UTILISATION OF MAQALIKA RESERVOIR AS A SOURCE OF POTABLE WATER FOR MASERU CITY IN LESOTHO

by

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ACRONYMS

AGOA	African Growth and Opportunities Act
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
DEFRA(UK)	Department for Environment Food and Rural Affairs
DRWS	Department of Rural Water Supply-Lesotho
DWA	Department of Water Affairs- Lesotho
DWAF	Department of Water Affairs and Forestry-Lesotho
GOL	Government of Lesotho
IMP	Integrated Management Plan
LHDA	Lesotho Highlands Development Authority
LHWP	Lesotho Highlands Water Project
LSPP	Land Surveys and Physical Planning-Lesotho
NES	National Environment Secreteriat-Lesotho
MNR	Ministry of Natural Resources-Lesotho
NHTC	National Health Training Centre-Lesotho
NTU	Nephelometric Turbidity
RSA	Republic of South Africa
SABS	South African Bureau of Standards
SCS	Soil Conservation Service
SMSA	Sediment Map of Southern Africa
STPP	Sodium Tripolyphosphate
SWeCO	Swedish Consulting Group
USA	United States of America
USEPA	United States Environmental Protection Agency
WASA	Water and Sewerage Authority-Lesotho
WHO	World Health Organisation
WRC	Water Research Commission-RSA
WSB	Water and Sewerage Branch-Lesotho
WSSD	World Summit for Sustainable Development
TDS	Total Dissolved Salts

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SYMBOLS

*	Multiplication
%	Percentage
+	Addition
-	Subtraction
=	Equal
/	Division
km^2	Square kilometres
m^3	Cubic meters
km	Kilometers
m	Meters
a	Annum
kl	Kilolitre
Ml	Megalitre
s	Seconds
l_o	Mixing length
V_t	Capacity after t years of operation
V_{50}	Capacity after 50 years of operation
$\sum$	Summation
γ_1	Weight of sediment
n	Number
MCM	Million Cubic Meters

ACRONYMS

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TDS	Total Dissolved Salts

ABSTRACT

Lesotho is a land locked country, entirely surrounded by the Republic of South Africa. Maseru is the capital of Lesotho and the country's main centre for commerce and industry. The study area is located on the North-Eastern outskirts of the Maseru urban area. The catchment occupies an area of $44km^2$ with a length of about 13 km and channel slope of 0.4 km/km. The Maqalika Reservoir was built in 1983 to meet the water demands for Maseru city up to 1995, and its storage capacity was 3.7 Mm^3. The storage is gradually decreasing as sediment, carried by the natural run-off accumulates in the reservoir. Moreover, water pumped into the reservoir from the Caledon River (which is heavily sedimented) adds its own contribution of silt. The reservoir is located in a very densely populated area, and is heavily polluted leading to high purification costs.

The study was motivated by the fact that Welbedacht Dam was constructed in 1973 in the Caledon catchment but downstream of Maqalika. After 20 years, 85% of the volume of the dam was silted. The study was intended in finding whether the positioning of the Maqalika reservoir is acceptable and to find its remaining capacity as a water body supplying a fast growing city. Consideration was also given to the effect of land use practices on the water quality of the Maqalika reservoir, including the cost incurred during purification.

The water quality data on physico- chemical was collected from the Water and Sewerage Authority and was analysed using excel spreadsheets. Results obtained were compared with WHO, SABS and National Standards of Lesotho. It was found that nitrates, phosphates and faecal coliforms levels were by far above minimum standards rendering water to be very contaminated and the source being leaking sewers, defeacation in dongas and leachate from Tsosane and Lower Thamae dumping site. Iron levels were also high with mean values beyond 0.3mg/l and the source being leachate from dumping sites, poor disposal of scraps and minerals from soil. Conductivity levels were high and the suspected source is waste solid disposal having a maximum of 442mS/m in March 2001. Hardness, temperature and alkalinity do not pose much danger to Maqalika water since recorded results were almost within

limits. Turbidity levels were very high and the main source was found to be catchment sedimentation through run-off.

For determination of the impact of sedimentation through pumping, hydrological data was obtained from the Department of Water Affair (DWA) and analysed using Excel spreadsheets to get sediment concentrations. A linear regression graph was plotted using discharge against sediment concentration that yielded $y = 0.0007x - 0.0019$. This was used in the Rooseboom mathematical equation for estimation of volume occupied by sediment from 1983 - 2002 and was found to be 6789 m^3. For determination of the impact due to catchment run-off, a map method of estimating sedimentation from ungauged catchments developed by Rooseboom was used and a volume of 4.598×10^6 m^3 was obtained showing that the main contributor of sedimentation in the reservoir is catchment run-off.

The chemical costs employed during purification were also compared between WASA and Umgeni Water of Kwazulu- Natal and WASA was found to be expensive with 9 cents/kl while Umgeni spent only 5.24 cents/kl.

CHAPTER 1

1.0 INTRODUCTION

This chapter provides a general overview of the prevailing situation in Lesotho. Most of the factors that have significant contribution to this study have been discussed.

1.1 Overview of the chapters

This thesis is structured as follows:

- Chapter 2 deals with general discussion on the water resources of Lesotho and the statement of the problem.
- Chapter 3 deals with the literature review and forms the basis from which this thesis is developed.
- Chapter 4 introduces the reader to the set-up of the study area and the current situation and formulates the design methodology.
- Chapter 5 assesses two methods of estimating sedimentation.
- Chapter 6 considers the effects of land use practices on water quality, analysing physico-chemical data.
- Chapter 7 deals with the cost implications comparing Water and Sewerage Authority (WASA) and Umgeni Water KwaZulu - Natal.
- Chapter 8 the discusses conclusion drawn from this study, lists all recommendations from the conclusion and provides a list of areas for further studies

1.2 Lesotho's Environmental and Socio-economic Information

1.2.1 Location

Lesotho is a land locked country, entirely surrounded by the Republic of South Africa (RSA) and is located between latitudes 28^0 35' and 30^0 40' south and longitudes 27^0 00' and 29^0 30' east. It is a country of high mountains and deep valleys. More than two thirds of the 30 648 km^2 of land is above 1750 meters. In the east and northeast of the country lies the Drakensberg mountains with the highest peak in Southern Africa : Thabana-Ntlenyana at 3482 meters above sea level. In the middle of the country lies the Maluti range, with several peaks well above 3000 meters, runs in a northeast to southwest direction and dominates the western lowlands (TAMS, 1996) (see map 1.0).

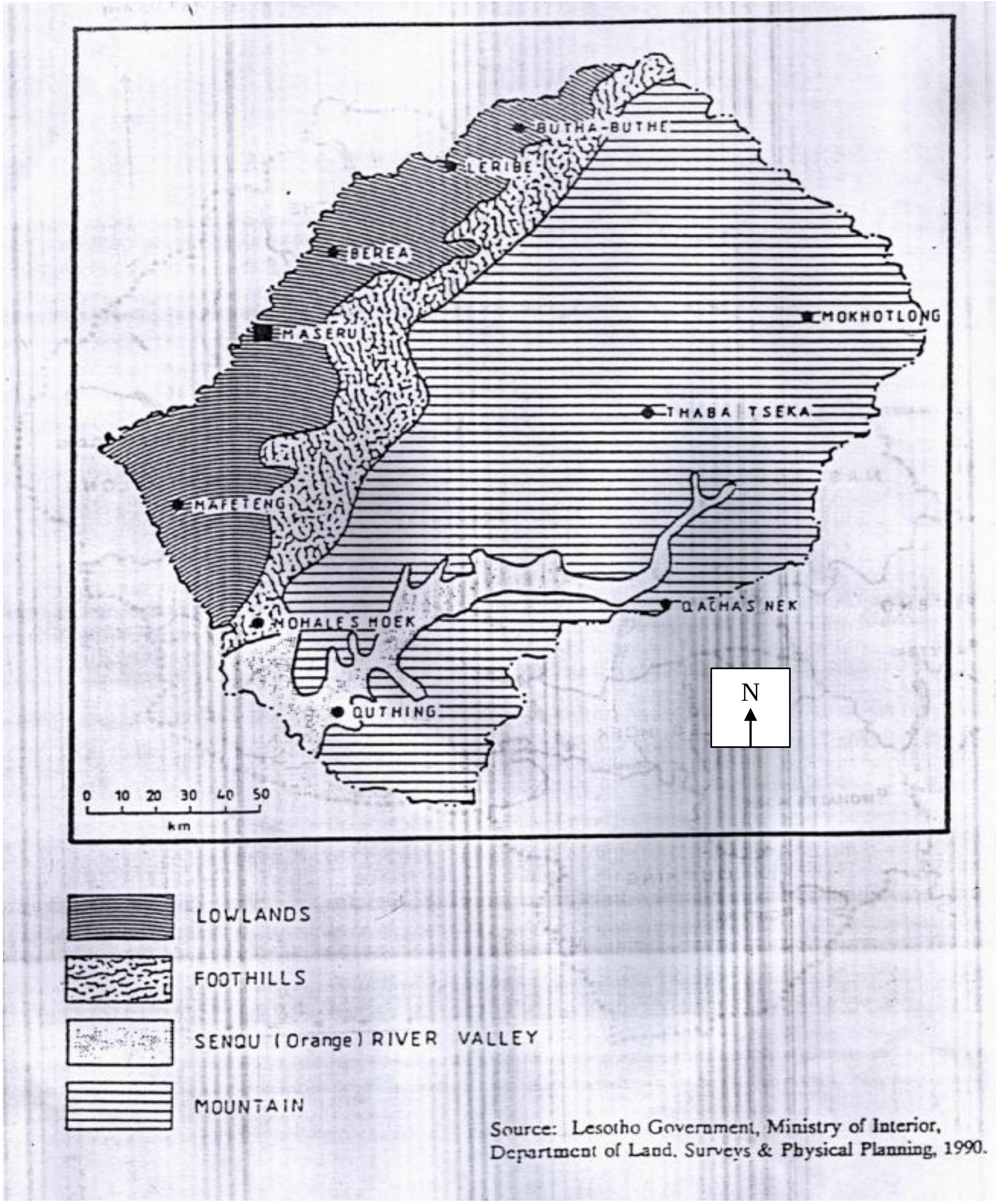
Map 1.0 Locational map of Lesotho,(source: hydrogeological map of Lesotho (1994)

The country can be categorised into three main topographic and geomorphic units: the lowlands, the foothills and the highlands (see map 1.1). The lowlands form the western part of the country, between the Mohokare (Caledon) river and the Maluti range, which constitutes the border with the RSA at an elevation of about 1800 meters. The geomorphology of this area is characterised by river systems originating from the mountain foothills with deep gullies, river terraces, flood plains, etc. The lowland area is the most highly populated and cultivated region. The mountain foothill is an intermediate zone to the east of the lowlands and below 2050 meters. The thin layer of the soil with irregular zones of vegetation, which covers that area, is the result of the ongoing soil erosion process. To the east, the Maluti range and the Drakensberg Mountains are dissected by the river systems that form very steep slopes and escarpments. This area is the least populated and is mainly grassland area (TAMS, 1996). The country is divided into ten districts, namely:

1. Maseru (capital)	2. Mafeteng
3. Berea	4. Leribe
5. Mohale’s Hoek	6. Quthing
7. Qacha ‘s Nek	8. Thaba-tseka
9. Butha-Buthe	10. Mokhotlong

