Medium – High
E7-6	Phoenix	Coal	Operating	Medium	Medium – High
E7-7	Goedehoop	Coal	Operating	Medium	Medium – High
E7-8	Koornfontein	Coal	Operating	Medium	Medium – High
E7-9	Sterling	Dimension stone	Operating	Small	Very low
E7-11	Boschmans	Coal	Operating	Medium	Medium – High
E7-12	Khutala	Coal	Operating	Medium	Medium – High
E7-14	Kriel	Coal	Operating	Small	Low – Medium
E7-15	Leeuwfontein	Coal	Operating	Small	Low – medium
E7-16	Stuart Coal	Coal	Operating	Small	Low – Medium
E7-17	Delmas Silica	Dimension stone	Operating	Small	Very low
E7-18	Leeuwpan	Coal	Operating	Small	Low – Medium
E7-19	Tavistock	Coal	Operating	Small	Low – Medium
E7-22	Matla	Coal	Operating	Medium	Medium – High

5.3.3 *Alluvial mining*

None known and none anticipated.

5.3.4 *Monitoring systems*

The Department of Water Affairs and Forestry (DWAF) regularly monitor flows and water quality at the Loskop Dam, as well as other upstream and downstream sites. In addition, DWAF also regulate the quantity and quality of all effluent discharges through a system of effluent discharge permits or licences. Each licensed effluent discharger is required to carry out a routine monitoring programme of the flow and quality of their effluent and supply this to DWAF. The Department then conducts a randomised series of audit samples to check the veracity of the effluent returns submitted by each discharger.

5.3.5 *Water quality data*

A selection of water quality data have been obtained to demonstrate some of the different effects that deep versus shallow coal mining has on water quality, and to show the changes that take place when mine water seeps, or is discharged into, surface streams (**Table 5.6**).

Table 5.6: Selected water chemistry data for water samples from a deep underground coal mine, a shallow underground coal mine and three surface water (stream) samples collected at different distances from their shallow underground coalmine source. (Data adapted from Hodgson & Krantz, 1999).

Parameter	**Sampling Sites**				
	Deep Underground Mine	**Shallow Underground Mine**	**Surface Flow (Close to source)**	**Surface Flow (0.75 km from source)**	**Surface Flow (1.5 km from source)**
pH	8.06	6.78	3.41	3.20	3.12
EC (mS/m)	164	228	120	212	219
Ca	186	561	60	139	144
Mg	89	107	38	83	91
Na	120	15	46	44	40
Cl	13	3	66	52	44
SO_4	910	1,767	562	1,460	1,509
Al	-	< 0.1	27	110	107
Co	-	0.04	0.92	1.63	1.58
Fe	-	21	2.7	5.6	11.8
Mn	-	3.2	25.5	37.5	36.7
Ni	-	0.1	0.39	1.13	0.94
Zn	-	0.36	0.74	2.05	1.95

5.3.6 Implications for water quality and quantity management

The available evidence suggests that the extensive areas of coal mining in this sub-catchment have had, and will continue to have, very high impacts on the sub-catchment's water resources and particularly, the water quality of all streams and rivers. The primary cause of these impacts is the extensive acid mine drainage where water of low pH, with high concentrations of total dissolved salts and metals, enters local water courses and results in a complete change in the water chemistry. The large volumes of acid mine drainage and the long period of time over which these discharges and seepages have taken place has resulted in the impacts still being discernable (as altered water chemistry characteristics) over two hundred kilometres downstream from the Witbank and Highveld Coalfields

These effects are also accentuated by seepages from power station ash dumps, as well as effluent discarded by different industries, including the Highveld Steel Plant and various foundry operations. The small, closed copper mining operations in the lower reaches of this sub-catchment have no impacts on the basin's water resources.

One of the positive aspects of increased salinity values caused by acid mine drainage is that the increased salt concentrations tend to diminish the presence of suspended sediments in local streams and rivers by auto-flocculating sediments.

Overall, the serious nature of the impacts caused by mining or attributable to mining in this sub-catchment has been the subject of concerted research and management attention for several years. The latest development has been the launching of the COALTECH 2020 programme that seeks to harness the collaborative efforts of all role players in a concerted attempt to derive appropriate and cost-effective management strategies that will help to resolve these problems.

5.4 The Middle Olifants sub-catchment

5.4.1 General description

5.4.1.1 Hydrology

This sub-catchment comprises the portion of the Olifants basin between Loskop Dam and the junction of the Selati and Olifants rivers. It receives upstream inflows from the Wilge and Little Olifants-Riet sub-catchments, as well as the Steelpoort and Blyde sub-catchments. Within this sub-catchment, the most important tributaries are the perennial Elands, Moses, Selons, Bloed and Makhutswi rivers, whilst several smaller tributaries, both perennial and seasonal or episodic, enter from the north-west and south-east.

One very large impoundment on the Olifants River, the Mogoma Matlala (Arabie) Dam, provides water supplies to numerous small towns and settlements in the sub-catchment, as well as large volumes of water for irrigation schemes along both banks of the Olifants River. Nine other medium-sized dams are also located in this sub-catchment and supply water for domestic use and for irrigation. Many of the mines and industries in this sub-catchment, as well as numerous small and large settlements, rely on water supplied from these ten dams, or use local boreholes or direct run-of-river abstraction from perennial rivers and streams. There are also over 500 small farm dams located in this sub-catchment and these trap water for domestic purposes and for limited areas of small-scale irrigation, as well as livestock watering.

Flow patterns in this portion of the Olifants River are relatively stable as they are controlled by water releases from the Loskop Dam, as well as from the Mogoma Matlala and Arabie dams. This sub-catchment receives relatively low rainfalls (average 600 mm per year) because large portions of the sub-catchment are located in a rain shadow zone. The large volumes of water that are used for irrigation, combined with high rates of evaporative loss, result in relatively low outflows from this sub-catchment to the Phalaborwa Barrage. In addition, severe veld degradation over several decades has resulted in extensive areas of soil erosion. As a consequence of this, the Olifants River carries large loads of suspended sediments. Much of this sediment is trapped by the larger impoundments, reducing their effective storage volume. A case in point is the relatively small Phalaborwa Barrage (with a full supply capacity of 11 million cubic metres); this impoundment normally has 60-70% of its volume taken up by accumulated sediments. During periods of high flows in the Olifants River, the Phalaborwa Water Board opens the scour gates at the Phalaborwa Barrage in an attempt to flush out some of the accumulated sediments. This results in extremely high concentrations of suspended sediments (55,000 – 70,000 mg/litre) further downstream in the Kruger National Park. In turn, the Massingir Dam in Mozambique traps these sediments and gradually loses its effective storage volume.

5.4.1.2 Geology

The geological features of this sub-catchment consist of a variety of different formations of greatly differing ages and compositions. The upper (south-western) reaches of this sub-catchment are underlain by the acid and intermediate intrusive rocks of the Waterberg Group, as well as small areas of mafic and ultramafic formations. The western portion of the sub-catchment is underlain by extensive Karoo Supergroup formations, principally basalts of the Lebombo Group and Clarens Formation sandstones, with smaller areas of Ecca Group shales, siltstones and mudstones. The central and eastern portions of this sub-catchment are underlain by a variety of rocks of the Bushveld igneous Complex. The most important of these are the Lebowa Granite suite to the south, with outcrops of the Rashoop Granophyre Suite, followed by rocks of the Rustenburg Layered Suite further to the north and east. Much of the northern portion of this sub-catchment is underlain by rocks of the Transvaal Sequence, with the silicified sandstones and quartzites of the Black Reef Quartzite Formation being very prominent, together with Chuniespoort dolomites and Pretoria group shales, hornfels and quartzites. These rock formations form the spectacular rock formations of the Drakensberg Mountain range through which the Olifants River has cut a steep-sided gorge. Quartzitic rocks of the Pretoria Group also outcrop at several points in the central portions of this sub-catchment.

In the most easterly portion of this sub-catchment, granitic and gneissic rocks of the Basement Complex underlie most of the area east and north of the Drakensberg Mountains. These formations have been intruded by rocks of the Gravelotte Group (part of the Murchison Sequence) and Rooiwater Complex. Here, quartzites, schists, basic lava and granitic rocks dominate the Gravelotte Group lithology, whilst easily erodable felsites and gabbros dominate the Rooiwater Complex lithology.

5.4.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into six main groups:

- Shallow to moderately deep sandy-clay loam soils on flat and undulating terrain overlying rocks of the Ecca Group, principally shales and silicified sandstones, in the western reaches of the catchment;
- Deep, black, blocky vertisols of the Springbok Flats in the south-western and western regions;
- Moderate to deep sandy loam soils lining long stretches of the Olifants River valley in its middle reaches;
- Shallow, sandy to sandy loam soils overlying granitic rocks of the Lebowa Granite Suite in the south-eastern portions of the sub-catchment;
- Moderate to deep clay loam soils over much of the lower portions of the sub-catchment (located away from the river channels), overlying the more porous unconsolidated sedimentary material; and
- Moderately shallow to moderately deep, clayey loam to clay-rich, fine-grained soils over granitic areas in the lower reaches of the sub-catchment.

Most of the soils are suitable for commercial agriculture when sufficient water is available. Virtually all of the areas with suitable soils, particularly the area downstream of the Loskop and Arabie dams, are contained within the jurisdiction of formal irrigation boards or Government Water Control Areas. Further away from the main river channels, land use is given over to small- and medium-scale livestock farming operations. A relatively wide variety of crops are produced on the irrigated and rain-fed areas, primarily maize, wheat, sorghum, cotton, tobacco, lucerne, potatoes, vegetables, sunflowers and soya bean. Large-scale citrus estates and sub-tropical fruit orchards are located in the northern (e.g. Zebediela Estate) and north-eastern portions of the sub-catchment. The black vertisols of the Springbok Flats area are highly productive and most irrigation water is provided from high-yielding boreholes. This region is perhaps the most economically important agricultural area in the sub-catchment.

Large areas of the former Lebowa are given over to small-scale cattle ranching and the raising of goats and donkeys. Much of the stock-rearing area in the central portions of this sub-catchment has been heavily overgrazed and soils erosion is very prevalent.

Several towns (e.g. Marble Hall, Roedtan and Lebowakgomo) and numerous smaller settlements and farming communities are present in the upper and middle reaches of the sub-catchment. Population numbers and density are greatest in the upper and central reaches of this sub-catchment and decline somewhat towards the downstream reaches. Some light industry is present in the towns of Marble Hall and Roedtan and these industries are geared specifically to meet the needs of the extensive agricultural in the sub-catchment.

5.4.1.4 Surface water users

All the towns in the sub-catchment rely on water supplied from the small and large water supply impoundments. In contrast, most of the numerous settlements in the sub-catchment have to rely on water supplied from boreholes, springs, and hand-dug wells or from run-of-river abstraction points. The large areas of irrigation agriculture consume most of the water used in the upper and central reaches of the sub-catchment. Formal irrigation boards control the allocation of water to each of the irrigation schemes in the sub-catchment. Contamination of local water resources by faecal coliform bacteria is a consequence of inadequate sanitation and the simultaneous use of water resources for domestic supplies and stock watering. Most of the mines and industries in the sub-catchment rely on water supplies from local boreholes.

5.4.1.5 Water management systems

The South African Department of Water Affairs and Forestry (DWAF) is responsible for the management of all aspects of water supply and water use in the sub-catchment. The Department operates a system of routine flow gauging at the Arabie Dam and other water supply dams, and pays particular attention to monitoring the quantity of water supplied to irrigation schemes and towns, as well as increasing attention to the quality of agricultural return flows and effluent discharges to the Olifants River. The various irrigation boards are responsible for the day-to-day management of water allocations for irrigation.

5.4.1.6 Human impacts on water resources (excluding mining)

The following activities can be expected to have an impact on water resources in the Middle Olifants sub-catchment:

- Landfills and solid waste disposal sites at all towns and larger settlements;
- Disposal of liquid (domestic, light and heavy industrial) effluent at all towns;
- Moderate volumes of runoff from towns, as well as all other urbanized areas;
- Non-point domestic effluent from numerous small settlements and farms;
- Minor non-point impact from non-intensive commercial or subsistence agriculture;
- Non-point impact of agricultural return flows from intensive irrigation areas; and
- Litter and domestic garbage discarded alongside the many roads that traverse the sub-catchment.

Examples of the types of effluents that are discharged into this sub-catchment are shown in **Table 5.7**, which list the water quality characteristics of four sewage treatment plant effluents.

Table 5.7: Water quality data for three sites on the Olifants River in the Middle Olifants sub-catchment. [All data are given in mg/litre, except pH (log units) and electrical conductivity (mS/metre)].

Parameter	Loskop Outflow	Olifantspoort	Rooipoort
pH	7.3	8.0	8.0
Conductivity	150	140	120
TDS	1105	900	800
Ca	75	60	45
Mg	60	55	50
Na	240	200	160

K	5.5	5	4.5
Cl	380	350	200
F	1.0	1.0	0.9
SO_4	155	100	80
Total Alkalinity	200	170	180
NH_4-N	0.06	0.05	0.05
NO_3-N	1.3	1.2	0.8
PO_4-P	0.03	0.02	0.02

These data reflect the important influence of agricultural return flows in the upper and central reaches of this sub-catchment, as well as the dilution effect due to inflows of better quality water downstream of the Olifantspoort sampling site.