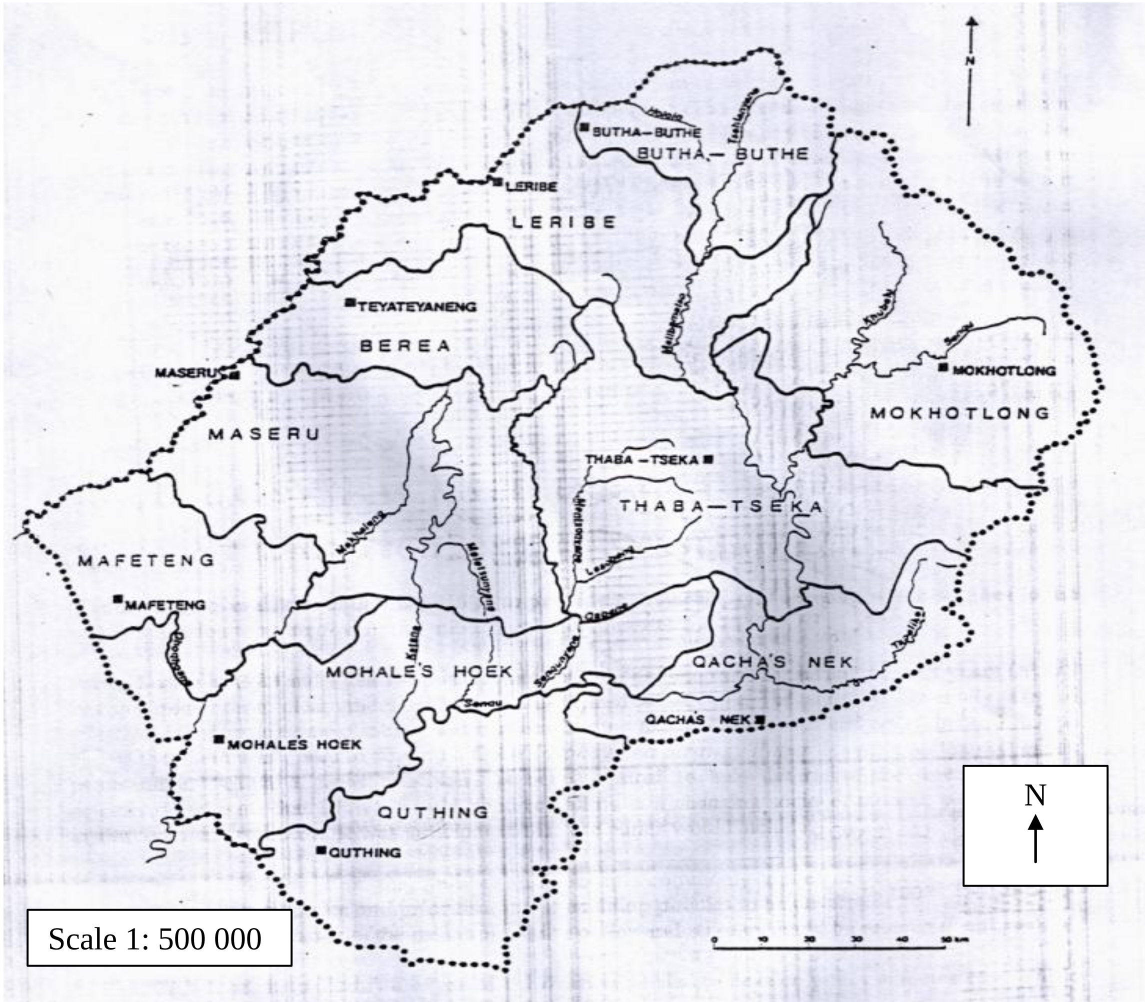
(see map 1.2)

Map 1.1 Map of ecological zones



Source: Lesotho Government, Ministry of Interior, Department of Land, Surveys & Physical Planning, 1990.

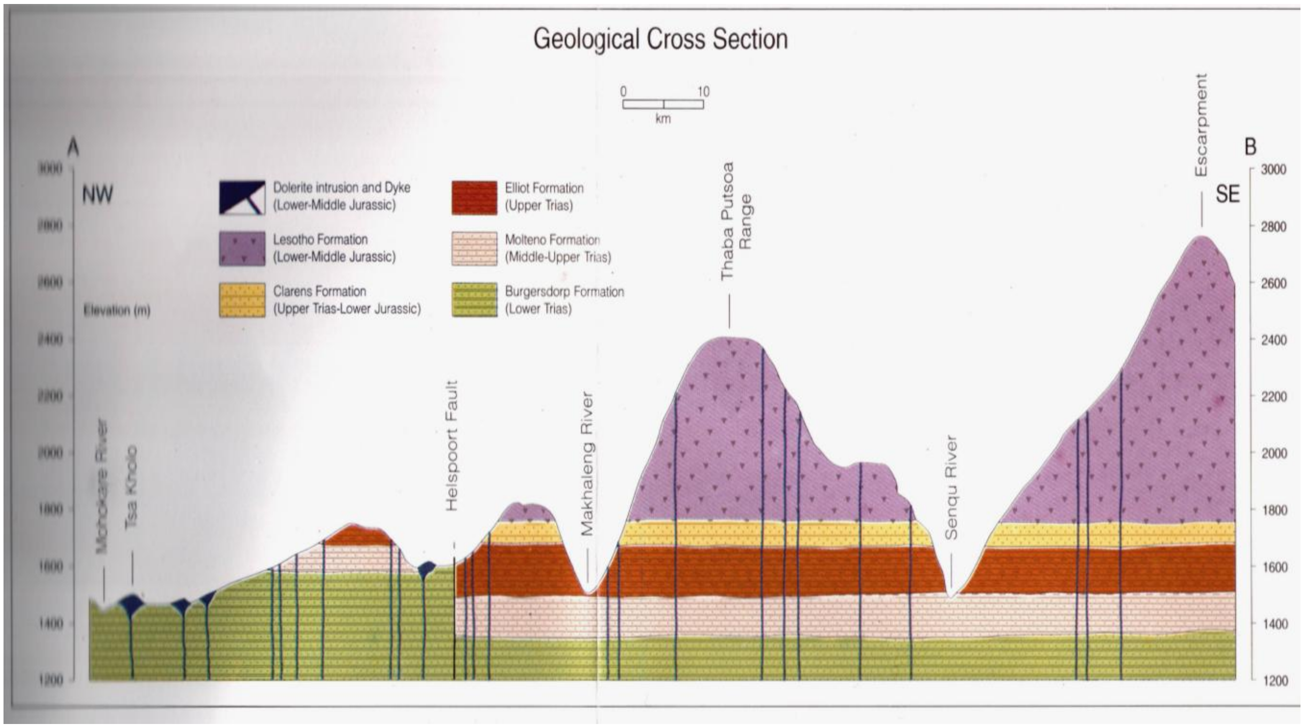
Map 1.2 Ten districts of Lesotho (source: DWA report, 1994)



1.2.2 Geology of the country

The geology of Lesotho is represented by a sequence of clastic sedimentary formations overlain by a laterally continuous section of basalt up to 1600 meters thick (TAMS, 1996). According to the Geological map of Lesotho (1981) all the consolidated rocks belong to the Karoo supergroup. Sedimentary beds of the Stormberg group are conformably overlain by volcanic flows of the Drakensberg group. Dolerite intrusives are incorporated in the Karoo sequence (see fig 1.0).

Fig 1.0 Geological cross section of Lesotho (source: Hydrogeological map of Lesotho, 1994)



1.2.2.1 Stormberg group

1.2.2.1.1. Elliot formation

Rocks belonging to the Elliot formation are exposed in the valley bottoms of some major rivers in the south. They consist of predominately red and polycoloured mudstones alternating with red and yellow medium fine grained sandstones and siltstones. Coarse but restricted channel lag deposits may occur at the base of some sandstone horizons. The arenaceous beds are typically lens shaped and commonly contain mud pebbles, especially where they overlie mudstone units. Some sandstone horizons are fairly rich in carbonate concretions while bioturbation occurs frequently in the mudstone horizons. The formation has a thickness of 250m (Geological map of Lesotho, 1981).

1.2.2.1.2 Clarens formation

The Clarens formation is well exposed along the valleys and plateaux of the foothills and lowlands. The sequence consists chiefly of buff and reddish fine grained sandstones, silty sandstones and siltstones. The lower part commonly contains shallow water intercalations consisting of red and subordinate polycoloured mudstones or silty stones. As these deposits are characterised by the underlying Elliot formation, the base of the Clarens formation is not always obvious. Large scale aelion cross-bedding characterises, in particular the upper part of the succession. Irregular carbonaceous patients can be found through the Clarens formation. The thickness of this formation attains 250m (Geological map of Lesotho, 1981).

1.2.2.1.3 Molteno formation

The formation consists of predominantly coarse grained and gritty, buff and white coloured bench-forming sandstones containing many small vein quartz pebbles alternating with soft, green and buff mudstones, siltstones and finer grained sandstones (Geological map of Lesotho,1981).

1.2.2.2 Drakensberg group

1.2.2.2.1 Lesotho formation (Basalt)

Drakensberg beds, consists of a conformable sequence of sub-horizontal tholeiitic basalt flows, occupy three quarters of the country and have a maximum preserved thickness of 1350m. The individual flows were probably powered out in a rapid succession as weathered surfaces are very rare between one flow and another. Amygdales, formed by volatile constituents trapped by the rapidly cooling margins of each flow, are filled with zeolites, quartz, agate or chalcedony (Geological map of Lesotho,1981).

1.2.2.3 Beaufort group

1.2.2.3.1 Burgersdorp formation

Rocks belonging to the Burgersdorp formation underlie the western part of the country and consist of light green and yellow, fine and medium grained sandstone alternating with poly-coloured mudstones and siltstones and have an exposed thickness of approximately 120m (Geological map of Lesotho,1981).

1.2.2.4 Dolerite (diabase)

Early Jurassic Karoo dolerites formed during the extrusion of the Drakensberg basalt occur profusely as vertical or sub-vertical dykes and near horizontal sills (Geological map of Lesotho,1981).

1.2.3 Soils and Erosion

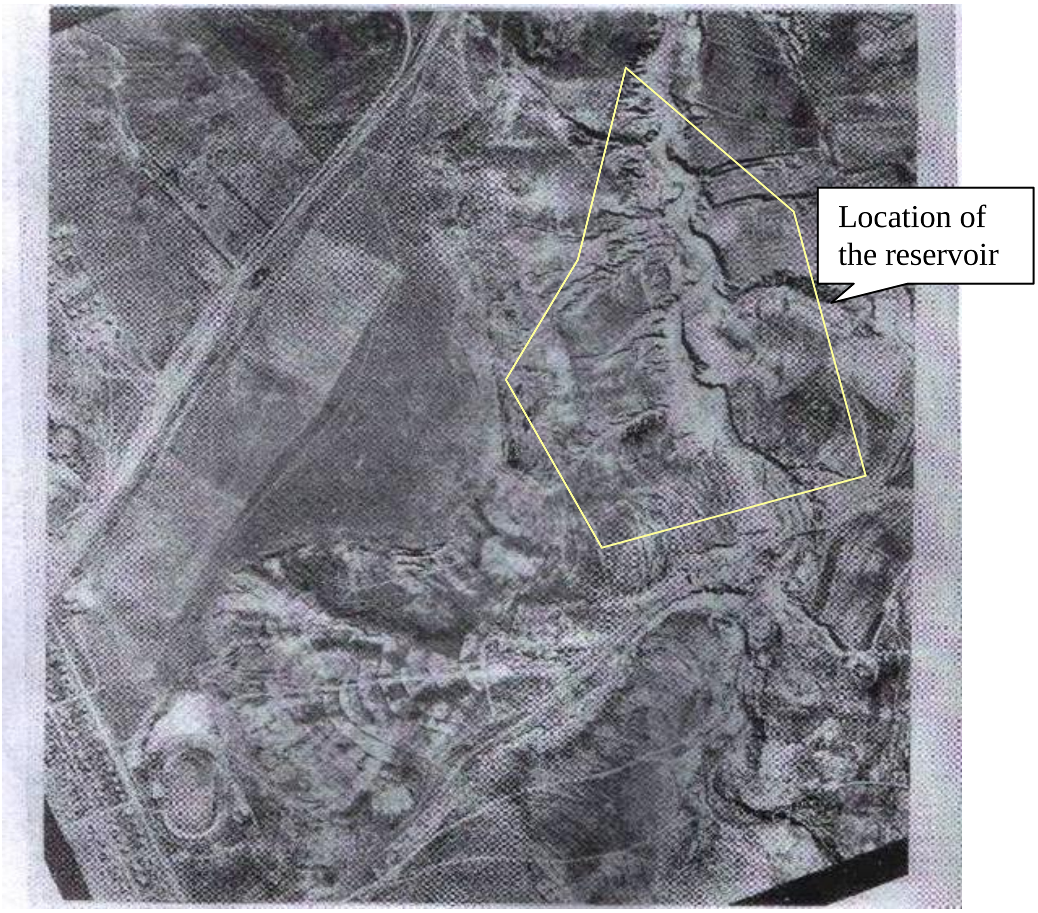
Soils which occur in the lowlands of Lesotho are red, yellow or brownish and shallow to deep (Mcleod ,1989, cited by Molapo ,1998). They are slightly acidic and are moderately well to poorly drained. Along major streams, thick, dark brown soils comprising mainly of clay and silt are found.

Mcleod (1989) cited by Molapo (1998) continues to state that steep slopes of mountains are typified by thin layers of soil originating from basalt. Soils that are found along streams and depressions are often very poorly drained, black, and moderately acid to neutral. The basaltic foothills have reddish brown, slightly acidic to strong acidic loams.

Previous studies suggest that soil loss from sheet and rill erosion is very high in quantitative terms, i.e. soil loss per annum from crop lands is 15,4 million tonnes; 23,4 million tonnes from rangeland; while gully erosion contributes 1 million tonnes (Damane *et al*, 1989, cited by Molapo,1998). The lowlands are worst affected by gully erosion with an estimated 20, 000 to 30, 000 gullies. About 4% of arable land is occupied by these gullies and their area increases at about 100 ha/yr (Environ. Research Institute,1990, cited by Molapo,1998). Figure 1.1 shows how Maqalika was affected in terms of erosion before the construction of the reservoir.

The problem of soil erosion is further compounded by widespread practices of cereal monocropping and the use of crop residues and animal manure as fuel which in turn have reduced soil fertility and altered soil structure. The damaged structure has a reduced capacity to resist rain erosion, retain nutrients, etc. (Molapo ,1998).

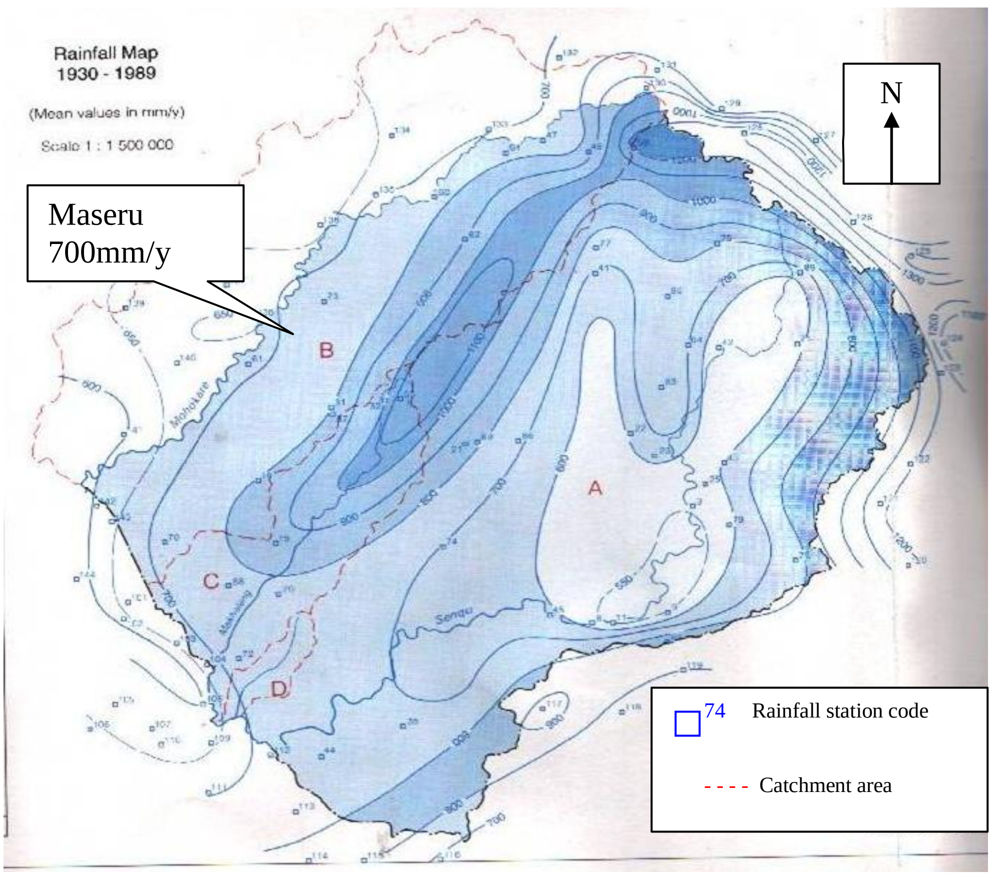
Fig 1.1 Maqalika river before construction of the dam (1961) (source: Maseru an illustrated history (Ambrose, 1993))



1.2.4 Climate

The Department of Water Affairs' report (DWA, 2003), stated that the climatic conditions of Lesotho are sub-humid to temperate with warm summers and cool to cold winters. The lowlands have an average monthly temperature of 6.7^0C in June and July, and 21^0C in January; the highlands experience the average temperature of 7^0C in June and 10.8^0c in January. The wet season falls between the months of September and April. The mean annual precipitation varies from approximately 500mm in the deep rain shadowed Senqu (Orange) valley to more than 1400mm in the mountains, north east of the country. On average, approximately 780mm of rainfall falls over the country annually (see map 1.3). In winter the highlands experience snow cover. Frost occurs throughout the winter months and is a powerful agent of mechanical weathering (Carroll and Bacomb, 1967 cited by Makhanya, 1979). At times frost occurs during the time when the crops are growing, causing considerable damage (Makhanya, 1979).

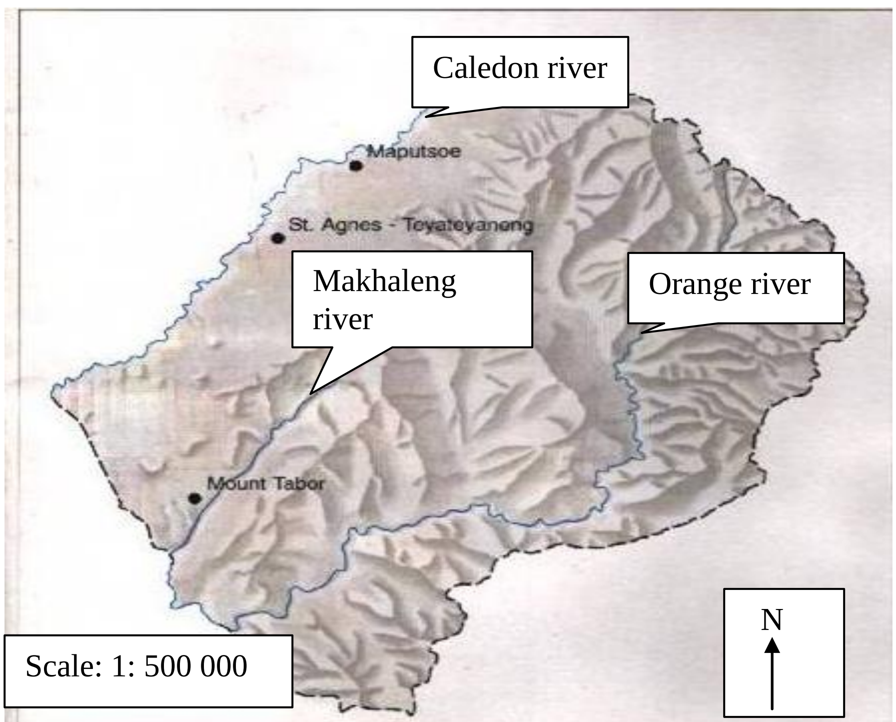
Map 1.3 Rainfall map of Lesotho (source: hydrogeological map of Lesotho, 1994)



1.2.5 Hydrology

TAMS (1996) pointed out that a particular feature of Lesotho is that all its rivers flow in the same south- westerly direction, due to the lower strata of sandstone being uniformly laid in a north-easterly to south-westerly plan. The three main rivers, the Senqu (Orange), Makhaleng and Mohokare (Caledon) leave the country at an elevation of approximately 1400m above sea level. The watershed between the Drakensberg and the Maluti constitutes the headwater of the Orange river, which is the largest catchment in RSA. The Makhaleng and the Mohokare are tributaries of the Orange River. Makhaleng joins Orange at the border and the Caledon, after flowing through the Welbedacht reservoir, joins the Orange at the Gariep reservoir (see map 1.4).

Map 1.4 Three main rivers of Lesotho (source: hydrogeological map of Lesotho, 1994)



The mean annual discharge of the Orange River at the first gauging station downstream of Lesotho at Oranjedraai, downstream of the confluence of the Senqu and Makhaleng, is 128 m^3/s for a catchment area of 24 550 km^2 , of which 96.8 % is within Lesotho's national territory. The Caledon river has a total drainage area of 13 442 km^2 when it leaves Lesotho. At this point the mean annual discharge is estimated to be $36m^3/s$. The river flows, like the rainfalls, are highly seasonal. On an average, 75% of the annual volume of the Orange River flows during the six wettest months from November to April. On the Caledon River, where it leaves Lesotho, 84% of the runoff occurs during the same period (TAMS, 1996).

1.2.6 Vegetation

There is an almost complete absence of natural tree growth in Lesotho especially in Maqalika catchment. This absence of natural trees and grass cover exposes the soil to detachment by direct impact of the raindrops particularly as the rainfall is of high intensity. The country is characterised by grassland with little or no natural tree growth (Makhanya, 1979).

Increased land pressure particularly in the form of overgrazing by livestock has caused general impoverishment of the flora and drastic changes in vegetation (Damane, 1996 cited by Molapo,1998).

1.3 Siltation of rivers and reservoirs

The sediment yield of a river catchment at an observation point is the amount of material transported by a river at the cross-section where the observation is made. Measurements have been made in several rivers in Lesotho since the early 1970’s, and are reported in a number of studies where sediment yields are estimated (TAMS, 1996).

A number of large reservoirs in RSA have been surveyed to establish general statistical information. Of particular interest to Lesotho are the measurements made in the Weldebacht reservoir on the Caledon River (TAMS, 1996).