5.4.2 Mining and mineral processing operations

The following mining operations are of interest in the Middle Olifants sub-catchment (**Figures 4.2 and 4.3**; **Table 5.8**).

Table 5.8: Mining operations in the Middle Olifants sub-catchment.

Code Number	Name of Mine	Commodity (ies) Mined	Status	Relative Size	Probable Impact
B7-13	Kopermyn	Gold	Closed	Small	Very low
B7-18	Doornfontein	Gold	Closed	Very small	Very low
C7-4	Mont Mare	Gold	Closed	Very small	Very low
C7-5	Marsfontein	Diamond - kimberlite	Operating	Small	Very low
C7-6	Hoegenoeg	Andalusite	Operating	Medium	Very low
C7-7	Lebowa Kgomo	Manganese	Closed	Small	Very low
C7-8	Pelongwe	Chrome, Platinum	Prospecting	Small	Very low
C7-9	Wonderboom	Platinum	Prospecting	Small	Very low
C7-10	Seogeng Quarry	Clay minerals	Operating	Very small	Very low
C7-11	Klipspringer	Diamond - kimberlite	Operating	Small	Very low
C7-12	Inca	Limestone / Dolomite	Operating	Small	Very low
C7-13	Calais	Clay minerals	Operating	Medium	Very low
C7-14	Karkaw	Limestone / Dolomite	Operating	Medium	Very low
C7-17	Stavoren	Zinc, Tin	Closed	Small	Very low
C7-24	Sekhukune	Andalusite	Prospecting	Small	Very low
C7-26	Lebowa Platinum	Chrome, Platinum	Operating	Large	Medium – High
C8-2	Freddies	Feldspar	Operating	Medium	Low

C8-3	Union Mica	Pegmatite - Muscovite	Operating	Medium	Low
C8-4	Union	Feldspar, Mica	Operating	Small	Very low
C8-5	Penge	Asbestos	Closed	Medium	Low
C8-6	Havercroft	Andalusite	Operating	Large	Low
C8-7	Annesley	Andalusite	Operating	Medium	Low
C8-8	Atta	Clay minerals	Operating	Medium	Low
C8-9	Dilokeng	Chrome	Operating	Large	Medium – High
C8-10	Mokoropo	Platinum	Closed	Small	Very low
C8-11	Montrose	Chrome	Operating	Large	Medium – High
C8-15	Maandagshoek	Vanadium	Closed	Small	Very low
C8-23	Pegmatite claims	Pegmatite -Tantalum	Operating	Very Small	Very low
D7-40	Perdekop	Fluorspar	Closed	Small	Very low

5.4.3 Alluvial mining

None known or anticipated.

5.4.4 Monitoring systems

The Department of Water Affairs and Forestry (DWAF) routinely collects water samples and gauges flows in the Middle Olifants sub-catchment, as part of its national monitoring programme. In addition, DWAF also regulate all large (> 150 m^3/day) water abstractions, and monitor the quantity and quality of all effluent discharges through a system of effluent discharge permits or licences. Each licensed effluent discharger is required to carry out a routine monitoring programme of the flow and quality of their effluent and supply this to DWAF. The Department then conducts a randomised series of audit samples to check the veracity of the effluent returns submitted by each discharger.

5.4.5 Water quality data

No specific water quality data relating to mining operations in this sub-catchment were obtained for this report.

5.4.6 Implications for water quality and quantity management

In spite of the fact that most mining operations in this water-short sub-catchment make use of dry processes and recycle up to 90% of their water use, increasing loads of trace metals and micro-pollutants continue to be found in downstream reaches of the Olifants River (Grobler *et al*., 1993). River reaches and tributaries with relatively low concentrations of trace metals are considered to be the result of natural weathering processes on local geological formations. High concentrations of the same trace metals in other river reaches are attributed to the consequences of mining activities.

In some areas, complaints have been voiced about the prevalence of asbestos fibres in water used for domestic consumption and laundry purposes. This is probably due to rain-induced erosion of waste rock dumps at the closed Penge Asbestos Mine.

5.5 The Steelpoort sub-catchment

5.5.1 General description

5.5.1.1 Hydrology

This sub-catchment consists of the area drained by the Steelpoort River and its main tributaries, the Klip, Dwars, Waterval and Spekboom rivers (**Figure 4.2**). All of these tributary rivers are perennial and rise on the western slopes of the north-south trending Drakensberg Mountains and flow north-north-eastwards where they join. The Steelpoort River then flows north-eastwards through a gorge in the escarpment before joining the middle reaches of the Olifants River. Ground water inflows from the Chuniespoort dolomites provide an important component of the water in the Steelpoort River.

Two small impoundments on the Dwars River provide water supplies to numerous small towns and settlements in the sub-catchment. Most of the mines and industries, as well as several settlements, rely either on ground water supplies via boreholes or direct run-of-river abstraction from the perennial rivers and streams in the sub-catchment. Several small farm dams in the upper reaches of the Steelpoort River and its tributaries trap water for domestic purposes and for limited areas of commercial irrigation along the Steelpoort valley, as well as livestock watering.

Flow patterns in the upper reaches of the Steelpoort River and its tributaries are relatively stable as these rivers drain an area that receives some of the highest rainfalls recorded in South Africa (average rainfalls in the headwater regions of these two rivers exceeds 1,100 mm per year). Whilst all the rivers are perennial, flows increase during the summer months when rain is received. Smaller tributary streams in the upper reaches are also perennial, though their flows are more variable.

5.5.1.2 Geology

The underlying geological formations beneath the Steelpoort sub-catchment consist predominantly of basic rocks of the Bushveld Igneous Complex, consisting predominantly of magnetite-rich gabbros, norites, anorthosites, pyroxenites and gabbroic rocks of the Rustenburg Layered Suite (RLS). These rocks form the base of the relatively flat-bottomed valley areas as well as forming the watershed marked by the steep-sided, more mountainous or hilly terrain to the east and west of the Steelpoort River.

The mountainous area located to the northeast of the sub-catchment (close to the confluence of the Steelpoort and Olifants rivers) consists predominantly of erosion-resistant quartzites shales and silicified shales of the Transvaal Sequence. These rocks form steep-sided hills and cliffs with little surface soil.

The Steelpoort Valley itself is a steep-sided valley that trends in a predominantly northeasterly direction as a result of the Steelpoort Fault. This regional structure appears to have been exploited by the Steelpoort River during its evolution. The valley floor is covered with extensive, deep deposits of colluvium (hillwash), with more recent (Quaternary) alluvial deposits located on the flood terraces on either side of the Steelpoort River.

5.5.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into three main groups:

- Moderate to deep, stony sandy-clay loam soils on the foot slopes, as well as the sloping and undulating terrain in the upper reaches of the sub-catchment;
- Shallow to moderately deep clayey loam soils lining the valley bottoms in the middle reaches of the sub-catchment; and
- Shallow to moderately deep fine to coarse sandy alluvial soils lining flood terraces on either side of the river channels, particularly in the central and lower reaches of the sub-catchment.

Most of the clayey loam soils in the upper and central parts of the sub-catchment are very suitable for cultivation and extensive rain-fed and irrigation agriculture is practiced in these regions. Water is pumped either directly from the Steelpoort River or from small storage dams on tributary streams for small-scale irrigation. Minor use is made of borehole water for irrigation, especially in the central and lower reaches, due to problems with vanadium contamination and possible toxicity. Further away from the main channel of the Steelpoort River, land use consists almost entirely of small- and medium-scale livestock (dairy and beef cattle) farming.

A few towns and several small settlements are located in the upper and middle reaches of the sub-catchment, though population densities become much lower in the lower reaches of the sub-catchment. The central and western portions of this sub-catchment support several small-scale subsistence farmers.

5.5.1.4 Surface water users

All the relatively small towns in the Steelpoort sub-catchment rely on water supplied from the water supply impoundments. In contrast, most of the numerous settlements in the sub-catchment have to rely on water supplied from boreholes, springs, and hand-dug wells or from run-of-river abstraction points. The areas of irrigation agriculture consume moderate quantities of water in the upper and central reaches of the sub-catchment. Formal irrigation boards control the allocation of water to each of the irrigation schemes in the sub-catchment. Most of the mines and industries in the sub-catchment rely on water supplies from local boreholes.

5.5.1.5 Water management systems

The South African Department of Water Affairs and Forestry (DWAF) is responsible for the management of all aspects of water supply and water use in the Steelpoort sub-catchment. The Department operates a system of routine flow gauging at the major water supply dams and reservoirs, and pays particular attention to monitoring the quantity of water supplied to irrigation schemes and towns, as well as increasing attention to the quality of agricultural return flows and effluent discharges to the Steelpoort River. The various irrigation boards are responsible for the day-to-day management of water allocations for irrigation.

5.5.1.6 Human impacts on water resources (excluding mining)

The following activities can be expected to have an impact on water resources in the Steelpoort sub-catchment:

- Small landfills and solid waste disposal sites at all towns and larger industries;
- Disposal of liquid (domestic) effluent at all towns and industries;
- Small volumes of runoff from the towns and urbanized areas;
- De-vegetation and other forms of veld degradation, leading to increased erosion and loads of suspended sediments in most streams and rivers;
- Non-point domestic effluent from numerous small settlements and farms;
- Minor non-point impact from non-intensive commercial or subsistence agriculture;
- Minor non-point impact of agricultural return flows from intensive irrigation areas; and
- Litter and domestic garbage alongside the roads that traverse the sub-catchment.

5.5.2 Mining and mineral processing operations

The following mining operations are of interest in the Steelpoort sub-catchment (**Figures 4.2 and 4.3**; **Table 5.9**).

Table 5.9: Mining operations in the Steelpoort sub-catchment.

Code No	**Name of Mine**	**Commodity (ies) Mined**	**Status**	**Relative Size**	**Probable Impact**
C7-23	Magneetshoogte	Iron, Vanadium	Prospecting	Small	Very low
C8-12	Winterveld	Chrome	Operating	Very large	High
C8-13	Doornbosch	Platinum	Closed	Small	Very low
C8-14	Lannex	Chrome	Operating	Large	Medium – High
C8-15	Boskloof	Vanadium	Prospecting	Small	Very low
C8-16	Kennedy's Vale	Vanadium	Operating	Medium	Medium – High
C8-17	Tweefontein	Chrome, Platinum	Operating	Very large	Medium – High
C8-18	Kruger's Post	Andalusite	Operating	Large	Low
C8-21	Thorncliffe	Chrome	Operating	Large	Medium – High
D7-1	Mapochs Vermiculite	Vermiculite	Operating	Small	Very low

D7-7	Nyala	Dimension stone	Operating	Small	Very low
D7-9	Belfast Granite	Dimension stone	Operating	Medium	Low
D7-12	Belfast #2	Dimension stone	Operating	Small	Very low
D7-16	Marlin	Dimension stone	Operating	Small	Very low
D7-44	Baviaanskloof	Vermiculite	Prospecting	Small	Very low
D7-45	Mapochs	Vanadium, Copper	Operating	Large	Medium – High
D7-46	Vanadiumkop	Vanadium	Prospecting	Small	Very low
D7-47	Driefontein	Vanadium	Closed	Small	Very low

5.5.3 Alluvial mining

None known or anticipated.

5.5.4 Monitoring systems

The Department of Water Affairs and Forestry (DWAF) routinely collects water samples and gauges flows in the Steelpoort sub-catchment, as part of its national monitoring programme. In addition, DWAF also regulate all large (> 150 m^3/day) water abstractions, and monitor the quantity and quality of all effluent discharges through a system of effluent discharge permits or licences. Each licensed effluent discharger is required to carry out a routine monitoring programme of the flow and quality of their effluent and supply this to DWAF. The Department then conducts a randomised series of audit samples to check the veracity of the effluent returns submitted by each discharger.

5.5.5 Water quality data

A set of water quality data are available for the Steelpoort River and the Dwars River, collected from sites upstream and downstream of a group of chrome and vanadium mining operations. These data are presented in **Table 5.10**. The data reveal clear effects of mining on general water quality (most probably due to forms of acidic seepage) but the data for chrome and vanadium concentrations are anomalous in that they show no clear indications of the chrome and vanadium mines having any effect on these substances in the rivers.

Table 5.10: Water quality data from five sites on the Steelpoort and Dwars rivers, close to chrome and vanadium mining operations. The sampling sites are as follows: (1) = Dwars River upstream of Tweefontein Chrome Mine; (2) = Dwars River downstream of Tweefontein Chrome Mine; (3) = Steelpoort River upstream of junction with Dwars River; (4) = Steelpoort River downstream of Vantec Vanadium Mine; (5) = Steelpoort River downstream of Lannex Section Chrome Mine; (6) = Steelpoort River downstream of Tubatse Ferrochrome Smelter. [All values given in mg/litre except pH (log units)].