The new Sediment Map of Southern Africa (SMSA) published by the WRC, indicates that Lesotho falls within two regions i.e. region 6 and 7 .In this case “6” indicates the erodibility index falling in the category of high sediment transport region. It consists of the upper Orange and Caledon catchments down to Gariep Dam, including the south-eastern part of Lesotho. Region 7, indicates the erodibilty index which also falls in high sediment transport region, consisting mainly of the basaltic formation. Sediment yielding areas in Southern Africa are located within region 6, in particular the Caledon River.

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The study by Jacobi (1977) cited by TAMS (1996) estimates the following annual sediment yields from 1970-1977 (see table 1.0) while the study conducted by S. Makhoalibe cited by TAMS (1996) from 1972-1984 is reflected in table 1.1.

Table 1.0 Annual sediment yields (1970 – 1977) (Source :TAMS, 1996)

Name of a river	**Catchment area (km^2)**	**Tons/km^2/yr**
South Phuthiatsana at Masianokeng	945	1,979
North Phuthiatsana at Mapoteng	386	2,968
Matsoku at Seshote	662	327
Malibamatso at Paray	3,240	219

Table 1.1 Annual sediment yields (1972 -1984) (Source: TAMS, 1996

Name of a river	Catchment area (km^2)	Tons/km^2/yr
Senqu at Seaka	19,875	210
Senqu at White-hill	10,900	140
Senqu at Koma-koma	7,950	70
Senqu at Mokhotlong	1,660	30
Malibamatso at Paray	3,240	60
Malibamatso at Lejone	1,157	9
Maphutseng at Maphutseng	323	500
Khubelu at Tlokoeng	852	14
Matsoku at Seshote	662	7
Bokong at Bokong	403	3
Mohokare at Mohlokaqala	5,600	930
North Phuthiatsana at Kolonyama	905	740
North Phuthiatsana at Mapoteng	386	2,050
Mohokare at Mashili	1,560	730
South Phuthiatsana at Masianokeng	945	1,380
Hlotse at Ha-Setene	728	790
Hololo at Khukhune	212	80

A study on sediment transport conducted by WRC on Caledon River at Jammersdrift gauging station from 1931 to 1942 indicates an annual sediment load varying from 2.8 to 53.6 million tons, with an average of 11.7 million tons per year or a sediment yield rate of 878 tons/km^2/yr (TAMS, 1996).

1.4 Socio-economic status

Lesotho is rated as one of the least developed countries in the world. It is a country of approximately 2.14 million people with the annual growth rate of 2.0% (Bureau of Statistics, 1996). 40% of the population is unemployed and has an adult literacy of 61% (Bureau of Statistics, 1996). Natural resources available are water, agriculture, grazing land and diamonds.

The level of poverty is higher in the rural Highlands, where infrastructure is limited, than in the urban Lowland districts. The situation has been aggravated by a decade-long retrenchment of Basotho migrants employed in the RSA mining industry. Moreover, rapidly increasing number of youths entering the labour force every year worsens the situation. The completion of phase 1 of the Lesotho Highlands Water Project (LWHP), which employed thousands of Basotho resulted in higher unemployment rate which was further exacerbated by the suspension of Phase 2 (DWA, 2003).

In recent years (1990-to date), the high unemployment rate was partly reduced by the creation of more than 10 000 jobs in the garment sector, resulting from the African Growth and Opportunities Act (AGOA), which grants duty free access of Lesotho textiles into the USA. However, the growth in this section is uncertain, as AGOA was likely to end in 2004 according to agreements but it is still operating in a shaky position. This calls for the need to look again at addressing the problem of unemployment (DWA, 2003).

1.4.1 Population of Lesotho

A formal census was held in 1875 and a population of 128 000 was recorded. This excluded a significant number of Basotho who had migrated to RSA. In the early 20th century, further population movements occurred as a result of the policy of the neighbouring States and the single entity which replaced them in 1910, the Union of South Africa. There was very little growth in Lesotho's population in the 1930's and 1940's. Evidence that is supported by the 1936 and 1946 census that gave Lesotho's population of approximately 661 000 and 689 000 respectively (TAMS, 1996).

By independence in 1996, the population of Lesotho was almost exactly one million. There was also a Basotho population just larger than this who regarded themselves as permanently settled in RSA. In the period 1966-1996, both the populations have doubled (TAMS, 1996).

Damane (1996) cited by Molapo (1998), suggested that rapid growth is one of the major factors contributing to the cumulative environmental degradation and poverty in Lesotho. Table 1.2 shows projected figures from 1996 to 2003 using a conservative population growth of 2 % and the formula of $p = x * 1.02^n$.

Whereby: x = constant population number, p = factorised population number and

n = exponent

Table 1.2 Population of Lesotho (1996 – 2003) (Source :Bureau of statistics, 1996)

Population number per district						
	1996	1996	1996	2003	2003	2003
	males	females	total	males	females	total
Butha-Buthe	57787	58693	116480	66379	67420	133799
Leribe	156397	162059	318456	179651	186155	365806
Berea	126505	130689	257194	145315	150121	295435
Maseru	199776	211459	411235	229480	242900	472380
Mafeteng	111078	113234	224312	127594	130070	257664
Mohale's hoek	95225	98534	193759	109384	113185	222568
Quthing	65073	68475	133548	74748	78656	153405
Qacha's Nek	36808	39466	76274	42281	45334	87615
Mokhotlong	44854	45625	90479	51523	52409	103932
Thaba-Tseka	66385	68571	134956	762556	78767	155022
Lesotho	968421	999933	1968354	1112411	1148609	2261020

The growth rate of the urban population is estimated to range between 6% and 11% per annum, as compared to 2.0 % for the whole country (Bureau of Statistics, 1996).

1.5 Legal framework and policy in the water sector

1.5.1 Water Sector Act (1978)

The act provides for the use and control of water, for the purpose of its protection and conservation. The main issues addressed in the act include: Source: (DWA (GOL), 2003)

- Water uses
- Acquisition and termination of water use permits
- Water administration
- Water disputes
- Compensation
- Servitudes
- Pollution and failure to prevent pollution
- Offences and penalties
- Regulations

1.5.2 Water Resources Policy (1999)

Lesotho prepared the Water Resources Management Policy in order to address the need to manage water resources for social, economic and environmental benefit for all in the country. The policy was adopted in 1999 and contains six policy statements and strategies for implementing them, the statements are;

- Rational exploitation and management of water resources
- Access to potable water by all people of Lesotho
- Water for basic human needs, and the "user pays" principle
- Protection of all environmental aspects of water resources
- Management of water for maximum benefit to Lesotho while taking cognizance of obligations to neighbours and downstream users
- Involvement of stakeholders in every stage of water resources development projects and demand driven expansion of water supply

Source: (DWA (GOL), 2003**)**

1.5.3 Environmental Act (2001)

The Environmental Act (2001) provides for the proper management of the environment and natural resources of the country. The Environmental Act stipulates that natural resources should be used to meet the needs of the people while ensuring that the ecosystems, on which all life depends, are protected. In order to achieve this, any development must undergo environmental impact study to produce the environmental impact statement.

CHAPTER 2

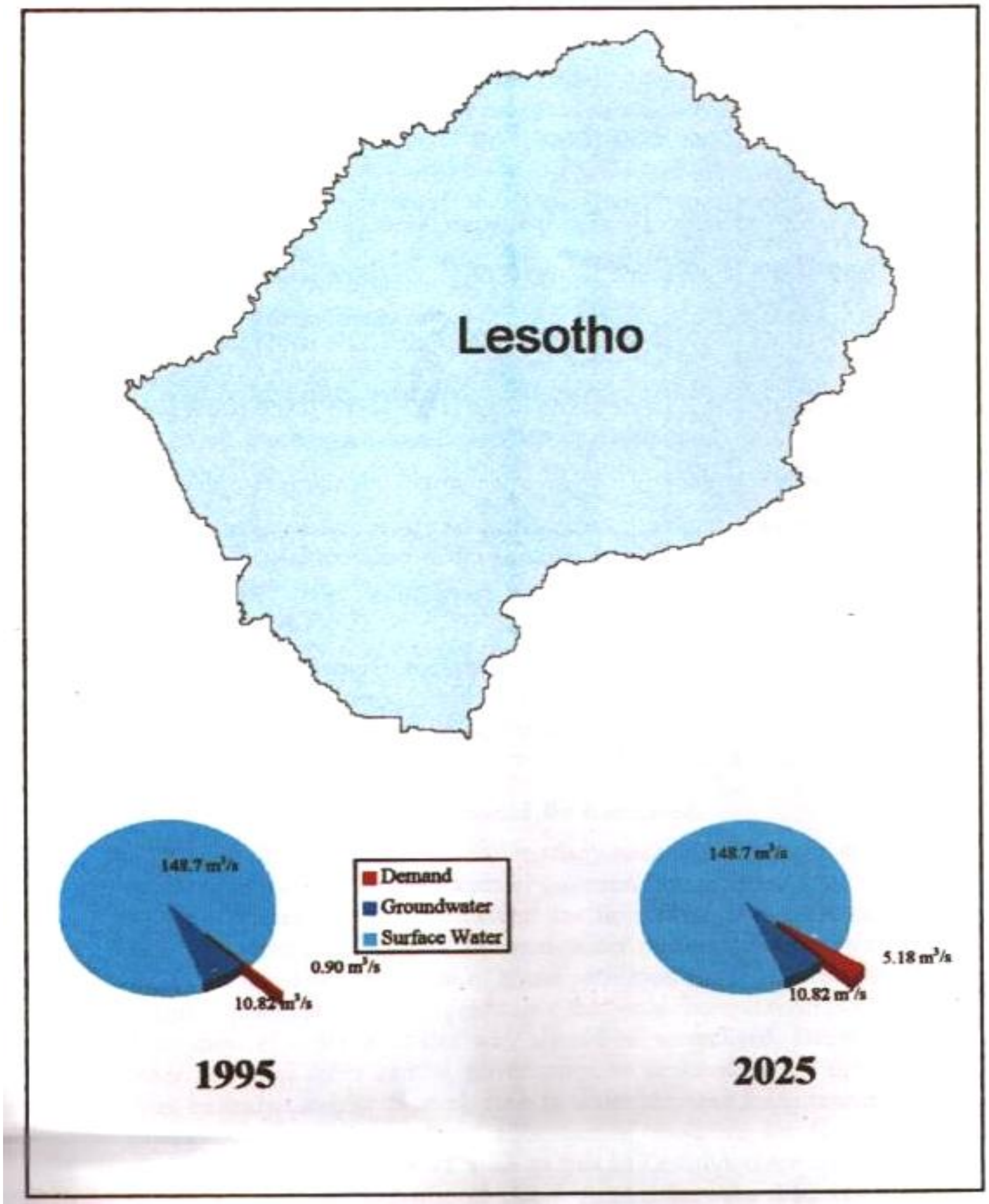
2.0 WATER RESOURCES

2.1 Introduction

Freedom from hunger and malnutrition, good health and a safe and stable environment are basic to sustainable development. It is abundantly clear that the path to achieving long lasting food and health security is sustainable development, and sustainable development includes the management and conservation of a natural resources base. Amongst the natural resources that are indispensable for human welfare and socio-economic development, water ranks as number one (Kay, 1999).

Water is crucial to development. As the world population tripled in the twentieth century, the use of renewable water resources has grown six fold. Nevertheless, in Lesotho, water is said to be the most abundant natural resource (TAMS, 1996). In support of the above statement TAMS (1996) pointed out that of the total water resources available (160 m^3/s), the water demand for the whole country was 0.9 m^3/s in1995 which is 0.85 %. The projections for 2025 suggested an increase to 5.18 m^3/s which is 3.2 % and hence portrays a clear indication of surplus water (see fig.2.0). Although comforting, this is misleading because it masks the ever growing demand and the limited access to clean water by a large population of the country (Molapo, 1998). Therefore, it follows that while the country may have surplus water; the initiatives of harnessing it are still at an infant stage or are not keeping pace with the ever increasing demand.

Fig. 2.0 Water resources in Lesotho (source: TAMS final report, 1996)



The demand of water will continue to increase substantially in the coming decades. At the same time, lakes, rivers, wetlands and marine water provide the vast majority of environmental goods and services, including fish. Many of these services depend on the integrity of aquatic ecosystem. This integrity has been affected by:

(1) The decline in surface area of the ecosystems

(2) Widely deteriorating water quality;

(3) Reduced quantities of water that are needed to sustain these ecosystems (World Summit for Sustainable Development (WSSD), 2002)

(4) Global warming

WSSD (2002) pointed out that some forecasts show that by 2025, more than 3 billion people will face water scarcity. But this is not because the world lacks water, the world water crisis is a crisis of governance not one of scarcity.

Linsley and Franzani (1979) stated that water is unequally distributed about the earth, and its availability at any place varies greatly with time. Finally, in its use of this resource, humanity pollutes much of the available fresh water and degrades it so that it is unfit for many or all uses. Hence, skilled planning and careful management are essential to achieve the level of efficiency in water use which will be regarded in the future.

In support of the above paragraph, SWECO (1979) states that the main rains in Lesotho occur in the three months, January to March (approximately 50 % of the total) and normally it might be expected that storage reservoirs would fill up at this time of the year and that the rivers would have a reasonable flow. By January 1973, 25 % of the water in Sebaboleng (a dam upstream, interconnected via a spillway, with Maqalika dam) had been used. The country then experienced an unprecedented severe drought. The rainfall in the three wettest months was only 20 % of the normal and the Caledon River at Maseru stopped flowing for nearly forty days. The town's water was then drawn completely from Sebaboleng dam and by the time the river flowed again 45 % of the storage had been used. This happened despite the fact that a complete ban on the use of water for gardening and irrigation was imposed by the Ministries of Works and Agriculture.

SWECO (1979) continues to state that during that very period it was obvious that the dry periods of the river at Maseru were increasing in length due to very rapid and unexpected increase in water abstraction upstream. The main causes of this were:

(i) heavily increased irrigation abstraction by farmers bordering the Caledon, but under the jurisdiction of the Orange Free State.

(ii) Ladybrand, the next town upstream, which is also under the jurisdiction of the Orange Free State had recently introduced a waterborne sewage system.

(iii) Ficksburg, another town under the Orange Free State approximately 60 km upstream of Maseru, has also just extended its sewage works.

From this one can deduce that this was a wake up call for authorities in Lesotho to start to think of more water augmentation for Maseru city, hence the construction of Maqalika reservoir in 1983 in the same catchment as Sebaboleng dam.

2.2 Institutions in water resources management in Lesotho

The Ministry of Natural Resources (MNR) through its departments is responsible for both water resources management and development and provision of rural and urban water supply. The institutions in the water sector are the Department of Water Affairs (DWA), which is a policy making body and responsible for water resources assessment and management throughout the whole country; the Department of Rural Water Supply (DRWS) provides water for rural areas; the Water and Sewerage Authority (WASA) is responsible for urban water supply and sanitation; the Lesotho Highlands Development Authority (LHDA) which is charged with the responsibility of managing the Lesotho Highlands Water Project (LHWP) and also with selling water to the Republic of South Africa (RSA).

2.3 Water supply and use

Historically, the availability of water has strongly influenced the pattern of settlement in Lesotho. The wide spread availability of perennial springs, arising from relatively high levels of rainfall and mountainous terrain, contributed to a more dense pattern of settlement than that to be found in the more arid, low-lying regions to the west of the border. The availability of perennial springs and surface water (rivers and lakes) certainly influenced the siting of villages before the introduction of borehole technology. Boreholes, equipped primarily with hand pumps, made it possible for settlements to expand into more arid parts of the western lowlands, filling areas which might not otherwise have been occupied (TAMS, 1996).

The above situation - that of an essentially rural population with a plentiful supply of water - is one that has changed markedly and at an accelerating rate within the past twenty years. Two components have contributed to change. The first was the rapid growth of population and the second was internal migration within Lesotho from the Maluti to the lowlands especially Maseru city. The result has been the need for increasing government intervention in supplying water for the population, both in rural and urban areas. For the rural area localities, the DRWS is in charge and for the urban areas WASA is in charge (TAMS, 1996).

2.4 Water Supply in Maseru

Previously, Maseru city used to be supplied with water from springs on the Berea Plateau (Macleod, 1989 cited by Molapo, 1998). Currently, the Caledon River is the main source of water for Maseru for both domestic and industrial uses (Molapo, 1998). During low flows, when water is less sedimented, the water is pumped directly from the river into the Maqalika reservoir, which is an off channel storage reservoir, then to the treatment plant. But during the rainy season when river stages are high and the Caledon heavily sedimented, the water is pumped directly from the river to the treatment plant (interview WASA engineers, 2003). The Maqalika reservoir also gets runoff water from the Mejametalana catchment through the Sebaboleng Dam, either by the spillway during the rainy season or release by pipeline during the dry season.

2.5 Statement of Problem

Maseru is the capital of Lesotho and has been the country's main centre for commerce and industry for the past 40 years. The water supply for urban area has been developed and operated by the Water and Sewerage Branch (WSB) under the Ministry of Water Energy and Mining. On the 1st of April, 1992 this oganisation became an autonomous authority, the Water and Sewerage Authority (WASA) (Lahmeyer International, 1996).

The population of Maseru urban area has approximately doubled in every 10 years since 1986 when it was reported to be 280 000. If the average annual growth rate of 7 % remains constant up to the year 2026, the population will climb to 928 814 from the 412 986 recorded in 1986 (Bureau of Statistics, 1996). As it has been projected, the water supply will need improvement to cater for additional numbers. At present the city of Maseru is supplied with water from the Caledon River and Maqalika Reservoir (DWA report, 1996).

The long term average annual discharge of Caledon River is approximately 807 M^3 or 807 MCM and is highly seasonal; 88 % of the run-off occurs from October to April, with a great variability within and between years. When it is necessary, the shortfall of raw water is supplemented from Maqalika reservoir, which is an off- channel storage reservoir on a minor tributary of the Caledon river (Mejametalana) on the north-eastern outskirts of Maseru urban area (DWA report, 1996).

The Maqalika reservoir was built to meet the water demands for Maseru city up to 1995, and its storage capacity was 3.7 Mm^3 (DWA,1998). The storage capacity has been gradually decreasing as sediment carried by the natural catchment run-off accumulates in the reservoir. Moreover, the pumping from Caledon river (which is heavily sedimented) into the reservoir makes its own significant contribution in reducing the capacity.

As mentioned earlier, the reservoir is located in a densely populated area. The planning of the residential areas around the reservoir is minimal and as a result, poor disposal of solids waste and domestic effluent probably results in high input of pollutants into the reservoir. Thus eutrophication development at the tail edges of Maqalika is evident, showing a clear indication of high levels of nutrients (see fig 2.1). Algae are one of the main indicators of high nutrient level of nitrates in water as depicted in figure 2.1. Many cases have been reported along the reservoir of domestic effluent being discharged directly into the reservoir. The situation is exacerbated by poor sanitation facilities and use of dongas for defaecation.

Fig. 2.1 Algal bloom showing the eutrophication at the Maqalika Reservoir

(source: Author, 2003)

2.5.1 Aim of this study

This study is intended to find:

(1) whether the positioning of the reservoir is in an ideal situation

(2) its capacity as a water body supplying a fast growing city

(3) the present and future water demand and

(4) its water resources management.

These questions are answered by analysing water quality data (physico-chemical data) and by applying mathematical models to estimate the current reservoir capacity.

2.5.2 Objectives of the study

- To determine the contribution of sediment through pumping from the Caledon River and natural catchment contribution through run-off. (addressed in chapter **5).**
- To determine the impact of pollution in the waterbody and its major contributors. (addressed in chapter 6).
- To determine the cost implication due to prevailing water quality. (addressed in chapter 7).
- To come up with recommendations that will help to ameliorate the situation and make the whole catchment manageable. (Addressed in chapter 8).

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2.5.3 Hypotheses

- The storage capacity is gradually decreasing
- The Caledon River, which acts as a border between RSA and Lesotho, is perceived to be both heavily sedimented and over exploited by both countries and hence, might no longer meet the demand.
- Human activities within the catchment play an important role in modifying the water quality of Maqalika.
- The expense of the modification to the spillway and the removal of houses around the reservoir is not cost effective.

2.5.4 Data generation

- The Mejametalana stream (seasonal flow), which has been dammed to form the reservoir, has no collected hydrological data hence data has been generated from available rainfall data.
- The Hydrological station of the Caledon River at Maseru has no representative data therefore, other stations with sufficient data has been used.

2.5.5 Limitations

- The study was not intended to discourage the use of the reservoir as a source of potable water supply but to try to discourage short term water resources planning as it impacts negatively on the country's economy.
- Water quality samples have not been taken from the reservoir for analysis but were obtained using that data available from various data sources, due to both time and budget constraints.
- Accumulation of sediments in the cascade dams upstream of Maqalika would not be modelled due to both time constraints and magnitude of the study.

CHAPTER 3

3.0 LITERATURE REVIEW

A number of studies in the literature are in show that the water quality within a catchment is a reflection of physical characteristics, natural process and human activities (e.g Molapo, 1998). This chapter contains a general literature review (including that on Lesotho) relating to water quality. For the purpose of this study the emphasis is entirely on sedimentation, water economics and some physico-chemical water quality parameters.

3.1 Sedimentation

An alluvial river is generally continually changing its position and shape as a consequence of hydraulic forces acting on its bed and banks and related biological forces interacting with these physical forces. The changes may be slow or rapid and may result from natural environmental changes or from changes caused by man's activities. When a river channel is modified locally, the changes frequently cause changes in channel characteristics both up and downstream. The response of a river to man - induced changes often occurs in spite of attempts to control this response (Simons and Senturk, 1976).

Intimately associated with the sediment load of a river is the erodibility of its catchment. Considerable local knowledge and experience gained from working with problems and observations relating to erosion and its correlation with geology, vegetation and soil cover are needed before one can reasonably infer what the silt load of a river is likely to be (Pitman *et al*. 1981).

Goldman *et al*.(1986), say that when land is disturbed for construction, road building, mining, logging, or other activities, the soil erosion rate increases from 2 to 40 000 times and millions of tons of this soil end up in the rivers, lakes, and reservoirs. As a matter of fact the Maqalika catchment is mainly a settlement area. Each year tax payers, land developers and property owners spend billions of Rands cleaning up sediment and repairing eroded stream banks, gullied hillsides, washed-out roads, mud-choked drains and other erosion damage.