Parameter	**Sampling Sites**					
	1	**2**	**3**	**4**	**5**	**6**

pH	8.5	8.3	8.8	8.7	8.8	8.9
TDS	439	721	566	1255	570	647
Ca	34	42	38	74	38	29
Mg	36	50	33	107	38	60
Na	18	29	74	145	63	60
K	0.3	1.6	2.5	2.8	2.5	2.7
Cl	7	20	88	101	55	55
F	0.1	0.1	0.2	0.2	0.1	0.1
SO_4	11	8	28	544	53	53
Total Alkalinity	273	438	246	204	263	310
Cr	0.003	0.003	0.003	0.135	0.003	0.003
V	0.003	0.003	0.032	0.017	0.003	0.015

5.5.6 Implications for water quality and quantity management

The available evidence (**Table 5.10**) indicates that mining operations in the Steelpoort sub-catchment do have adverse effects on water quality in the river systems. However, there does not appear to be a clear indication (from these data) that the mines are contributing significant quantities of either chrome or vanadium to the rivers. Instead, it is possible that there is "natural background contamination" by chrome and vanadium, as reflected in the "upstream" samples.

The precise extent and nature of any contamination from mining activities in the Steelpoort sub-catchment needs to be resolved unequivocally. There is considerable tension between farmers, irrigators and mine operators in this region around allegations of various types of metal toxicity to crops and livestock and the matter must be clarified as soon as possible. Concerted attention should be paid to a sampling and monitoring campaign that must be designed to prove whether or not there is indeed any form of metal contamination and, if so, the extent of such contamination and the precise source of such contamination. Only then can potential management options be evaluated and implemented.

5.6 The Blyde sub-catchment

5.6.1 General description

5.6.1.1 Hydrology

This sub-catchment consists of the area drained by the Blyde River and its main tributary, the Ohrigstad River (**Figure 4.2**). Both the Blyde and Ohrigstad rivers rise on the western slopes of the north-south trending Drakensberg Mountains and flow northwards towards the escarpment edge where they join at the Blydepoort Dam, which is located at the edge of the escarpment. From the Blydepoort dam, the Blyde River cascades down a steep series of rapids to its lower reaches, where the river again flows northwards to join the Olifants

River north of the town of Hoedspruit. Ground water from the Chuniespoort dolomites provides an important component of the water in the Blyde River.

The Blydepoort Dam is the largest impoundment on the Blyde River and regulates flows in the lower reaches. Several small farm dams in the upper reaches of the Blyde and Ohrigstad rivers trap water for domestic purposes and for limited areas of commercial irrigation, as well as livestock watering. The small Ohrigstad Dam provides water for the town of Ohrigstad.

Flow patterns in the upper reaches of the Blyde and Ohrigstad rivers are relatively stable as these rivers drain an area that receives some of the highest rainfalls recorded in South Africa (average rainfalls in the headwater regions of these two rivers exceeds 1,500 mm per year). Both rivers are therefore perennial, though flows increase during the summer months when rain is received. Smaller tributary streams in the upper reaches are also perennial, though their flows are more variable. In its lower reaches, the Blyde River receives small quantities of water from several episodic tributary streams that only contain water during the summer months.

5.6.1.2 Geology

The geological characteristics of the Blyde sub-catchment consist of a relatively complex series of lithological formations that underlie the area forming the Drakensberg Mountains. In the eastern portion of the upper reaches of the sub-catchment, the most important features are the deep layers of dolomites of the Chuniespoort Formation, interspersed with alternating layers of indurated shales and quartzites of the Pretoria Series of the Transvaal Sequence. In the western portion of this zone, the sub-catchment is underlain by complex sequences of shales, conglomerates, silicified sandstones and quartzites of the Transvaal Sequence. The hard, erosion-resistant rocks forming the northward continuation of the Drakensberg Mountains rise steeply from the Mpumalanga Lowveld, forming conspicuous, steep-sided cliffs.

Water moving through the deep layers of Chuniespoort dolomites in the upper parts of the sub-catchment becomes saturated with calcium carbonate; this precipitates out to form tufa when the water appears above ground level. As a consequence, most of the waterfalls in the area are layered with thick, “growing” deposits of tufa.

In the northern parts of the sub-catchment, downstream of the Blydepoort Dam, crystalline gneissic and granitic rocks of the Basement Complex underlie the catchment. These coarse- to fine-grained, feldspar-rich rocks have been intruded by numerous hard, fine-grained syenite “plugs” that are more erosion-resistant; these are visible as stack-like features across the otherwise undulating terrain in the lower parts of the sub-catchment. In addition to the intrusive syenite formations, the basement complex has also been intruded by a large number of dolerite dykes. These dolerites are softer and more easily eroded than the Basement Complex rocks and the dykes are often visible as troughs in the landscape. These troughs collect rainfall and act as local watercourses; this water enhances the erosion process.

5.6.1.3 Pedology, agriculture and land use

Soils in the sub-catchment can be divided into four main groups:

- Moderate to deep sandy and clay-loam soils on flat, gently-sloping and undulating terrain overlying dolomite, limestone and sandstones in the upper reaches of the catchment;
- Moderate to deep sandy to clay loam soils lining long stretches of the Blyde and Ohrigstad river valleys in their middle reaches;
- Moderate to deep clay loam soils over much of the middle portions of the sub-catchment (located away from the river channels), overlying the more porous unconsolidated sedimentary and hillwash material; and
- Moderately shallow to moderately deep, coarse-grained sandy loam to clay-rich, fine-grained soils derived from granites and gneisses over most of the lower reaches of the sub-catchment.

Most of the clayey loam soils are very suitable for irrigated agriculture when sufficient water is provided. Virtually all of the suitable soils are contained within the jurisdiction of formal irrigation boards or Government Water Control Areas. Further away from the main river channels, most of the land use is given over to small-scale irrigation from farm dams as well as the raising of small and large livestock (dairy and beef cattle, goats and sheep). A wide variety of crops are produced, ranging from intensive vegetable production to tobacco, maize, citrus and sub-tropical fruits, sorghum and sunflowers. Minor areas of plantation forestry (mostly Pines and Eucalyptus) are also located in the wetter portions of the sub-catchment.

A few small towns and numerous smaller communities are present in the upper reaches of the sub-catchment, whilst numerous scattered settlements and small towns characterize the lower portions of the sub-catchment. The number and density of population declines with increasing distance from the upper reaches. Most of the towns in the sub-catchment are service centres for the agricultural sector and have small fruit and vegetable processing operations.

5.6.1.4 Surface water users

All the towns in the sub-catchment rely on water supplied from small water supply impoundments located nearby. In contrast, most of the settlements have to rely on water supplied from boreholes or from run-of-river abstraction points and, occasionally (in the lower reaches), from local boreholes. The areas of irrigation agriculture consume most of the water used in the upper reaches of the sub-catchment. Immediately downstream of the Blydepoort dam, the large Blyderivierspoort Irrigation Scheme is a major water user. Water from the Blydepoort Dam is also released on demand to flow downstream to the Phalaborwa Barrage on the Olifants River, where it is used to supplement the declining Olifants River flows that are available to water users in the urban-industrial complex at the town of Phalaborwa. Recent estimates suggest that the water from the Blydepoort Dam may account for some 30% of the total water used by Phalaborwa.

A formal Irrigation Board controls the Blyderivierspoort Irrigation Scheme. Recent improvements in the methods of delivering water to the farmers are likely to achieve a 40% reduction in water use by this irrigation scheme. However, this “water saving” is seen as an ideal opportunity to improve the reliability of water supplies to the large number of settlements in the lower reaches of this sub-catchment who lack access to formal water supply infrastructure.

5.6.1.5 Water management systems

The South African Department of Water Affairs and Forestry (DWAF) is responsible for the management of all aspects of water supply and water use in the sub-catchment. The Department operates a system of routine flow gauging at the Blydepoort Dam and pays particular attention to the quantity of water supplied to irrigation schemes and towns, as well as increasing attention to the quality of agricultural return flows and effluent discharges to the Blyde and Ohrigstad rivers.

The Blyderivierspoort Irrigation Board is the only formal irrigation board located in this sub-catchment and it is responsible for al aspects of water supply to the irrigation scheme as well as for releases to the Phalaborwa barrage.

5.6.1.6 Human impacts on water resources (excluding mining)

The following activities can be expected to have an impact on water resources in the sub-catchment:

- Small landfills and solid waste disposal sites at all towns;
- Disposal of liquid (domestic) effluent at all towns;
- Small volumes of runoff from the towns and urbanized areas;
- De-vegetation and other forms of veld degradation, leading to increased erosion and loads of suspended sediments in most streams and rivers;
- Non-point domestic effluent from numerous small settlements and farms;
- Minor non-point impact from non-intensive commercial or subsistence agriculture;
- Minor non-point impact of agricultural return flows from intensive irrigation areas; and
- Moderate amounts of litter and domestic garbage alongside the roads that traverse the sub-catchment.

5.6.2 Mining and mineral processing operations

The following mining operations are of interest in the Blyde sub-catchment (**Figures 4.2 and 4.3**; **Table 5.11**).

Table 5.11: Mining operations in the Blyde sub-catchment.

Code Number	**Name of Mine**	**Commodity (ies) Mined**	**Status**	**Relative Size**	**Probable Impact**
C8-19	Morgenzon	Gold	Operating	Small	Low
C8-20	Astra	Gold	Operating	Small	Low

5.6.3 Alluvial mining

No information is available on the present situation, though it is well known that large numbers of alluvial miners panned for gold near the town of Pilgrims Rest during the late 19th and early 20th Century. It can be anticipated that a few small-scale miners will still undertake occasional exploratory work in the upper reaches of this sub-catchment.

5.6.4 Monitoring systems

The Department of Water Affairs and Forestry (DWAF) routinely collects water samples and gauges flows in this sub-catchment, as part of its national monitoring programme. In addition, DWAF also regulate all large (> 150 m^3/day) water abstractions, and monitor the quantity and quality of all effluent discharges through a system of effluent discharge permits or licences. Each licensed effluent discharger is required to carry out a routine monitoring programme of the flow and quality of their effluent and supply this to DWAF. The Department then conducts a randomised series of audit samples to check the veracity of the effluent returns submitted by each discharger.

5.6.5 Water quality data

A few water quality data for four sites along the upper reaches of the Blyde and Ohrigstad rivers were available from the Department of water Affairs and Forestry. These data are presented in **Table 5.12**, below.

Table 5.12: Water quality data for four sites on the Blyde sub-catchment. All values are given in mg/litre, except pH (log units).

Parameter	**Sampling Site**			
	Blyde River at Willemsoord	**Blyde River at Chester**	**Blydepoort Dam**	**Ohrigstad Dam**
TDS	140	140	140	46
pH	7.55	7.35	8.30	6.65
Ca	30	28	32	31
Mg	8	11	11	10.8
Cl	5.4	5.3	4.6	7.2
SO_4	7	6	9	5
Total Alkalinity	64	67	70	56
NH_4-N	0.08	0.07	0.2	0.13
NO_3-N	0.23	0.29	0.35	0.15
PO_4-P	0.010	0.009	0.009	0.007

These data reflect the influence of the dolomitic formations on the water chemistry and also the presence of agricultural return flows enriched with fertilizers.

5.6.6 Implications for water quality and quantity management

The available evidence suggests that the only likely source of any impact on local water resources and water quality would be the two small gold mines located near the town of Pilgrims Rest (**Table 5.12**). These impacts would most likely be localized and consist almost entirely of minor increases in suspended sediment concentrations and, possibly, the risk of small cyanide spills from the extractive workings. It is also likely that the many (> 100) small, abandoned gold mines and surface workings around Pilgrims Rest will be subject to acid mine drainage linked to the oxidation of pyrite in the gangue rock. A few small associations of arsenopyrite in the gangue rock suggest that arsenic may also cause minor, localized problem in a few streams.

5.7 The Selati sub-catchment

5.7.1 General description

5.7.1.1 Hydrology

The Selati River rises on the eastern slopes of the Wolkberg Mountains, which form part of the Drakensberg Mountain chain. From its source in this high rainfall zone, the river flows eastward for approximately 140 kilometres before joining the Olifants River some 10 kilometres to the east of the town of Phalaborwa. The Selati River has two main tributaries in its upper reaches; these are the Ngwabitsi and Mulati rivers.

The upper reaches of the Selati sub-catchment consist of steep-sided valleys with sharply defined cliff faces on the eastern side of the escarpment. The local relief changes dramatically as the escarpment drops sharply on its eastern flank to the flat or undulating terrain of the dry Lowveld region. Here, the topography is characterized by gently sloping valleys and isolated outcrops of granitic rocks.

Immediately downstream of the Gravelotte road bridge, the Selati River is partially impounded by a series of 10 small weirs over a distance of some 20 kilometres. These weirs mark the points where irrigation water is abstracted for large-scale commercial irrigation farms.

In its upper reaches, the Selati River is perennial. However, the combination of little or no inflows from seasonal tributary streams in its middle and lower reaches, coupled with large-scale water abstractions in the middle reaches, has resulted in the Selati River being a seasonal river over most of its lower reaches. At the town of Phalaborwa, discharges of treated domestic effluent and seepage from large-scale tailings dams provide a source of “perennial” flows for the final few kilometres before it joins the Olifants River. In effect, the final few kilometres of the Selati River only contain effluent during the dry winter months, though this becomes “diluted” when normal summer flows resume.