Rooseboom (1978) cited by Pitman *et al.* (1981) suggest that from studies conducted on sediment discharge patterns in R.S.A rivers and from the comprehensive analysis of available data, that the annual sediment yields of different catchments varied from less than 10 t/km^2 to more than 1000 t/km^2. Moreover, it was found that sediment loads transported by local rivers consisted mainly of small particles (0.2mm) and concluded that it was not the carrying capacity of the river that determined the sediment load but the availability of erodable sediment on the surface of the catchment.

Each year an estimated 80 million tons of sediment is washed from construction sites into the lakes, rivers and waterways of the United States. Although this sediment is only a fraction of the total sediment load, it is the major source of pollution of many lakes and streams that drain small catchments in which development is occurring. The needless destruction of nature and the consequent burden on the taxpayer for cleanup could be avoided if cities, provinces and land developers implemented simple erosion control practices (Goldman *et al*.1986).

The primary sources of erosion in the United States are agriculture, logging, mining and construction. Although agriculture produces the largest percentage of the total sediment, construction causes the most concentrated form of erosion (Goldman *et al*. 1986).

Pitman *et al*. (1981) cited by Rooseboom (1992) pointed out that there are indications that sediment displaces water in reservoirs at between 1.25 and 0.7 m^3/t of mass, depending upon the age of the deposit and the degree to which and frequency with which the bed of the reservoir is exposed between floods. According to (Rooseboom, 1992) a dry density of 1350 kg/m^3 (specific volume 0.74 m^3/t) has been found to be an acceptable average for a 50-year-old deposit under South African conditions; hence the development of the following mathematical equation for sediment yield estimation:

$V_t/V_{50} = 0.376 \ln t/3.5$

The above equation is reliable when “t” is greater than or equal to 10 years.

Sediment density increase with time as it settles (Gibson *et al*. (1967,1981)) cited by Basson and Rooseboom (1999). $\ell T = \ell_o + K \log T$

Where: ℓT = density after T years of compaction

ℓ_o = initial density

K= constant which depend upon size analysis of the sediment

Miller (1953) cited by Basson and Rooseboom (1999) developed an approximation of the integral for determining the average density of all sediment deposited in years, assuming constant sediment input with time.

$\ell T = \ell_o + 0.4343 K_o (T/T\text{-}1 \ (\ln T)\text{-}1)$

Verification of method of Miller (1953) cited by Basson and Rooseboom (1999).

$$V_t/V_{50} = \frac{t\,(\gamma_1 + 0.4343\ K(50/49)\ \ln 50-1)}{50\,(\gamma_1 + 0.4343\ K((t/t-1)\ \ln t-1)}$$

Pitman *et al*. (1981) pointed out that the estimation of the proportion of the rolling sediment, or bed load, presents a further difficulty. Studies have indicated that the bed load is seldom likely to exceed 10% of the total silt load (Pitman *et al.* 1981). Most reservoirs trap practically the whole bed load component and hence trap efficiency curves relate primarily to suspended silt.

The trap efficiency of a reservoir is simply the percentage of the total incoming sediment retained in the reservoir. It is commonly expressed as a ratio of the quantity of sediment deposited to the total sediment inflow. Two of the primary factors upon which the reservoir trap efficiency depends are the sediment particle fall velocity and the rate of flow through the reservoir. Particle fall velocity is influenced by such factors as particle size and shape, water viscosity, and the chemical composition of water. The rate of through- flow is determined by the rate of change of storage volume resulting from the inflow to and the outflow from the reservoir. Where stratification occurs, however, through flow can be highly non-uniform. Further important factors are:-

(a) Capacity of storage relative to mean inflow.

(b) Shape of reservoir basin

(c) Manner of regulation of outflow and orientation of spillway and outlets relative to direction.

(d) Reservoir stage at time of arrival of a flood.

(e) Water temperature.

(f) Presence of salts that might promote or inhibit flocculation and hence sedimentation.

(g) Removal by wind action of dried sediments exposed at low reservoir level.

(h) Shrinkage and compaction of sediments.

These factors were taken from Pitman *et al*. (1981).

Erosion and sedimentation cause both environmental and economic impacts. Both are important, but it is often only an economic impact that spurs a public authority to take action. Environmental impacts are harder to see; they tend to build up slowly and not produce dramatic results for very many years, when it may be too late to correct the problem (Goldman *et al*.1986). Chow (1964) pointed out that the amount of sediment which moves out of any catchment varies greatly from one problem area to another, depending upon geologic, climatic, physical, vegetative and other conditions.

3.2 Soil Characteristics

The characteristics listed below are important in determining soil erodabilty (Goldman *et al*.1986).

- texture
- organic matter content
- structure (poorly structured less compaction hence easily eroded)
- permeability (less compaction high permeability)

The four characteristics listed above are interrelated.

3.2.1 Soil texture

Soil texture refers to the sizes and proportions of the particles making up a particular soil. Sand, silt and clay are the three major classes of soil particles. Soils high in sand content are said to be coarse-textured. Because water readily infiltrates into sandy soils, the runoff and consequently the erosion potential and hence the sedimentation are relatively low. Soils with high a content of silts and clay are said to be fine textured or heavy. Clay, because of its stickiness, binds soil particles together and makes a soil resistant to erosion. However, once the fine particles are eroded by heavy rain or fast-flowing water, they travel great distances before settling (Goldman *et al*.1986).

3.2.2 Organic matter

Goldman *et al*. (1986) explain that organic matter consists of plant and animal litter in various stages of decomposition. Organic matter improves soil structure and increases permeability, water holding capacity and soil fertility. Organic matter in an undisturbed soil or in mulch covering disturbed sites reduces runoff and, consequently, the erosion potential. It is the arrangement of soil particles into aggregates. A granular soil is the most desirable one in terms of infiltration of water. Soil structure affects the soils ability to absorb water. When the soil surface is compacted or crusted, water tends to runoff rather than infiltrate. The erosion hazard increases with increased runoff. Loose, granular soils absorb and retain water, which reduces runoff and encourages plant growth.

Goldman *et al*. (1986) suggested that soil permeability of the soil refers to the ability of the soil, soil texture and organic matter to all contribute to permeability. Soils with high permeability produce less runoff at lower rate than soils with low permeability, which minimizes erosion potential.

3.2.3 Topography

Slope length and steepness are critical factors in erosion potential, since they determine, in a large part, the velocity of runoff. The energy (thus the erosive potential) of flowing water increases as the square of the velocity increases. Long, continuous slopes allow runoff to build up momentum. The high velocity runoff tends to concentrate in narrow channels and produce rills, gullies and dongas (Goldman *et al*.1986).

The shape of a slope also has a major bearing on erosion potential. The base of a slope is more susceptible to erosion than the top, because runoff has more momentum and is more concentrated as it approaches the base. Constructing a convex slope magnifies this problem whereas a concave slope reduces it. Leaving a relatively flat area at the base of a slope not only reduces erosion but allows sediment from the upper portion of the slope to settle out (Goldman *et al*. 1986).

3.3 Sedimentation Control

Sedimentation generally limits the life span of a reservoir. The replacement of lost storage capacity is a world-wide problem and the need exists to limit, as much as possible, reservoir construction without thorough investigation (Basson and Rooseboom, 1999). This is especially true in semi-arid regions where catchment or sediment control methods cannot be implemented successfully. Limited suitable new dam sites, socio-economic considerations when raising a dam, and environmental concerns related to the construction of especially medium-scale to large-scale dams are all factors favouring reservoir dredging (Basson and Rooseboom, 1999).

During the past decades a great number of dams have been constructed in river systems to create storage capacity for power generation, irrigation, drinking water supply and flow generation. Independent of the purpose of water resources schemes, they clearly have one thing in common: the fact that they always constitute an artificial interruption in the hydro-morphological river regime. The practice of reservoir operations teaches that such interference leads to sedimentation, which is one of the main threats to reservoir management regarding operational efficiency lifetime (Basson and Rooseboom, 1999).

Welbedacht dam was constructed on the Caledon River in 1973, as the main water source of Bloemfontein, and later of Botshabelo. Most of its original full capacity of 113.8 MCM was, however, quickly lost due to sedimentation and in 1991 only 17 MCM of storage volume remained, which is only 15% of the total (Basson and Rooseboom, 1999). Wallace (1994) cited by Basson and Rooseboom (1997) pointed out that the Mbashe weir in the Eastern Cape province silted up almost completely within two years of completion.

Chow (1964) pointed out that from the catchment, the trap efficiency of the reservoir and the ultimate specific weight of the deposited sediment fix the total volume of sediment which needs to be considered in the design of a structure to avoid premature loss of storage dedicated to a specific purpose for a given period of time.

3.3.1 Design of reservoir for control

The basic characteristics in developing a reservoir are the hydrologic conditions and services requirements such as flood mitigation for the reservoir for a given period of time. To prevent premature loss of capacity, an additional storage volume is usually incorporated into the reservoir to allow for sediment (Chow, 1964)

3.3. 2 Vegetation for control

Goldman *et al*. (1986) suggested that vegetation for control of erosion must be well suited to the local environment. They must be vigorous and trouble free i.e do not pose any danger of being a weed and adapted to the soils and climate of a site. Chow (1964) suggested that vegetation normally seeds on exposed delta deposits of reservoir to form (alien) invasive weed vegetation screens which reduce inflow velocities and increase the roughness coefficient, encouraging deposition above the reservoir crest elevation within the reservoir basin and immediately upstream.

3.3.3 Catchment structures

3.3.3.1 Check dams

Construction of check dams such as weir and flumes could be vital for the reduction of velocity of flow in the channel thus reducing erosion of the channel bed. Goldman *et al*. (1986) suggested that check dams are closely related to sediment barriers; the materials and construction are similar. Sandbags, logs, rock, silt fences, gravel filters and straw dikes can function as check dams.

3.3.3.2 Channel linings

Channel linings are essential for slowing velocities in channels and reduction of peak flows. A lining that slows velocity not only reduces erosion but also reduces the peak flow by spreading it over a longer time period. Thus it can be used as part of a storm management system. Soil channels are also vital for encouraging infiltration into the soil. If it is permeable, infiltration occurs, thus encouraging plant growth (Goldman *et al*.1986). Chow (1964) suggested that the selection of sites of channel linings for effective sedimentation requires both the evaluation and delineation of the principal sediment-source areas in the catchment.

3.3.4 Venting sediment

Occasionally, appreciable amounts of sediment may be vented from reservoirs by use of gated outlets or special curtains to encourage movement of high concentrations of sediment in suspension, through or over a dam (Chow, 1964). An effective venting method depends upon maintaining the movement of sediment while still in suspension. Deposition of sediment reduces the bottom slope and cohesive and adhesive forces on particles in deposited sediment are greater than the dragging forces of flow normally developed by the release of water through gated outlets. As a result, erosion and entrainment of deposited sediment particles are minor, with the exception of a very localized area adjacent to the intake (Chow, 1964).

3.3.5 Sediment removal

Deposited sediment may be removed from reservoirs periodically by hydraulic or mechanical means. These methods have been used successfully in restoring the capacity of many reservoirs. These often represent the only means of restoring capacity where there are physical limitations on the height of a dam or where alternative sites are not available. The type of equipment used for removal of sediment depends upon the nature of the sediment and location of the disposal area (Chow, 1964). Hydraulic dredging is the most economical for fine grained, submerged materials where nearby disposal areas are available (Basson and Rooseboom, 1999 and Chow, 1964).

3.4 Selection of the reservoir site

The following criteria are important in site selection: (Basson and Rooseboom, 1999).