5.7.1.2 Geology

In its upper reaches, the sub-catchment is underlain by rocks of the Transvaal Sequence, which form the major portion of the Drakensberg Mountain range. The lithology is dominated by quartzites, chert, hornfels, basic lava and dolomite. The dolomite outcrops, in particular, are important sources of good quality water in the upper catchment and contribute water throughout the year.

Further to the east and south, rocks of the Gravelotte Group (part of the Murchison Sequence) and Rooiwater Complex outcrop in the vicinity of the town of Gravelotte. Quartzite, schists, basic lava and granitic rocks dominate the Gravelotte Group lithology. These greenstone formations contain important deposits of antimony and gold, with minor deposits of mercury and zinc. An extensive deposit of heavy mineral sands (illmenite, rutile and zirconium) is located near the town of Gravelotte.

The felsites and gabbros of the Rooiwater Complex are easily eroded and contribute increased levels of sediments in the valley depressions and river channels. Further to the east, the rocks of the crystalline Basement Complex outcrop at various points across the Lowveld. These rocks consist mainly of potassium-rich granites and gneisses with feldspar and mica outcrops. The exposed weathered granites are easily eroded, particular where the vegetation cover is sparse or denuded. Accelerated rates of sediment production occur in this region, with large amounts of coarse and fine sediments accumulating in river channels. The slightly harder rocks of the Mashimale Suite are intrusive into the rocks of the Basement Complex and are visible as stack-like outcrops of fine-grained, light-coloured granites.

The Phalaborwa area is underlain by granite and gneiss rocks of the Basement Complex. These were intruded by a cyclical series of alkaline-rich magmas that have given rise to the highly mineralised carbonatite and pyroxenite rocks of the Phalaborwa Complex. Plugs and dykes of fine-grained syenite that were intruded during the alkaline phase of the Phalaborwa Complex are resistant to weathering and remain as conspicuous stack-like hills and ridges.

North-east to south-west trending dykes and sills of undifferentiated mafic intrusives (mainly Karoo age dolerite) occur over much of the Lowveld Basement Complex, with particularly well-developed examples of dyke swarms in and around the Phalaborwa area. These rocks are less resistant to weathering than their granite and gneiss host rocks and give rise to negatively weathered linear features in the landscape, often forming or delineating drainage lines.

5.7.1.3 Pedology, agriculture and land use

Soils in the Selati sub-catchment can be divided into four broad groups or regions:

- Small areas of shallow, sandy or gravely soils the upper reaches;
- Areas of sandy colluvial soils at the foot of the escarpment, grading into red apedal soils in the western part of the sub-catchment;
- Shallow, brownish to greyish-brown sandy soils overlying coarsely weathered rock in the eastern portion of the sub-catchment; and
- Transported alluvial deposits of coarse to fine-grained sands and silts located along drainage lines.

The upper reaches of the Selati sub-catchment contain small areas of plantation forestry (Pines) and there are important natural forests on the steep escarpment slopes. The central portion of the sub-catchment supports extensive rain-fed and irrigated agriculture, consisting primarily of citrus and sub-tropical fruits, as well as smaller areas of vegetables. The central and lower reaches of the Selati River provide an important source of water for game farms and a few livestock (cattle and goats) rearing farms. In areas located away from the main river channel, rain-fed subsistence agriculture is important, with livestock rearing of cattle, goats and donkeys.

The town of Phalaborwa is the largest town in the sub-catchment and forms the regional service centre for the entire area with the development of light and heavy industries associated with the mining activities in the area. The smaller towns of Namagale and Lulekane serve principally as dormitory towns for staff employed on nearby mines and industries. Several smaller settlements are located in rural areas or communal lands within the former homeland states of Gazankulu and Lebowa.

5.7.1.4 Surface water users

The mines and larger industries in the town of Phalaborwa receive either domestic quality or industrial quality water from the Phalaborwa Water Board. The town of Phalaborwa and its associated mines and industries is the largest and most important water user in the Selati sub-catchment. The Phalaborwa Water Board provides almost all of the water required by the town of Phalaborwa from the Phalaborwa Barrage, located on the Olifants River. When water levels in the Phalaborwa Barrage fall to low levels, the Board requests releases of additional water from the Blydepoort Dam to supplement inflows to the Phalaborwa Barrage and assure water supplies to the town.

All the other smaller towns in the sub-catchment rely on water supplied from small water supply impoundments or, in the case of the town of Gravelotte, water transferred into the sub-catchment from the Letaba sub-catchment. Most of the smaller settlements in the sub-catchment have to rely on water supplied from boreholes or from run-of-river abstraction points and, occasionally (in the middle reaches), from local boreholes or hand-dug wells. The small areas of irrigation agriculture are important water users in the middle reaches of the sub-catchment.

The Selati sub-catchment is considered to be water-stressed and relies almost entirely on inflows from the Olifants River. The promising deposits of heavy mineral sands near Gravelotte cannot be exploited cost-effectively because of the general shortage of water in the sub-catchment.

5.7.1.5 Water management systems

The South African Department of Water Affairs and Forestry (DWAF) is responsible for the management of all aspects of water supply and water use in the sub-catchment. The Department operates a system of routine flow gauging and water quality sampling at specific points and pays particular attention to the quantity of water supplied to irrigation schemes and towns, as well as increasing attention to the quality of agricultural return flows and effluent discharges.

The Phalaborwa Water Board has been delegated the responsibility for all aspects of water supply to, and effluent discharge from, the town of Phalaborwa. In addition, the Board also controls flow releases from the Blydepoort Dam on the Blyde River. Small irrigation boards control the allocation of water for irrigation in the upper reaches of the Selati River.

5.7.1.6 Human impacts on water resources (excluding mining)

Given that the lower reaches of the Selati River are "normally" seasonal, but now are perennial as a result of continual seepage and effluent discharges from Phalaborwa and its mines and industries, it is difficult to separate "non-mining" impacts from those that are directly attributable to mining operations. Nevertheless, an impression can be gained by comparing the analyses of water samples collected upstream and downstream on the lower reaches of the Selati River with those in the nearby Olifants Barrage and the Olifants River nearby (**Table 5.13**).

What is immediately evident is that the quality of the water in the Selati River immediately upstream of the town of Phalaborwa is already very poor, probably as a result of agricultural return flows and other effluent discharges upstream. After the inflow of the seepage and effluent from Phalaborwa, the concentrations of a few constituents increases but there is no overall improvement or worsening of water quality. In contrast, the water quality in the Phalaborwa Barrage is comparatively good and, when mixed with water from the Selati River, there is a marked deterioration in water quality as shown by the results for Mamba Weir (**Table 5.13**). At the time when these samples were collected, September, the flow from the Phalaborwa Barrage was almost exactly equal to the flow of the lower reaches of the Selati River, approximately 0.5 m^3/second; this would suggest that the water from the Selati River would have been diluted by about 50% by water from the Olifants River.

Table 5.13: Comparison of water quality characteristics of samples collected from the Selati River upstream of Phalaborwa and downstream of all effluent discharges, with water samples collected from the Olifants River at the Phalaborwa Barrage and at Mamba Weir (B7M015) below the confluence of the Selati and Olifants Rivers. [All data are given as mg/litre, except ph (log units) and conductivity (mS/metre)].

Parameter	**Selati River (Upstream)**	**Selati River (Downstream)**	**Phalaborwa Barrage**	**Mamba Weir (B7M015)**
Conductivity	342	358	48	192
pH	7.5	7.2	7.9	7.9
Ca	142	104	26	61
Mg	214	204	25	100
Na	280	325	38	141
K	84	113	1	63
Cl	1,322	1,230	34	128
F	4.3	4.4	0.3	2.1

SO_4	531	594	19	254
Si	9	18	8	11.0
Total Alkalinity	266	145	170	162
NH_4-H	0.21	0.16	0.04	0.05
NO_2-N + NO_3-N	0.24	0.07	0.10	0.02
PO_4-P	0.08	0.35	0.01	0.16
Fe	0.031	0.132	-	0.131
Mn	0.095	0.332	-	0.045
Cu	0.004	0.006	-	0.002

5.7.2 Mining and mineral processing operations

The following mining operations are of interest in the Selati sub-catchment (**Figures 4.2 and 4.3**; **Table 5.14**).

Table 5.14: Mining operations in the Selati sub-catchment.

Code Number	**Name of Mine**	**Commodity (ies) Mined**	**Status**	**Relative Size**	**Probable Impact**
B8-12	Letaba	Zinc, Silver, Copper	Operating	Medium	Low
B8-13	Athens	Antimony	Operating	Medium	Low
B8-14	Alpha Gravelotte	Antimony	Operating	Medium	Low
B8-15	Discovery	Gold	Operating	Medium	Low
B8-16	Lenyenye	Clay minerals	Operating	Medium	Low – Medium
B8-17	Foskor	Phosphate, Zirconium	Operating	V. Large	Large
B8-18	Palabora Copper	Copper, Titanium	Operating	V. Large	Large
B8-19	Foskor	Vermiculite	Operating	Large	Low -Medium
C8-1	Inyoni Astra	Gold	Operating	Small	Low
C8-22	Cobra Emerald	Emerald	Operating	Small	Low-Very low

5.7.3 Alluvial mining

None known or anticipated, though there is some small-scale prospecting for tantalite and columbite in pegmatite formations upstream of the town of Phalaborwa.

5.7.4 Monitoring systems

The Department of Water Affairs and Forestry (DWAF) routinely collects water samples and gauges flows in this sub-catchment, as part of its national monitoring programme. In addition, DWAF also regulate all large (> 150

m^3/day) water abstractions, and monitor the quantity and quality of all effluent discharges through a system of effluent discharge permits or licences. Each licensed effluent discharger is required to carry out a routine monitoring programme of the flow and quality of their effluent and supply this to DWAF. The Department then conducts a randomised series of audit samples to check the veracity of the effluent returns submitted by each discharger. Each industry and mining operation in Phalaborwa regularly monitors its effluent discharge quality and reports the results to the Department.

5.7.5 Water quality data

The water quality data for the lower Selati River shown in **Table 5.13** are representative of the typical water quality of this reach during the dry months of the year. During the summer months when "normal" runoff patterns resume, the water quality improves dramatically. Nevertheless, aquatic ecosystems are exposed to greatest stress during the dry winter months when river flows are lowest; at this time of year, the poor quality water in the Selati River can b expected to have the greatest impact on water in the lower Olifants River.

5.7.6 Implications for water quality and quantity management

The "new" inflows of effluents from mining operations into the lower reaches of the Selati River has a positive effect in that, despite its poor quality, this water supplements the flows in the lower Olifants River. However, the resultant water quality of the lower Olifants River is not considered to be suitable for protection of aquatic ecosystems (DWAF, 1996) and is also unfit for human consumption at the Olifants and Balule rest camps in the Kruger National Park. In addition, the quality of water entering the Massingir Dam in Mozambique would also be unsuitable for irrigation of sensitive crops and may contravene the requirements of international agreements between South Africa and Mozambique. This aspect needs to be checked very carefully and, if verified, a concerted effort should be made to improve the quality of mining effluents discharged into the lower reaches of the Selati River.

5.8 The Middle and Great Letaba sub-catchment

5.8.1 General description

5.8.1.1 Hydrology

This sub-catchment consists of the area drained by the Great and Middle Letaba rivers and their main (perennial) tributaries, the Klein Letaba, Molatotsi, Nsama, Politsi, Letsitele, Thabina rivers, as well as the episodically flowing tributaries, the Ngwenyeni, Shipikani and Tsende rivers (**Figure 4.2**). The tributaries of the Great and Middle Letaba rise on the high rainfall northern slopes of the east-west trending Drakensberg

Mountains, flowing first to the north-east and then east-south-east to join the Olifants River inside the Kruger National Park shortly before it enters Mozambique. The "perennial" of the Great and Middle Letaba rivers are only perennial in their upper reaches, becoming progressively more seasonal and episodic as they flow eastwards. The three episodic tributaries rise at different points in the drier eastern portion of this sub-catchment within the Kruger National Park.

From the mid-1960s, flows in the Great Letaba River have declined progressively sue to rapidly increasing water abstraction in the upper reaches. For the last twenty-five years, flows in the lower reaches of this river have been entirely seasonal with no surface flow recorded during the dry winter months. This has posed several problems for the Kruger National Park, as the Great Letaba River is an important source of water for game animals. Accordingly, several small reservoirs were constructed along the lower reaches of the Great Letaba River inside the Kruger National Park to provide assured supplies of water during the dry winter months.

There are several water supply dams and reservoirs located in the headwater zones of all the tributaries of the Great and Middle Letaba rivers. These reservoirs supply water for domestic consumption in the several towns, as well as irrigation water for the extensive areas of irrigation agriculture at the foothills of the Drakensberg Mountains and along both banks of the larger rivers. In the drier central and eastern portions of this sub-catchment, the many settlements, farmsteads and small towns rely on boreholes or run-of-river abstraction for their water supplies. During the dry winter months, these communities depend entirely on borehole water supplies.

The sub-catchment also contains several hundred small farm dams. These provide important sources of water for small farming operations, livestock watering and domestic consumption.

5.8.1.2 Geology

In its upper reaches, this sub-catchment is underlain by rocks of the Transvaal Sequence, which form the major portion of the Drakensberg Mountain range. Quartzites, silicified sandstones, chert, hornfels, basic lava and dolomite dominate the lithology. The dolomite outcrops, in particular, are important sources of good quality water in the upper catchment and contribute water throughout the year. These rocks form prominent landscape units along the watershed.

Further to the east and north-east, rocks of the Gravelotte Group (part of the Murchison Sequence) and Rooiwater Complex outcrop and are visible as a range of low hills that trend south-west to north-east. Quartzite, schists, basic lava and granitic rocks, with considerable base metal mineralization and numerous pegmatites on the periphery of this formation, dominate the lithology. In the south, these greenstone formations are referred to as the "Murchison Greenstones" and contain important deposits of antimony and gold, with minor deposits of mercury and zinc. In the north, these formations also outcrop as low ranges of folded hills and are named the "Giyani Greenstones". The Giyani Greenstone area has a very similar lithology to that of the Murchison Group and is also heavily mineralised, with important gold deposits. An unfortunate aspect of the lithology here is the presence of arsenopyrite.

In the south-west of the sub-catchment, felsites and gabbros of the Rooiwater Complex are found at the foot of steep hill slopes. Similar outcrops, comprising rocks of the Banderlierkop Complex, outcrop in the north-western portion of the sub-catchment. Both of these rock types are relatively easily eroded and contribute increased levels of sediments in the valley depressions and river channels. Granitic and gneissic rocks of the crystalline Basement Complex underlie most of the central and eastern portions of the sub-catchment. These rocks outcrop at various points across the Lowveld, forming prominent hills or koppies. The exposed weathered granites are easily eroded, particular where the vegetation cover is sparse or denuded. Accelerated rates of sediment production occur in this region, with large amounts of coarse and fine sediments accumulating in river channels. The eastern portion of the sub-catchment is marked by the Lebombo Mountains, consisting of acidic and intermediate rhyolites and lavas of the Karoo Sequence. Small areas of Quaternary deposits line the broad shallow bed of the Great Letaba River along its lower reaches.

A large number of dolerite dykes and sills have intruded the Basement Complex granites and gneisses. These rocks are less resistant to weathering than their granite and gneiss host rocks and give rise to negatively weathered linear features in the landscape, often forming or delineating drainage lines that become filled with coarse rock and gravel fragments.

5.8.1.3 Pedology, agriculture and land use

Soils in the Selati sub-catchment can be divided into four broad groups or regions:

- Large areas of moderately deep to deep, reddish clay-rich soils in the upper reaches, occasionally becoming leached to form pale-coloured kaolinitic deposits;
- Areas of sandy colluvial soils at the foot of the escarpment, grading into red sandy-clay soils in the western part of the sub-catchment;
- Shallow, brownish to greyish-brown sandy soils overlying coarsely weathered rock in the central and eastern portion of the sub-catchment; and
- Transported alluvial deposits of coarse to fine-grained sands and silts located along drainage lines.

The upper reaches of the Great and Middle Letaba sub-catchment contain large areas of plantation forestry (both Pines and Eucalyptus) and there are important natural forests on the steep escarpment slopes and upland areas. The central portion of the sub-catchment supports extensive rain-fed and irrigated agriculture, consisting primarily of citrus and sub-tropical fruits, as well as smaller areas of cotton, oil seeds and vegetables. The central and lower reaches of the Great Letaba River provide an important source of water for game farms and livestock (cattle and goats) rearing farms. In areas located away from the main river channel, rain-fed subsistence agriculture of drought-tolerant crops is important, with livestock rearing of cattle, goats and donkeys.

Land use in the entire eastern portion of the sub-catchment is wildlife conservation, with the Kruger National Park occupying the largest area. Several smaller game reserves and game farms are also located close to the western border of the Kruger National Park in some of the driest areas of the sub-catchment.

The towns of Tzaneen and Giyani are the largest towns in the sub-catchment and form regional service centres with the development of a few light industries associated with the agricultural activities in the area. Several smaller settlements are located in rural areas or communal lands within the former homeland states of Gazankulu, Lebowa and Venda.

5.8.1.4 Surface water users

The larger towns and their associated industrial activities receive domestic water supplies from nearby water storage reservoirs. These water storage reservoirs also supply irrigation water to a number of irrigation boards located in the upper and middle reaches of the Great and Middle Letaba rivers, as well as their larger tributaries. Irrigation is by far the largest water user in this sub-catchment. The demand for water in this sub-catchment far exceeds the available supplies and this sub-catchment is considered to be water stressed.

Most of the smaller towns and settlements in the sub-catchment rely on water supplied from small farm dams or local boreholes. In some cases, the smaller settlements have to rely on run-of-river abstraction (when surface water is available) or on hand-dug wells and boreholes.

5.8.1.5 Water management systems

The Department of Water Affairs and Forestry (DWAF) are responsible for all aspects of water use and effluent discharge in this sub-catchment. The responsibility for supply of irrigation water has been delegated to several irrigation boards. These organizations are required to submit regular returns informing DWAF as to the quantity of water delivered and any permits issued or cancelled.

The Department also regulates all large (> 150 m^3/day) water abstractions, and monitors the quantity and quality of all effluent discharges through a system of effluent discharge permits or licences. Each licensed effluent discharger is required to carry out a routine monitoring programme of the flow and quality of their effluent and supply this to DWAF. The Department then conducts random audits to check the veracity of the effluent returns submitted by each discharger.

5.8.1.6 Human impacts on water resources (excluding mining)

The following activities can be expected to have an impact on water resources in the Great and Middle Letaba sub-catchment:

- Small landfills and solid waste disposal sites at all towns;
- Disposal of liquid (domestic) effluent at all towns;
- Small volumes of runoff from the towns and urbanized areas;
- De-vegetation and other forms of veld degradation, leading to increased erosion and loads of suspended sediments in most streams and rivers;
- Non-point domestic effluent from numerous small settlements and farms;
- Minor non-point impact from non-intensive commercial or subsistence agriculture;

- Minor non-point impact of agricultural return flows from intensive irrigation areas; and
- Moderate amounts of litter and domestic garbage alongside the roads that traverse the sub-catchment.

5.8.2 Mining and mineral processing operations

The following mining operations are of interest in the Middle Letaba and Great Letaba sub-catchment (**Figures 4.2 and 4.3**; **Table 5.15**).

Table 5.15: Mining operations in the Middle Letaba and Great Letaba sub-catchments.

Code Number	Name of Mine	Commodity (ies) Mined	Status	Relative Size	Probable Impact
B7-8	Soekmekaar	Corundum	Operating	Small	Low
B8-2	Giyani alluvial	Gold	Artisan (few)	V. small	Low - Medium
B8-4	Giyani Phosphate	Phosphate	Prospecting	Small	Very low
B8-5	Letaba Vermiculite	Vermiculite	Prospecting	Small	Very low
B8-6	Marikani	Vermiculite	Prospecting	Small	Very low
B8-7	Letaba	Vermiculite	Prospecting	Small	Very low
B8-8	Main Mine	Gold	Operating	Small	Low
B8-9	Main Stone	Dimension stone	Operating	Medium	Very low
B8-10	Golden Davey	Gold	Operating	Small	Low
B8-11	Davey	Feldspar	Operating	Small	Very low

5.8.3 Alluvial mining

Alluvial gold mining takes place along the Nsama River where it crosses the Giyani Greenstone formation. The number of people involved in this activity is apparently low, but their activities contribute mercury and arsenic to the river.

5.8.4 Monitoring systems

The Department of Water Affairs and Forestry (DWAF) routinely collects water samples and gauges flows at a few sites in this sub-catchment, as part of its national monitoring programme.

5.8.5 Water quality data

A selection of water quality data has been obtained for this sub-catchment (**Table 5.16**). Whilst these data do not refer specifically to the implications of mining activities, they do provide a picture of the general water quality in the rivers of the sub-catchment

Table 5.16: Representative water quality data for the Great and Middle Letaba rivers, as well as the Nsama, Thabina, Klein Letaba and Letsitele rivers. [All data are given as mg/litre, except pH (log units) and electrical conductivity (mS/metre)].

Parameter	**G. Letaba (Tzaneen)**	**G. Letaba (KNP)**	**M. Letaba**	**K. Letaba**	**Thabina**	**Letsitele**	**Nsama**
pH	6.4	7.45	7.3	7.4	7.6	7.3	7.7
Conductivity	4.0	21.4	20.6	28.6	26.1	19.5	32
TDS	37	165	162	219	221	162	248
Ca	2	14	18	18	28	20	21
Mg	1	7	8	14	12	7	14
Na	4	18	9	17	9	11	23
K	1.2	4.2	4.5	2.8	0.8	2.1	4.4
Si	6.4	7.3	5.8	14.8	9.9	8.9	11.1
Total Alkal.	11	71	89	108	122	75	123
Cl	4	23	5	11	6	13	15
F	0	0.1	0.2	0.1	0.2	0.1	0.2
SO_4	4	5	4	9	7	5	8
Fe	0.57	1.58	0.19	0.38	0.93	0.19	0.41
Mn	0.05	0.22	0.06	0.04	0.26	0.06	0.10

These data demonstrate that the general water quality in the Great and Middle Letaba rivers and their main tributaries is generally good. The declining water quality along the length of the Great Letaba River probably reflects a combination of evaporative concentration and irrigation return flows.

5.8.6 Implications for water quality and quantity management

The available evidence suggests that there is little evidence of any adverse effects that could be attributed to mining activities. However, given the alluvial mining activities in the Nsama River, it would be prudent to examine the water quality of this tributary more closely.

The other mining and quarrying activities in the upper reaches of the Middle Letaba River would be likely to increase suspended sediment levels.

5.9 The Shingwedzi sub-catchment

5.9.1 General description

5.9.1.1 Hydrology

This sub-catchment consists of the area drained by the Shingwedzi River and its major tributaries, the Phugwane, Mphongolo and Shisha rivers in South Africa, as well as the slightly smaller Mozambican portion

(**Figure 4.2**). The tributaries of the Shingwedzi River rise on the eastern slopes of the range of low, north to south trending hills that mark the watershed between this sub-catchment and that of the Levuvhu sub-catchment of the Limpopo basin. All the tributaries of the Shingwedzi River are located in low rainfall areas and therefore only have seasonal or episodic flows during the wet summer months of each year. Most of the catchment area of the Shingwedzi River and its tributaries lies within the boundaries of the Kruger National Park.

From the mid-1960s, flows in the Great Letaba River have declined progressively sue to rapidly increasing water abstraction in the upper reaches. For the last twenty-five years, flows in the lower reaches of this river have been entirely seasonal with no surface flow recorded during the dry winter months. This has posed several problems for the Kruger National Park, as the Great Letaba River is an important source of water for game animals. Accordingly, several small reservoirs were constructed along the lower reaches of the Great Letaba River inside the Kruger National Park to provide assured supplies of water during the dry winter months.

There are a few small farm dams located in the headwater zones of all the tributaries of the Shingwedzi River; these supply water for domestic consumption in several small settlements and mines. In the drier central and eastern portions of this sub-catchment within the Kruger National Park, boreholes are used to supplement water supplies during the dry winter months. In the eastern portion of this sub-catchment located within Mozambique, the residents of the many small settlements located along the banks of the Shingwedzi River rely on hand-dug wells in the river and stream beds for their water supplies.

5.9.1.2 Geology

The geological features of the Shingwedzi sub-catchment consist predominantly of large areas of granitic and gneissic rocks of the crystalline Basement Complex underlying the western and central portions of the sub-catchment, together with the acidic and intermediate rhyolites and lavas of the Karoo Sequence that form the northern extension to the Lebombo Mountains. Within Mozambique, extensive Quaternary deposits of semi-consolidated sandstones and mudstones, with slightly older Tertiary deposits of the Mazamba, Jofane and Cheringoma Formations, underlie the sub-catchment. In addition, there are a few outcrops of Grunja and Sena post-Karoo complex rocks that consist predominantly of alkaline dolerites and shales. Recent alluvial deposits are present along wide flood terraces on either side of the Shingwedzi River.

The granitic and gneissic rocks of the Basement Complex outcrop at various points across the central area of the sub-catchment, forming prominent hills or koppies. These exposed weathered granites erode easily, and accelerated rates of sediment production occur in this region, with large amounts of coarse and fine sediments accumulating in river channels.

Small outcrops of the Giyani Greenstone Formation occur in the western and southern portions of this sub-catchment, together with outcrops of Timbavati Gabbro close to the Lebombo Mountains. Several dolerite dykes and sills have intruded the Basement Complex granites and gneisses across the central and southern portions of this sub-catchment. These rocks are less resistant to weathering than their granite and gneiss host rocks and give rise to negatively weathered linear features in the landscape, often forming or delineating drainage lines that become filled with coarse rock and gravel fragments.