- ❖ Catchments should be as small as possible.
- ❖ Low sediments yield catchments should be selected, if possible.
- ❖ No major cities, towns or infrastructure should be located near the headwater of a reservoir.
- ❖ Topography suitable for sediment passing should be utilised if possible e.g. shallow slopes.
- ❖ The storage capacity should be optimized to give a suitable capacity-inflow ratio in order to operate the sediment sluicing/flushing of a storage reservoir.
- ❖ If possible, reservoir basin characteristics should facilitate sluicing, flushing or density current venting.

- Off-channel storage options should be seriously considered.
- A catchment with erodable soils should be avoided and the geology of the site should not contaminate water and should allow minimal seepage.

3.5 Water quality

3.5.1 Hardness

Hardness is generally defined as the sum of the polyvalent cations present in water and expressed as an equivalent quantity of calcium carbonate ($CaCO_3$). The most common such cations are calcium and magnesium (Pontius, 1990).

Several investigators attribute a protective effect to the presence of calcium and magnesium (Pontius, 1990). A moderate increase in calcium in the diet has been observed to lower levels of circulating organic cholesterol; this is speculated as a possible factor in relating water hardness and cardiovascular disease. Magnesium is theorized to protect against lipid deposits in arteries and may also have some anticoagulant properties that could protect against cardiovascular diseases by inhibiting blood clot formation (Pontius, 1990).

Total hardness consists of temporary carbonate or carbonate hardness and permanent or non-carbonate hardness. The former is removed by boiling, while the latter is not. The scale formed inside kettles is the temporary hardness removed by boiling. Hardness should be measured in mg/l as $CaCO_3$ and the description may be given as follows:

Table 3.0 Hardness classification (source: Twort *et al*. 1974)

Concentration (mg/l)	**Status**
0-50	Soft
50-100	Moderately soft
100-150	Slightly hard
150-200	Moderately hard
Over 200	Hard
Over 300	Very hard

This term will fit the characteristics "feel" of water as the consumer will feel it when washing with soap. The WHO "highest desirable level" of 100 mg/l for hardness seems unduly low and is not consistent with the correspondence figure of 75mg/l given for calcium. A statistical connection between the hardness of water and the incidence of cardio-vascular diseases has been found but no causal relationship has been established (Twort *et al*.1974).

3.5.2 Phosphates

Phosphates in surface waters originate principally from sewage effluents including their detergent content; they may also come from concentrated farmyard manures or from industrial effluents (Twort *et al*. 1974). However, the Maqalika catchment is mainly a built settlement area. Phosphorus is an essential nutrient for algae, contributing to eutrophication of reservoirs (Twort *et a*l.1974).

Due to noxious (blue – green) algal blooms that occur in surface waters, there is presently much interest in controlling the amount of phosphorus that enters surface waters in domestic and industrial waste discharges and natural run-off (Metcalf and Eddy, 1972).

The usual forms of phosphorus that are found in aqueous solutions include orthophosphate, polyphosphate, and organic phosphate. The orthophosphate are available for biological metabolism without further breakdown. The polyphosphates include those molecules with two or more phosphorus atoms, oxygen atoms and in some cases, hydrogen atoms combined in a complex molecule. Polyphosphates undergo hydrolysis in aqueous solutions and revert to the orthophosphate forms; however, this hydrolysis is usually quite slow (Metcalf and Eddy, 1972).

The cultural eutrophication of surface waters is an environmental problem which is presently a major global concern (Heckrath *et al*.1995 cited by Molapo, 1998). The economic implications of the process include increased costs for purification of drinking water, deterioration of recreational value, and damage to commercial fishing (Mason, 1997 cited by Molapo, 1998).

Molapo (1998) pointed out that a high population density of algae and zooplankton can block primary filters. Even limited quantities of algae could overload sand filters thereby drastically reducing the filtration process. The blocked filters severely reduce the passage of water at treatment plants hence necessitating frequent cleaning of the filters. The clean up has some cost implications which could otherwise have been avoided. In cases where the supply of potable and industrial water comes from one source, the blockage could have serious repercussions on the economy and public health of the region.

3.5.3 Nitrates

Mitsch and Jorgensen (1989) point out that manure used as a natural fertilizer in agriculture in Denmark could be a source of nutrient input to lakes and streams or course nitrate contamination of the groundwater and surface water. Nitrate is one of the major ions in natural waters. The mean concentration of nitrate nitrogen in a typical surface water supply would be around 1 to 2 mg/l, however, individual wells can have significantly higher concentrations. A survey conducted in South Dakota found that out of 1000 wells, 4% had NO_3-N greater than 100 mg/l, 9% had greater than 50mg/l, 17% had greater than 20mg/l, and 27% had greater than 10mg/l. Nitrites do not typically occur in natural water at significant levels; their presence would indicate likely wastewater contamination and or a lack of oxidizing conditions (Pontius, 1990).

Methemoglobinenia causes "blue babies" and has caused some 262 reported cases and 29 deaths. It is caused by nitrates in water consumed by infants less than 6 months of age. In children of that age or under, the nitrates are reduced in the body to nitrites which react with the oxygen receptor sites on the hemoglobin fraction of the blood and impair its oxygen carrying capacity. The reaction does not occur in older children or adults. The water responsible has nitrates in excess of 10mg/l, and in all cases it has been groundwater. High nitrates in waters are not uncommon and it is probable that subclinical cases in addition to more severe cases may occur that are not reported. One safeguard might be to use nitrate – free water for direct consumption by babies and making up food formulas. Water quality standards, however, specify an upper bound (10mg/l) for nitrate in public water supplies (Steel and McGhee, 1979).

3.5.4 Alkalinity

The cause of alkalinity is the presence of bicarbonates, carbonates and hydroxides of calcium, magnesium, potassium and sodium. Of these calcium happens to be the most usual constituent causing alkalinity. The most usual substances causing alkalinity, calcium and magnesium bicarbonates, happen also to be the cause of temporary hardness. This is nearly always due to Base Exchange softening; including natural softening in deep underground strata, as was established by thresh (Twort *et al*. 1974). The alkalinity of many waters is in the range 100 to 200 mg/l; a few contain up to 400 mg/l. No harm comes from the consumption of such waters (Twort *et al*. 1974).

3.5.5 Turbidity

Turbidity is caused by suspended solids in water. It is measured by comparing the sample with standard solutions by optical means and various standards are used in different countries. WHO suggest that turbidity should normally be below 5 units and not above 25 units. A turbidity of 5 units is apparent to the eye and higher standard is normally desirable in treated water. There is no safe limit to turbidity, the slightest trace in normally clear water, such as chalk well water, might be a sign of serious pollution (Twort *et al*. 1974).

Suspended materials are undesirable for aesthetic reasons, but their primary effect on quality lies in their ability to shield micro-organisms from disinfectant (McGhee, 1991). Metcalf and Eddy (1972) pointed out that extraneous organic material will react with most oxidizing disinfectants by absorption and by protecting entrapped bacteria.

Three general classes of particle contribute to turbidity in natural water:

- clay;
- organic particles resulting from the decomposition of plant and animal debris; and
- fibrous particles such as asbestos.

Soil particles constitute the major part of suspended matter in most natural waters. Discharge of sewage and other wastes can contribute significantly to turbidity (DWAF, 1993).

3.5.6 Conductivity

The electrical conductivity of water provides an indication of dissolved salts salinity or total dissolved salts (TDS) content. Low concentrations have nutritional value, particularly calcium and magnesium salts. High concentrations of salts can have undesirable effects in terms of aesthetic acceptability of water, health and economics. Excess salts impart an unpleasant taste to water and intensify scaling and corrosion (DWAF, 1993).

Water with extremely low total dissolved solids concentrations may be objectionable because of its flat, insipid taste (WHO, 1984 cited by DWAF, 1993). Some of the physiological effects which may be directly related to high concentrations of dissolved salts include:

- laxative effects mainly from sodium, sulphate and magnesium;
- the adverse effect of sodium on certain cardiac patients;
- the effect of sodium on women with toxaemia associated with pregnancy; and
- some effects on kidney function at high concentration (USEPA,1986 cited by DWAF, 1993).

Increased conductivity in water increases the water's ability to complete the electrochemical circuit and ability to conduct a corrosive current. The dissolved solids may also affect the formation of protective films (Pontius, 1990).

3.5.7 pH

The pH of natural waters is a measure of the acid – base equilibrium achieved by various dissolved compounds and which is a result of the carbon dioxide – bicarbonate equilibrium system. This system involves various constituent equilibria, all of which are affected by temperature (WHO, 1984; USEPA, 1986; cited by DWAF, 1993).

pH is a measure of the concentration of the free hydrogen ion in water. Water and other chemicals in solution, will ionize water to a greater or lesser degree. The ionization reaction of water may be written;

$HOH = H^+ + OH^-$ (Steel and McGhee, 1979).

The pH of natural water plays an important role since it influences physical – chemical and biological process in the aquatic environment. The geology and geochemistry of rocks and soils also affect the pH and the alkalinity of the aquatic system. Biological activity can influence the variability of pH in natural waters. Nutrient cycling and discharge of industrial effluents into aquatic environments can result in pH fluctuations. Discharge to the atmosphere and subsequent deposition or precipitation of acid – forming substances into the aquatic environment which can also alter acid – base balances in natural water. Such alterations may lead to a reduced acid – neutralizing capacity in waters, resulting in the lowering of the pH (USEPA, 1986; Canadian Guidelines, 1987 cited by DWAF, 1993).

3.5.8 Iron

Iron in water causes hardness, but its important effect is that, in very small amounts, (about 0.3 mg/l and above), it will cause taste, discolouration of clothes, plumbing fixtures (problems in plumbing materials), and incrustations in water mains. Iron is very common in the environment and water containing carbon dioxide, which seeps through iron bearing material, dissolves it to form ferrous bicarbonate, $Fe(HCO_3)_2$. The ferrous bicarbonate however, is easily oxidized into ferric hydroxide, $Fe(OH)_3$ which is precipitated as rusty, yellow ochre sediment. As previously indicated, iron in water is frequently accompanied by heavy growths of crenothrix which worsen staining, pipe clogging and other troubles. It should be recognized that iron in water may result from corrosion of the water mains, which will require appropriate corrective measures (Steel and McGhee, 1979).

Iron is the fourth most abundant element in the earth's crust. It is released naturally into the aquatic environment from weathering and leaching of sulphate ores (pyrites, FeS_2) and igneous, sedimentary and metamorphic rocks. Iron oxides and hydroxides are similarly released through leaching from sandstones. The presence of iron in water and the environment is also attributable to human activities, such as acid mine drainage, the burning of coke and coal, sewage, landfill leachates, mineral process, iron – related industries and the corrosion of iron and steel (Canadian Guidelines (1987) and cited by DWAF (1993)).

3.5.9 Temperature

Temperature affects the solubility of oxygen in water, the rate of bacterial action and the rate of re-aeration. The critical condition is generally in warm weather when water utilization rates are high and availability is low (Steel and McGhee, 1979).

Pontius (1990) pointed out that microbial re-growth is not only due to bacterial strains that quickly adjust to limited nutrient sources, but also to water temperature. Water temperature above 10^0 C accelerates the growth of adapted organisms with slow generation times. Low water temperatures result in a balance between new cell development and death of old cells.