5.9.1.3 Pedology, agriculture and land use

Soils in the Shingwedzi sub-catchment can be divided into three broad groups:

- Areas of sandy colluvial soils at the foot of hills, grading into shallow, reddish-coloured sandy-loam soils in the western part of the sub-catchment;
- Shallow, brownish to greyish-brown sandy soils overlying coarsely weathered rock in the central and eastern portion of the sub-catchment; and
- Transported alluvial deposits of coarse to fine-grained sands and silts located along drainage lines.

Land use in the upper reaches of the Shingwedzi River and its tributaries consists of small-scale subsistence agriculture and some game farming and wildlife conservation in nature reserves. The central portion of the sub-catchment is located within the Kruger National Park and land use therefore consists entirely of wildlife conservation.

Land use in the eastern (Mozambican) portion of the sub-catchment consists almost entirely of small-scale subsistence agriculture, with most cultivated areas being located on flood terraces close to stream and river channels. Some Mozambican settlements also grow a few Mango and Cashew Nut trees and raise a few livestock.

No towns of any size occur within the sub-catchment.

5.9.1.4 Surface water users

Water use within this sub-catchment consists almost entirely of subsistence agriculture and wildlife conservation. Domestic water supplies to the small settlements located along the banks of the Shingwedzi River in Mozambique are provided from hand-dug wells. Boreholes provide domestic water supplies to the tourist camps located within the Kruger National Park.

5.9.1.5 Water management systems

The Department of Water Affairs and Forestry (DWAF) are responsible for all aspects of water resource management in the upper (South African) reaches of the Shingwedzi sub-catchment.

In Mozambique, the Mozambican Department of Water Affairs does not monitor flows or water quality in the Shingwedzi River, but does monitor the Olifants River downstream of the Shingwedzi-Olifants confluence.

5.9.1.6 Human impacts on water resources (excluding mining)

The following activities can be expected to have an impact on water resources in the Shingwedzi sub-catchment:

- Small landfills and solid waste disposal sites at tourist camps in the Kruger National Park;
- De-vegetation and other forms of veld degradation, leading to increased erosion and loads of suspended sediments in most streams and rivers;
- Non-point domestic effluent from numerous small settlements and farms;
- Minor non-point impact from non-intensive commercial or subsistence agriculture;
- Minor amounts of litter and domestic garbage alongside the few roads that traverse the upper reaches of the sub-catchment.

5.9.2 Mining and mineral processing operations

The following mining operations are of interest in the Shingwedzi sub-catchment (**Figures 4.2 and 4.3**; **Table 5.17**).

Table 5.17: Mining operations in the Shingwedzi sub-catchment.

Code Number	Name of Mine	Commodity (ies) Mined	Status	Relative Size	Probable Impact
A8-9	Shingwedzi	Gold	Abandoned	Very small	Very low
B8-1	Shingwedzi Alluvial	Gold	Abandoned	Artisan (few)	Very low
B8-2	Giyani Alluvial	Gold	Operating	Artisan (few)	Low – Medium
B8-3	Golden Pocket	Gold	Prospecting	Very small	Very low

5.9.3 Alluvial mining

There are two sets of alluvial gold mining activities in this sub-catchment, one of which has apparently been abandoned (**Figures 4.2 and 4.3**; **Table 5.17**). The Giyani alluvial goldfield apparently spreads over the watershed between this sub-catchment and the Letaba sub-catchment to the south; hence it is recorded in both sets of information.

5.9.4 Monitoring systems

Monitoring of water quality is conducted in South Africa only.

5.9.5 Water quality data

No water quality data for this sub-catchment could be obtained in time for inclusion in this report.

5.9.6 Implications for water quality and quantity management

The alluvial gold mining activities in this sub-catchment are the only ones likely to have any implications for water quality. The rocks of the Giyani Greenstone Formation contain deposits of arsenopyrite and the artisan gold miners also use mercury to separate out the gold. Therefore, there is a small possibility that arsenic and mercury may pose localized problems in the upper reaches of this sub-catchment.

5.10 The Timbavati-Klaserie sub-catchment

5.10.1 General description

5.10.1.1 Hydrology

This sub-catchment consists of the lowest portion of the Olifants basin in South Africa and contains the area drained by the Timbavati and Klaserie rivers, as well as the Nhlaralumi and several smaller tributary streams (**Figure 4.2**). The Klaserie River rises on the eastern slopes of the Drakensberg Mountains, whilst the Timbavati Rivers rises in the foothills of the Drakensberg Mountains. The other tributary streams rise from outcrops of low granitic hills scattered across the Lowveld within the boundaries of the Kruger National Park (KNP). The Klaserie River is perennial only in its upper reaches and most of its water is lost by evaporation or abstraction for irrigation. Apart from the Klaserie River, all the other rivers and streams have episodic flows only during the wetter summer months. Overall, the predominantly episodic tributary rivers in this sub-catchment do not provide very large quantities of water to the Olifants River.

Most of the catchment area of the Timbavati and Klaserie rivers and their tributaries lies within the boundaries of the KNP, with a small portion located between the foot of the Drakensberg Mountains in the west and the western boundary of the KNP. There are several small farm dams located in the headwater zones of the Timbavati and Klaserie rivers outside the KNP, as well as one larger water supply impoundment on the Klaserie River. Most farms outside the KNP and the tourist camps inside the KNP rely on boreholes for their water supplies, particularly during the dry winter months of the year.

5.10.1.2 Geology

The geological features of the Timbavati – Klaserie sub-catchment are similar to those of the Shingwedzi sub-catchment. Most of the area is underlain by large areas of granitic and gneissic rocks of the crystalline Basement Complex, with the acidic and intermediate rhyolites and lavas of the Karoo Sequence to the east forming the northern extension to the Lebombo Mountains. In the western portion of the sub-catchment, rocks of the Transvaal Sequence forming the Drakensberg Mountains underlie the western edges of the area drained by the upper Klaserie River. Recent alluvial deposits are present along wide terraces on the banks of all of the larger rivers and streams, and particularly the lower reaches of the Olifants River.

The granitic and gneissic rocks of the Basement Complex outcrop at various points across the central area of the sub-catchment, forming prominent hills or koppies. These exposed weathered granites erode easily, and accelerated rates of sediment production occur in this region, with large amounts of coarse and fine sediments accumulating in river channels.

Small outcrops of the Murchison Greenstone Formation occur in the northwestern and northern portions of this sub-catchment, together with outcrops of Timbavati Gabbro close to the Lebombo Mountains. Several dolerite dykes and sills have intruded the Basement Complex granites and gneisses across the central and southern portions of this sub-catchment. These rocks are less resistant to weathering than their granite and gneiss host rocks and give rise to negatively weathered linear features in the landscape, often forming or delineating drainage lines that become filled with coarse rock and gravel fragments.

5.10.1.3 Pedology, agriculture and land use

Soils in the Timbavati-Klaserie sub-catchment can be divided into three broad groups:

- Areas of sandy-clay colluvial soils at the foot of the Drakensberg Mountains, grading into shallow, reddish-coloured sandy-loam soils in the western part of the sub-catchment;
- Shallow, brownish to greyish-brown sandy soils overlying coarsely weathered rock in the central and eastern portion of the sub-catchment; and
- Transported alluvial deposits of coarse to fine-grained sands and silts located along drainage lines.

Land use in the uppermost reaches of the Timbavati-Klaserie sub-catchment consists of small-scale irrigation agriculture, subsistence agriculture and game farming. The central and eastern portions of the sub-catchment are located within the Kruger National Park and land use therefore consists entirely of wildlife conservation.

Hoedspruit is the only town of any size in this sub-catchment.

5.10.1.4 Surface water users

Water use within this sub-catchment consists almost entirely of irrigation, subsistence agriculture and wildlife conservation. Domestic and irrigation water supplies to the farms and small settlements located in the upper reaches of this sub-catchment are provided by irrigation water released from the Jan Wassenaar Dam. Boreholes and hand dug wells provide water for most of the smaller settlements located away from riverbanks. Boreholes are usually the only source of water for the tourist camps in the many game farms and private nature reserves. The Kruger National Park tourist rest camps at located at Balule and Olifants receive their water supplies directly from the lower reaches of the Olifants River.

5.10.1.5 Water management systems

The Department of Water Affairs and Forestry (DWAF) are responsible for the management of water resources and the allocation of permits for water use and effluent discharge. The responsibility for supply of irrigation water is delegated to the local irrigation board.

5.10.1.6 Human impacts on water resources (excluding mining)

The following activities can be expected to have an impact on water resources in the Timbavati-Klaserie sub-catchment:

- Small landfills and solid waste disposal sites at the town of Hoedspruit, as well as at tourist camps in the Kruger National Park and on private game reserves;
- Over-grazing and other forms of veld degradation, leading to increased erosion and loads of suspended sediments in most streams and rivers;
- Non-point domestic effluent from several tourist camps and farms;
- Minor non-point impact from non-intensive commercial or subsistence agriculture;
- Minor amounts of litter and domestic garbage alongside the few roads that traverse the upper reaches of the sub-catchment.

5.10.2 Mining and mineral processing operations

None known.

5.10.3 Alluvial mining

None known or anticipated.

5.10.4 Monitoring systems

The Department of Water Affairs and Forestry (DWAF) collect a few water samples and gauge flows in the perennial upper reaches of the Klaserie River, whilst staff members of the Kruger National Park assist with flow gauging and water quality monitoring at two sites along the lower Olifants River.

5.10.5 Water quality data

No water quality data were available for this sub-catchment.

5.10.6 Implications for water quality and quantity management

In the absence of any mining activities, there are no implications for water quality or water resources in this sub-catchment.

5.11 The Lower Olifants (Mozambique) sub-catchment

5.11.1 General description

5.11.1.1 Hydrology

This sub-catchment consists of the lowest portion of the Olifants basin in Mozambique and contains the area drained by the Olifants River as it emerges into Mozambique from South Africa, down to its confluence with the lower reaches of the Limpopo River (**Figure 4.2**). A few small episodic tributary streams also enter the Olifants River in this sub-catchment and the Olifants River is known in Mozambique as the '*Rio des Olifantes*'.

The large Massingir Dam is located in this sub-catchment and controls all flows in the lower reaches of the Olifants River before it joins the Limpopo River. Water is released from Massingir Dam to supplement flows in the lower Limpopo River and to provide irrigation water for the large Chokwe irrigation Scheme. Most of the small settlements located in this sub-catchment rely either on the Massingir Dam or on shallow hand-dug wells for their water supplies.

5.11.1.2 Geology

The acidic and intermediate rhyolites and lavas of the Karoo Sequence that form the Lebombo Mountains, mark the western boundary and dominate the geological features of the lower Olifants sub-catchment. Elsewhere, extensive Quaternary deposits of the Mazamba, Jofane and Cheringoma Formations, underlie the sub-catchment. In addition, there are a few outcrops of Grunja and Sena post-Karoo complex rocks that consist predominantly of alkaline dolerites and shales. Recent alluvial deposits are present along wide flood terraces on either side of the lower Olifants River.

5.11.1.3 Pedology, agriculture and land use

Soils in the lower Olifants sub-catchment can be divided into three broad groups:

- Areas of sandy colluvial soils at the foot of the Lebombo Mountains, grading into shallow, reddish- or greyish-coloured sandy-loam soils in the western part of the sub-catchment;
- Deep, brownish to greyish-brown sandy soils overlying coarsely weathered sedimentary rocks in the central and eastern portion of the sub-catchment; and
- Transported alluvial deposits of coarse to fine-grained sands and silts located along drainage lines and riverbanks.

Land use in the lower reaches of the Olifants River and its few episodic tributaries consists entirely of small-scale subsistence agriculture and some irrigation, with most cultivated areas being located on flood terraces close to stream and river channels. Some Mozambican settlements also grow a few Mango and Cashew Nut trees and raise a few livestock. No towns of any size occur within the sub-catchment.

5.11.1.4 Surface water users

Water use within this sub-catchment consists almost entirely of rain-fed subsistence agriculture and irrigation. Domestic water supplies to the small settlements located in this sub-catchment are provided primarily from hand-dug wells.

5.11.1.5 Water management systems

The Mozambican Department of Water Affairs is responsible for management of water supplies and water quality in this sub-catchment.

5.11.1.6 Human impacts on water resources (excluding mining)

The following activities can be expected to have an impact on water resources in the lower Olifants sub-catchment:

- De-vegetation and other forms of veld degradation, leading to increased erosion and loads of suspended sediments in streams and rivers;
- Non-point domestic effluent from numerous small settlements; and
- Minor non-point impact from non-intensive commercial or subsistence agriculture;

5.11.2 Mining and mineral processing operations

None known.

5.11.3 Alluvial mining

None known or anticipated.

5.11.4 Monitoring systems

In Mozambique, the Mozambican Department of Water Affairs monitors flows in the Olifants River downstream of the confluence of the Olifants and Shingwedzi rivers as part of its regulation of irrigation water to the Chokwe irrigation Scheme.

5.11.5 Water quality data

No water quality data are available for this sub-catchment.

5.11.6 Implications for water quality and quantity management

The complete absence of any information on possible mining activities in this sub-catchment prevents conclusions being drawn.

5.12 Summary of impacts of mining operations on water resources of the Olifants basin

The wide variety of mining operations and mineral processing activities located within the Olifants basin have differing degrees of impact on both the water resources available to other users and on the water quality of these resources. From the available data, it seems clear that those mining operations that are located within low rainfall regions of the basin (predominantly the north-eastern and eastern regions, where physical weathering processes dominate) have relatively low and/or localized impacts on the water resources. In contrast, mining operations located in the wetter regions of the basin (predominantly the southern regions, where chemical weathering processes prevail) tend to have far more extensive impacts. This seems to be due to the presence of ample moisture within the soil profile that enables continual chemical changes to take place and allows the water available to mobilize and transport the different contaminants that become available.

A summarized overview of the actual and anticipated impacts of mining operations and mineral processing plants in each sub-catchment of the Olifants basin is given in **Table 5.17**. This information provides a useful impression that could be used to focus water resource management plans and water quality management plans in the different component areas of the Olifants basin.

6. CONCLUSIONS

This study on the impacts of mining and mineral processing on water resources and water quality in the Zambezi, Limpopo and Olifants basins was carried out within extremely tight time and budget constraints. As a result, it was not always possible to obtain sufficient information on mining activities or their impacts on water resources and water quality, nor was it possible to ensure an equitable spread of information between the different river basins. Nevertheless, despite these constraints, this study represents the first attempt to present a holistic overview of the extent of mining activities in the three river basins and their actual or potential impacts on the water resources within these basins.

An important point that must be emphasized at the outset is that this study does not seek to assign blame or to allege misconduct by any mining operation or water resource management authority. This study simply aimed to compile, collate, synthesize and analyze available information, and then to present this is a form that could be used by all stakeholders involved in the “mining and sustainable development” debate.

Although this study was conducted within a very short period of time, a wide range of informed opinion was consulted and extensive use was made of information available in technical reports and published sources. Whilst some data sets could not be obtained because they were too costly, the Project Team was still able to compile, collate and synthesize a considerable amount of information to produce this report. In essence, therefore, this report represents a first step towards a more comprehensive analysis of the impacts of mining and mineral processing activities on the biophysical environment. As such, the report should prove to be useful for a wide range of stakeholders and should also be used as a basis for directing future investigations and research activities in this arena.

Against this introductory background, it is important to recognize that several types of mining activities in different geographic areas are under-reported in this document. Similarly, the report does not contain a comprehensive set of data or information relating to mining and mineral processing impacts on water resources. In particular, the Project Team had great difficulty in obtaining full details of mining operations in several SADC countries, and could seldom gain access to sensitive data on water resource and water quality impacts attributable to mining. These deficiencies should be remedied in future work so that a more complete picture can be obtained.

Arising from the data and information presented in this report, a series of conclusions have been drawn; these are presented below in no specific order of precedence.

6.1 The extent and significance of impacts in the three river basins

6.1.1 Acid mine drainage impacts on water resources and water quality

Acid mine drainage (AMD) represents the most widespread and pervasive mining-related impact in the three basins studied. Almost all of the mineralised targets for mining consist of sulphide ore bodies or are contaminated with sulphides, especially iron sulphide ("pyrites"). Whenever these ores are exposed to air and moisture, the sulphide minerals present start to oxidize via a well-known set of autocatalytic reactions to give high concentrations of total dissolved salts (particularly sulphates), low pH values and high concentrations of dissolved metal ions (especially iron). The resulting solution is toxic to most forms of aquatic life and can lead to dramatic changes in ecosystem functioning as well as changes in the structure and chemical composition of soils. The process of sulphide oxidation is very difficult to stop once it has started and the resulting AMD can persist for centuries, as proven in some English lead and tin mines.

Specific areas of concern around AMD in the three river basins studied are:

- The prevalence of AMD in the high-sulphur coalfields located within the Olifants basin in South Africa. These problems of AMD are accentuated both by the number of collieries and by their size, as well as the long time periods over which they have operated (decades), and the relatively abundant supplies of water that are available in this area. Water quality changes attributable to AMD from this area can be discerned (principally as changes in the sulphate to chloride ratio in water samples) for up to two hundred kilometres downstream in the Olifants River.

- The large-scale AMD problems associated with mines on the Zambian Copperbelt, where numerous, very large copper mines have operated for decades. Many of the Zambian copper mines appear to have operated for prolonged periods without due attention being paid to the correct siting and operation of tailings dams, and proper treatment of effluent before discharge to the Kafue River. Fortunately, the carbonate-rich local lithology provides some safety in the form of a large buffering capacity that can effectively neutralize much of the AMD produced. However, this situation is not sustainable indefinitely and concerted effort will be needed to redesign, and perhaps even relocate, some of the tailings dams, whilst improving general housekeeping practices and effluent treatment process efficiencies.

- At a smaller scale, gold and base metal mines that exploit these commodities in the different Greenstone Formations in the three basins studied here also experience problems due to AMD. In these cases, however, the presence of arsenopyrite in the gangue rock provides an added problem in the form of arsenic liberation during sulphide oxidation. This arsenic is highly toxic and can have dramatic negative effects on aquatic ecosystems, coupled to adverse impacts on human health if water users drink contaminated water downstream of these operations.

- The extent of AMD impacts and perceptions of their severity appears to be closely related to the tendency for the acidic solution to move away from its source and contaminate water resources progressively further away from its origin. In sites where the AMD remains close to its source, the severity of the problem is perceived to be less. This contrasts with situations where the influence of AMD can be seen several tens of kilometres away from its source; here the problem is perceived to be far worse, even if the total quantities of acid involved are similar. This so-called "mobility" of AMD, is the result of increased quantities of water being available to "move" the AMD away from its starting point. The water responsible for "moving" the acid from its source can be derived either from high local rainfalls, or from mining operations that use large volumes of process water that must be discarded after use.

Where the available moisture exceeds the losses due to evaporation, AMD can be expected to "move" away from its source and pose a larger problem for a mining operation. This tendency is reflected in the use of the Weinert N weathering index. Physical or mechanical weathering processes dominate in areas with a high Weinert N index experience; available moisture levels are low and AMD is seldom a problem. The converse holds for moister areas with a low Weinert N index. Whilst this understanding will not resolve existing AMD problems, it provides useful information as to the most suitable types of effluent processing and control processes that will be needed for new mines in specific areas.

- No universal or permanent "cure" for the AMD "problem" has yet been found, though temporary, site-specific solutions have been demonstrated in several southern African mining operations. It is therefore possible that AMD problems will continue to persist for the foreseeable future despite the enormous expenditures and concerted attention paid to the problem so far. However, despite this somewhat gloomy outlook, the collaborative COALTECH 2020 initiatives in South Africa have shown real promise in devising innovative ways to manage the AMD problem. This initiative involves representatives of all the major mining houses, as well as scientists, engineers and academics, and seems to offer the greatest opportunity of dealing with the AMD issue successfully.

6.1.2 Impacts due to the release of potentially toxic metals

No mining operation is ever fully successful in recovering every part of the metal or metals that it seeks to extract. Residual metals that pass through the mining processes enter the external environment where they have the potential to pose varying types of problem to the biophysical environment. The most noticeable problems concern the toxicity of nearly all metals when they are present as metal ions in solution. Almost every metal has the potential to cause some form of harm to aquatic life if it is present in sufficiently high concentrations. The more important "problem" metals are mercury, cadmium, chrome, vanadium, zinc, copper, and, to a lesser extent, iron and manganese, because these metals exert toxic effects at relatively low concentrations if they are present in specific oxidation states or forms.

Specific areas of concern around potentially toxic metals are:

- The release of hexavalent chrome from chrome mining operations and from ferroalloy smelters and refineries in South Africa and Zimbabwe. If discharged to the aquatic environment, hexavalent chrome can be extremely toxic to aquatic life.

- The persistent use of mercury to concentrate gold by artisan gold miners poses toxicity risks to the aquatic environment and to the health of the miners. It appears that almost every artisan gold mining operation in Malawi, Mozambique, South Africa, Tanzania, Zambia and Zimbabwe uses mercury extraction methods
- Vanadium and chrome contamination of ground and surface waters by vanadium and chrome mines located on the Bushveld Igneous Complex in South Africa, particularly the Steelpoort Valley and the region around Rustenburg in the Crocodile sub-catchment.

- Antimony, cadmium and tin contamination of surface waters in Greenstone Formations mined for these metals, or as contaminants in gold mining operations located in Greenstone rock formations in South Africa and Zimbabwe. Specific examples are the Murchison and Giyani Greenstone Formations in South Africa.

- Copper contamination of various levels arising from copper mines and smelters on the Zambian Copperbelt, the areas close to the Great Dyke in Zimbabwe, the Selibe-Phikwe copper-nickel mine in eastern Botswana and the Phalaborwa area in South Africa.

- Iron and manganese contamination of surface streams, either in solution or as unsightly oxy-hydroxide precipitates, caused by aeration of iron-rich acidic solutions associated with pyrite oxidation and AMD. Specific examples occur in several iron ore mines and in gold and coalmines in South Africa and Zimbabwe.

- Zinc and lead contamination associated with AMD of low-grade ore stockpiles at Kabwe in Zambia and the Letaba Mine in South Africa.

- Antimony contamination associated with mines located on the Murchison Greenstone Formation in South Africa.

6.1.3 Impacts due to the release of potentially toxic substances

The most important issues here relates to the potential for contamination posed by organics and solvents used to separate metals from their ores during the processing phases. Most attention has been paid to cyanide used in gold mining because of the very large volumes of cyanide that are used and its toxicity to most forms of life. Importantly, cyanide can exist in numerous different forms and not all of these forms are equally toxic. In addition, cyanide is rapidly photo-oxidized to harmless carbon dioxide and nitrogen gas in sunlight, thereby greatly reducing the potential toxicity risk; the general public seldom appreciates this feature.

Discussions with stakeholders have revealed that their specific areas of concern around potentially toxic substances relate entirely to issues associated with cyanide and are seldom attributable to any specific mine or mining operation:

- The discharge of cyanide-rich tailings to tailings dams at most gold mines and their subsequent seepage from these sites into the aquatic environment.

- Inadequate control maintained over cyanide processes on gold mines such that spillages occur and contamination results.

- Occasional spillages caused by rupturing of cyanide storage tanks at gold mines, resulting in localized contamination.

- The potential for the release of toxic hydrocyanic acid (HCN) gas from cyanide-rich tailings at most gold mines.

- Small-scale (non artisan) gold mines not being able to adequately manage their cyanidation processes and causing localized cyanide pollution.

6.1.4 Salinity impacts

The most important issues associated with impacts caused by salinity (or total dissolved salts) relate to the potential for deterioration water quality for other water users and the aquatic environment. In particular, acid mine drainage is often closely associated with increased salinity levels and decreased fitness for use of the water.

Specific areas of concern around salinity impacts are:

- Reduced crop yields when the salinity of irrigation water is increased due to contaminated by mining and metal processing operations such as those experienced in areas affected by AMD. Specific examples are those experienced in the middle reaches of the Olifants River downstream of the Witbank and Highveld coalfields, and the middle reaches of the Crocodile River downstream of the Thabazimbi iron ore mines.

- Flocculation of clay particles in soils irrigated with high salinity water such that the soil structure is adversely affected. Examples of this feature can be seen along the Middle and Great Letaba rivers where increasing salinities have exacerbated the dispersive characteristics of some soils near Letaba Ranch.

- Adverse osmotic effects on aquatic plants and animals caused by increased salinity levels and altered sodium : potassium ratios. In turn, this reduces the ability of aquatic plants to withstand adverse temperature effects during the summer months, prevents completion of seed-setting and germination processes, disrupts aquatic plant life cycles and interferes with nutrient transformation processes in the aquatic environment. Examples of this can be seen in the upper reaches of the Riet, Steenkool and Olifants rivers where benthic algal communities have been altered by increased salinities and lowered pH values associated with AMD.

- Decreased rates of photosynthesis in aquatic plants exposed to increased salinity levels leads to reduced productivity and altered community structures in aquatic ecosystems. Examples of this can be seen in the lower reaches of the Olifants River where benthic algal communities have disappeared from certain habitats.

6.1.5 Impacts due to suspended solids

The most important impacts associated with increased suspended solids levels are the often very visible changes that occur to aquatic habitats and the aquatic biota. Specific areas of concern are:

- Decreased light penetration to the bottom sediments, leading to a dramatic loss of benthic photosynthetic organisms. Examples are to be found in the lower reaches of the Olifants River following sediment scouring of the Phalaborwa Barrage.

- Clogging of fish gills, preventing them from breathing and leading rapidly to death. This can cause a dramatic change in the composition of fish populations, with only those species able to breathe air being able to survive (e.g. Barbel, *Clarias gariepinus*). Examples of this feature are to be seen downstream of some clay pits near Pretoria, where large volumes of fine sediments are occasionally released during rainfalls.

- Coating the surface of aquatic plant leaves with a layer of fine sediments that prevent photosynthesis and lead to the death of the plants. Examples can be seen in the middle reaches of the Olifants River where accelerated erosion of mine waste rock piles leads to increased levels of suspended sediments.

- Deposition of (previously suspended sediments onto the bottom of river beds when water flow rates decline leads to the smothering of both micro- and macro-habitats for aquatic invertebrates. This loss or alteration of habitat results in a rapid loss of these organisms and interruptions in the food webs of the affected area. Again, specific examples of this can be seen in the middle and lower reaches of the Olifants River in South Africa. An additional example is provided by the lower reaches of the Mazowe River in Zimbabwe and Mozambique where artisan alluvial gold mining has caused a dramatic increase in suspended sediment levels. A similar situation has been recorded from the artisan alluvial gold mining on the Luenha River in Mozambique.

- Suspended sediments occur in a variety of different particle sizes and often “carry” considerable quantities of adsorbed ions, especially metal ions; these present a potential toxicity problem to both aquatic and terrestrial organisms. Occasional examples of this have been recorded from the Mwambashi River on the Zambian Copperbelt, where cattle died after drinking river water containing particles of suspended / adsorbed copper.

6.1.6 Changes to patterns of water supply and demand

All mining activities require water for a wide variety of processes, from dust suppression after blasting and during ore conveying, to dissolution of the commodity of interest and to transportation of waste sludge and tailings to disposal sites. In addition, water is also needed for domestic purposes for mine workers and their families. Impacts associated with changes to patterns of water supply and demand are normally greatest in arid and semi-arid areas. Specific concerns relate to:

- In arid areas, the quantity of water required by a specific mining operation can have a dramatic influence on the regional water balance. Inevitably, the promise of economic returns from mining will have an influence on decision-making by water supply authorities as to whether or not the required water should be supplied. In turn, the provision of water to a mining operation will mean that less water is available for other users, including the aquatic environment.

- Any effluent discharged by a mining operation affects the quality of the receiving environment and the fitness of the receiving water for other users. In arid areas, mining effluents lead to increased salinities and their associated effects. Examples of this can be seen in the drier regions of all three of the river basins evaluated in this report.

- Importantly, mining operations need reliable water supplies that will be provided with a very high level of assurance. This is necessary to avoid the risk of any processing problems in the hydro-metallurgical processes that may be caused by water shortages. Because of the unreliability and variability of rainfall in many parts of southern Africa, dams and water supply reservoirs are needed to ensure that the mining operations receives the water it needs. Construction of a dam on a river has far-reaching impacts on both ground water and river flows, as well as water quality, downstream of the structure. Typical examples can be seen at the Phalaborwa Barrage in the Olifants basin, downstream of the Vinetia Diamond Mine near the Limpopo River, and downstream of the Selibe-Phikwe copper-nickel mine near the Macloutse River in Botswana. Similar, related, effects occur when hydroelectric impoundments are built to supply electricity needed for mining and for metal refineries. The Kariba Dam that supplies electrical power to the Zambian Copperbelt is a good example of this type of effect.

6.1.7 Impacts caused by small-scale (artisan) mining

Small-scale mining activities, particularly the unlicensed (artisan) type, seldom have access to appropriate technologies or mining methods. Most of the activities are not subject to proper health, safety and environmental controls, nor are they easily manageable by mining authorities. Specific concerns relate to:

- Accelerated erosion of areas adjacent to workings that have been de-vegetated for construction materials or fuel wood leads to increased suspended sediment loads in nearby streams and rivers. Examples of this can be seen around the Ndola Rural emerald workings and the Lundazi aquamarine workings in Zambia

- Excavation of flood terraces and riverbanks increases the instability of these riverbanks and enhances the likelihood of increased flood scouring. Examples of this have been recorded from alluvial gold diggings on the Mazowe River in Zimbabwe and Mozambique.

- Excavation of river sediments exposes these sediments to oxidizing conditions and enhances the solubilization and release of any metal ions that may previously have been previously trapped as insoluble sulphides. Examples of this can be seen in the Mazowe River in Zimbabwe.

- Gold panning and operation of sluice boxes increases loads of suspended sediments in downstream reaches. Examples of this have been recorded from the alluvial gold diggings on the Luenha River in Mozambique, the Mazowe River in Zimbabwe and Ruhuhu River in Tanzania.

- Washoff of mercury used to concentrate gold leads to increased risks of mercury toxicity to aquatic and terrestrial organisms, as well as to the miners. Examples of this have been recorded on the Mazowe alluvial gold diggings in Zimbabwe.

6.1.8 *"Peripheral" or indirect impacts linked to mining*

The pivotal nature of mining activities in the general development of southern Africa means that they inevitably have had several "peripheral" or indirect impacts on the biophysical environment. A few specific examples are highlighted here to sketch the scope of the concerns:

- The influx of miners and their families and dependents into existing and new mining areas is often accompanied by the development of informal and unserviced settlements. In turn, these are characterized by poor or inadequate sanitation systems with the result that nearby watercourses become contaminated with sewage and domestic garbage. This can be clearly seen in several areas of the Zambian Copperbelt (See **Figure 3.15**) in the Kafue sub-catchment of the Zambezi basin, as well as the platinum and chrome mines of the Crocodile sub-catchment in the Limpopo basin and the Witbank and Highveld coalfields in the Olifants basin of South Africa.

- Settlements that develop in the peripheral areas of mining operations often rely on subsistence agriculture for their livelihoods. This results in progressive de-vegetation of the areas around such mines as trees are cleared for fuel wood and to open up areas for cultivation. Good examples of this can be seen around many towns on the Zambian Copperbelt (See **Figure 3.15**). In extreme cases, the subsistence agriculture may extend into local wetlands or 'dambos', thereby reducing their ability to attenuate stream flows and prevent flooding.

- Increased population numbers places greater pressure on every natural resource in an area. This pressure varies from demands for fuel and water, housing and construction materials, to accelerated exposure of the catchment surface to erosion processes. Singly, many of these effects may well be non-significant. However, when they occur simultaneously, their significance may increase by orders of magnitude. Once again, these "cumulative effects" are clearly visible on the Zambian Copperbelt.

- The construction of the Kariba Dam to provide an assured source of hydroelectric power (principally for the Zambian Copperbelt, but also for cities and towns in Zimbabwe) had a number of "unanticipated" or "peripheral" effects. Whilst the most noticeable of these was probably the dramatic rescue of thousands of animals from newly flooded areas and the explosive spread of Kariba Weed on the newly formed lake, some 55,000 people had to be resettled from the flood basin. This had a sequence of profound social and economic consequences that had not been anticipated and the process has helped to fuel the growing debate on the relative costs and benefits associated with the construction of large dams.

6.2 Current management approaches to prevent, minimize and abate impacts caused by mining operations

Over the years, increasing consciousness of the need to minimize impacts on the biophysical environment has driven considerable international and local debate around the impacts of mining and mineral processing operations. This has proceeded in tandem with a mounting awareness that modern society is completely reliant on minerals and the goods and services acquired from and/or with minerals. The process has been accompanied by new and progressive developments in regional and international legislation that seek to balance the costs of environmental impacts to society against the benefits derived so as to ensure greater equity for all beneficiaries and stakeholders.

Most miners are fully aware that it makes good business sense to prevent unnecessary impacts and that efficient management of their mining operations will help to maintain costs at low levels. In achieving a balance between the need to minimize impacts on the environment, enhance the wider social benefits of mining, and maintain shareholder confidence in their investments, the mining sector as a whole has had to collaborate progressively more closely. This has helped to develop a wider acceptance of mining amongst society in general and has allowed mine operators the opportunity to demonstrate their commitment to sustainable development principles. Some examples of current and proposed management approaches in the mining sector as a whole are listed below.

6.2.1 Improved and harmonized legislation

In the past, mining has been subject to legislation that contained conflicting principles, policies and requirements and was passed by several different government departments. This made it extremely difficult for mine operators to comply fully with legislation and exposed them to unnecessary legal problems. Recent developments include:

- In each southern African country, greater attention is being paid to harmonizing different pieces of legislation that control or affect mining activities and their consequences in an effort to eliminate inconsistencies and unnecessary duplication of effort. This activity is being extended beyond national borders in an effort to ensure that the different pieces of legislation in each SADC country are aligned and congruent with one another.

- The new draft Minerals Bill in South Africa represents a fundamentally new way of approaching the whole issue of mineral rights and the responsibilities of the different parties involved in mineral exploitation activities. Government is consulting with all stakeholders in the process of developing specific clauses in the new Minerals Bill.

- In South Africa, the Department of Mineral and Energy Affairs is in the process of revising and updating the Aide Mémoire for environmental management programmes on mines. This will facilitate prevention of environmental impacts (particularly those on the water environment) and assist mine management to undertake targeted remedial actions where these are required.

6.2.2 Improved stakeholder participation in decision-making

Worldwide, the general public has expressed a keen desire to participate fully in all aspects of decision-making and southern Africa is no exception to this trend. The governments of all SADC countries are extending the range of debates and processes that enable all stakeholders to contribute. Some typical examples are listed below:

- The proponents of all new developments (including mining) are required to identify and seek out the relevant stakeholders and help them to participate fully in decisions that may affect their livelihoods.

- The Environmental Impact Assessment (EIA) process is now established in almost all SADC countries and, in each case, stakeholder participation is required by law.

- Water resource management legislation in several SADC countries now makes specific provision for stakeholders to take an active part in decision-making processes and in the execution of water conservation and management practices.

- The SADC protocols on water resource management and the sharing of trans-boundary watercourse systems have been ratified by all SADC states and represent two examples where all the countries in the region will ensure full collaboration.

6.2.3 Collaborative, industry-wide initiatives

In the past, many different mining companies tended to develop their own, in-house solutions to specific problems that affected their operations and these were seldom shared with competing companies. Inevitably, this led to considerable duplication of effort and unnecessary expenditure in those areas where the problems that were tackled were common to all mining operations (e.g. acid mine drainage). Gradually, this situation has changed until, today, there is widespread inter-company collaboration. Two examples will suffice here:

- A consortium of gold mining companies in South Africa and Australia collaborated closely on a detailed research programme that was designed to better understand the chemistry of cyanide in gold mine tailings, and to develop appropriate treatment technologies and management actions.

- The COALTECH 2020 project involves representatives from the coal mining industry, government departments, consulting engineers and scientists, academics and local authorities in a team-based approach to the multi-facetted problems facing the South African coalmining industry. One of the most intractable problems that is being addressed in this project is the thorny issue of acid mine drainage from collieries. The most promising approaches so far identified include joint efforts to trap and collect acid mine drainage, followed by its treatment at centralized treatment facilities. This would bind the different coalmining companies into an effective partnership and help to eliminate situations where one mine might neglect its responsibilities.

6.2.4 Use of specific technologies for effluent treatment

Over the years, considerable attention has been paid to the development and refinement of cost-effective treatment technologies for almost all of the important contaminants found in mine wastes. Whilst the specific configuration of a particular treatment process will depend on the detailed chemistry of the waste stream to be treated, the generic technologies are now well understood. One example will suffice:

- The Water Research Commission and the firm Pulles Howard and DeLange have produced a series of detailed manuals describing specific effluent treatment processes that can deal with the important contaminants found in mine wastewaters. This information provides a firm foundation that enables a mine operator to customize a particular process to suit his specific circumstances. The manuals also define clearly the administrative processes that must be followed to obtain effluent discharge permits.

6.2.5 Environmental management systems

In recent years, there has been far greater awareness of the need for effective and efficient management control systems that will help to maximize the effectiveness of waste control systems, ensure a standard level of quality control, and make sure that all staff members within a mining operation are fully aware of their responsibilities. The most widespread systems in use today are those of the International Standards organization (ISO), in particular the ISO14000+ series of environmental management systems. The added benefit of these systems is that they represent an internationally accepted system of accreditation and certification that provides all stakeholders with a guarantee of specific levels of performance and care.

- Unfortunately, not all mining operations have implemented a formal system of environmental management such as the ISO14000+ system advocated here. Many smaller mines, all alluvial gold mining operations and most quarrying operations have no formal environmental management system in place.

- A concerted effort should be made by the relevant authorities to enhance the awareness of all mine operators that an environmental management system such as the ISO 14000+ series will help to minimize any adverse effects their operations may have and will also help to improve the effectiveness and efficiency of their operations.

7. RECOMMENDATIONS

Arising from the detailed findings presented and the conclusions drawn in this report, the following five recommendations can be made:

1. That this report be accepted as having fulfilled the requirements set out in the Terms of Reference for this assignment;

2. That copies of this report should be circulated to relevant stakeholders in the MMSD (SOUTHERN AFRICA) Project and its Steering Committee;

3. That the detailed conclusions drawn in **Section 6** of this report should be studied carefully and, wherever appropriate, the necessary remedial actions and decisions should be taken by the relevant stakeholders;

4. That the specific recommendations listed in **Table 7.1** should be carefully evaluated by the MMSD (SOUTHERN AFRICA) Project Team and that copies be communicated to all the relevant stakeholders; and

5. That a copy of this report be provided to the SADC Mining Sector Co-ordinating Unit to assist them in their efforts to develop and expand the mining industry in all SADC countries.

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