3.5.10 Microbiological Assessment

Microbiologically, polluted water has long been associated with the transmission of infectious diseases such as gastroentitis, amoebiasis, giardiasis, salmonellosis, dysentery, typhoid fever and hepatitis (Cruan, 1986 cited by DWAF, 1993). A feature of bacterial pathogens is a generally high infective dose (10 – 1000 or more organisms required to cause infection) while viral pathogens and parasites have low doses (1 – 10 organisms). The protection of public health through control of microbial water quality is an important goal of water quality management (DWAF, 1993).

Faecal coliforms, and more specifically *Esherichia coli (E-coli)*, are the most common bacterial indicators of faecal pollution, and hence the possible presence of faecally – associated pathogens in domestic water supplies. Faecal coliform bacteria are almost definitely of faecal origin from warm – blooded animals, and this correlation is strengthened if confirmation of *E. coli* is conducted (Grawbow, 1986; Canadian Giudelines, 1987 cited by DWAF, 1993).

The WHO (1984) and Canadian Guidelines (1987, cited by DWAF, 1993) pointed out that *E.coli* usually comprises approximately 97% of coliform bacteria in human faeces. The remainder includes other *Escherichia spp.* and *Citrobacter spp.* Faecal coliforms have been shown to 93 – 99 % of coliform bacteria in faeces from humans, poultry, cats, dogs and rodents. Some faecal coliform tests also enumerate *Klebsiella spp.* which can originate from non – faecal sources. Hence, confirmation of *E. coli* is the preferred indicator of faecal pollution of natural water.

Total coliforms, refers to all bacteria which produce colonies with a typical metallic sheen within 20 – 24 hours of incubation at 35 ^{0}C on m-Endo Agar. It gives an indication of the general sanitary quality of water since this group includes bacteria of faecal origin. However, many of the bacteria in this group may originate from growth in the aquatic environment (Grawbow, 1984; Kfir, 1989 cited by DWAF, 1993).

CHAPTER 4

4.0 DESCRIPTION OF THE STUDY AREA AND METHODOLOGY

4.1 Description of study area

The study area is located on the north-eastern outskirts of the Maseru urban area, just below the main road to Berea, before the Mabote residential area. The catchment area extends to the south-eastern sides of Lithabaneng and Nelese, on the south-western side lie Lower and Upper Thamae, Borokhoaneng, Mohalalitoe, Maseru East, Qoaling and Seoli, while on the Eastern side lies Berea plateau, Motimposo, Tsosane and Mabote (see map 4.0).

The catchment occupies an area of 44 km^2, its length is about 13 km and channel slope is 0.4km/km (DWA, 2003). The Sebaboleng dam is situated upstream of the Mejametalana stream and connected to Maqalika through a spillway (see fig 4.0**)**. The former receives water mainly as run-off from the surrounding area, Mejametalana stream and other streams are seasonal. Sebaboleng has a maximum depth of 10m (WASA engineers,1998 sited by Molapo,1998). It has a full capacity of 0.84 MCM and active storage of 0.56 MCM (Lahmeyer International, 1996), while Maqalika has a storage capacity of 3.7 MCM and a dam wall 25m high (Aide Memoire,2001).

Map 4.0 Locational map of Maqalika (source: topographic map of Lesotho sheet no.32 (2000))

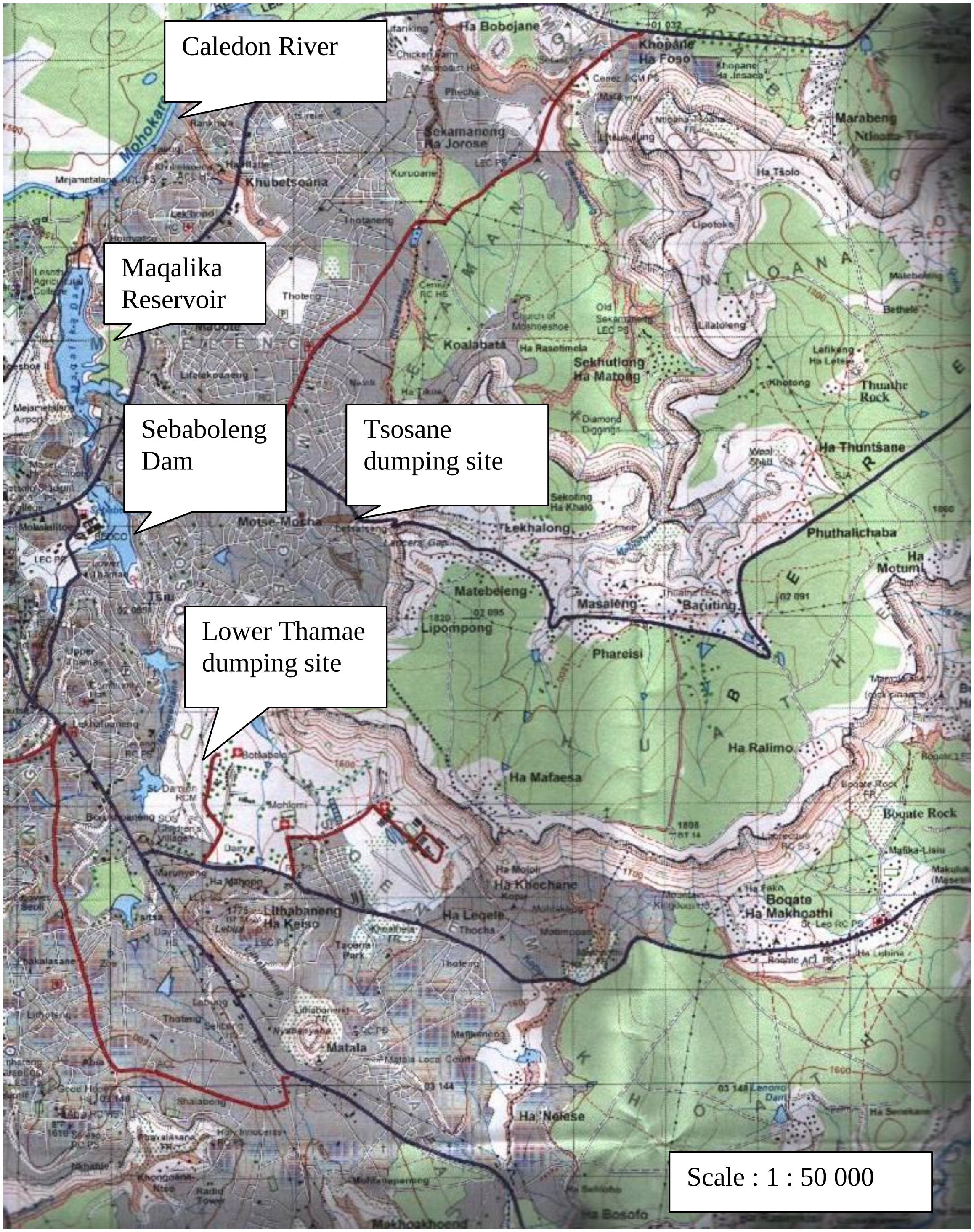


Fig 4.0 Spillway linking Sebaboleng with Maqalika (source: Author (2003))

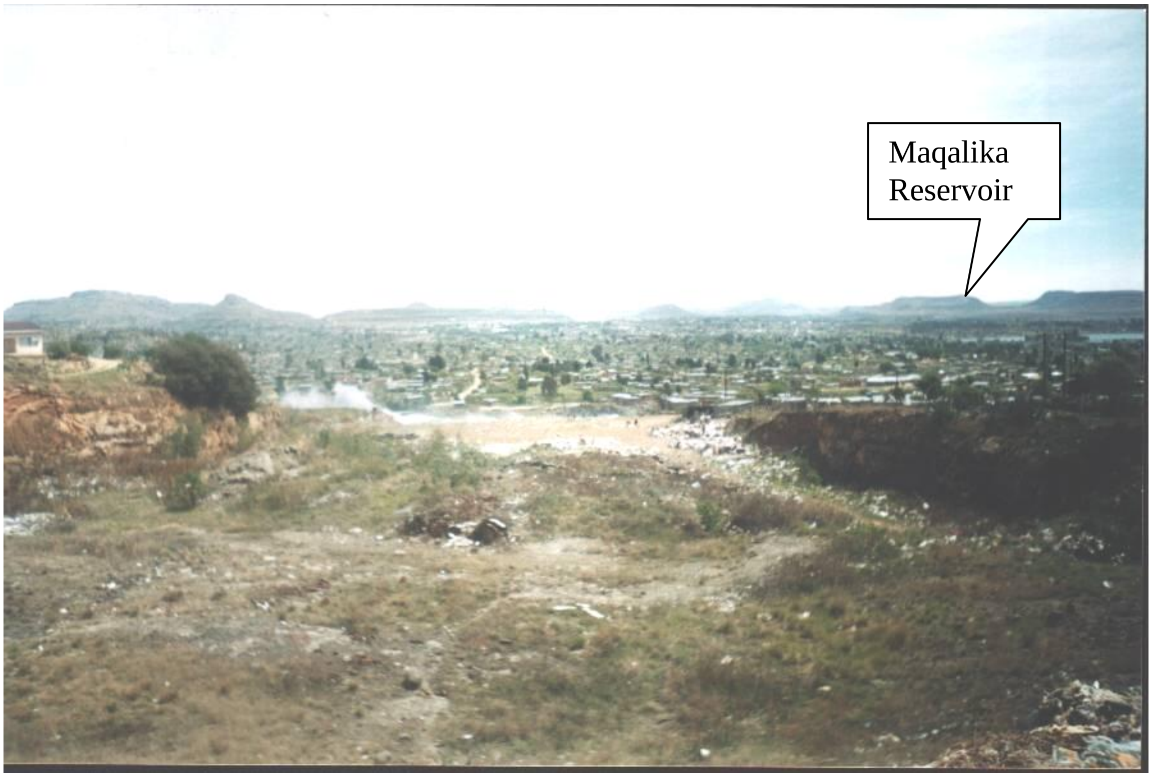
Maqalika reservoir was constructed in 1983 to meet the water demands for Maseru city until 1995. It is a zoned clay core embankment constructed on the Mejametalana creek. Features of the dam include an ungated, concrete lined spillway on the right abutment and an outlet works on the left abutment. Two pipes discharge water pumped from the Mohokare River into Maqalika reservoir (Aide Memoire, 2001)

From the location of the reservoir it becomes apparent that it is now an integral part of the lives of the neighbouring communities, hence its water quality has deteriorated very seriously such that it no longer meets its original requirements. Molapo (1998) pointed out that earth dams constructed upstream of Sebaboleng dam could possibly be acting as pollution sinks. However, most of them are severely silted up and have thick plantations of *Cattail* (*Typha*) and common reed (*Phragrimites australis*) (see fig. 4.1).

Fig. 4.1 Common reed fringing at Mejametalana dam upstream of Maqalika (source: Author, 2004)

The main land use within the catchment is a settlement area that comprises medium to low income houses (see fig 4.2). Most houses are not connected to WASA's sewerage reticulation system and thus the use of both septic tanks and VIP latrines is very common.

Fig 4.2 Tsosane dumping site and the surrounding settlements (source: Author, 2003)



Sources of pollution include leaking septic tanks, car repair garages, filling stations spillage, illegal and legal dumping sites, domestic effluent, sedimentation from run-off, etc. Most of the people use open pits for domestic rubbish which becomes mobile due to run-off during the rainy season and this ends up, in due course in the reservoir (see fig. 4.3 and fig. 4.4).

Fig 4.3 Leaking sewer at Lekhaloaneng upstream of Maqalika (source:Author, 2004)

Fig. 4.4 Disposal of domestic waste at Lithabaneng (source:Author, 2004)

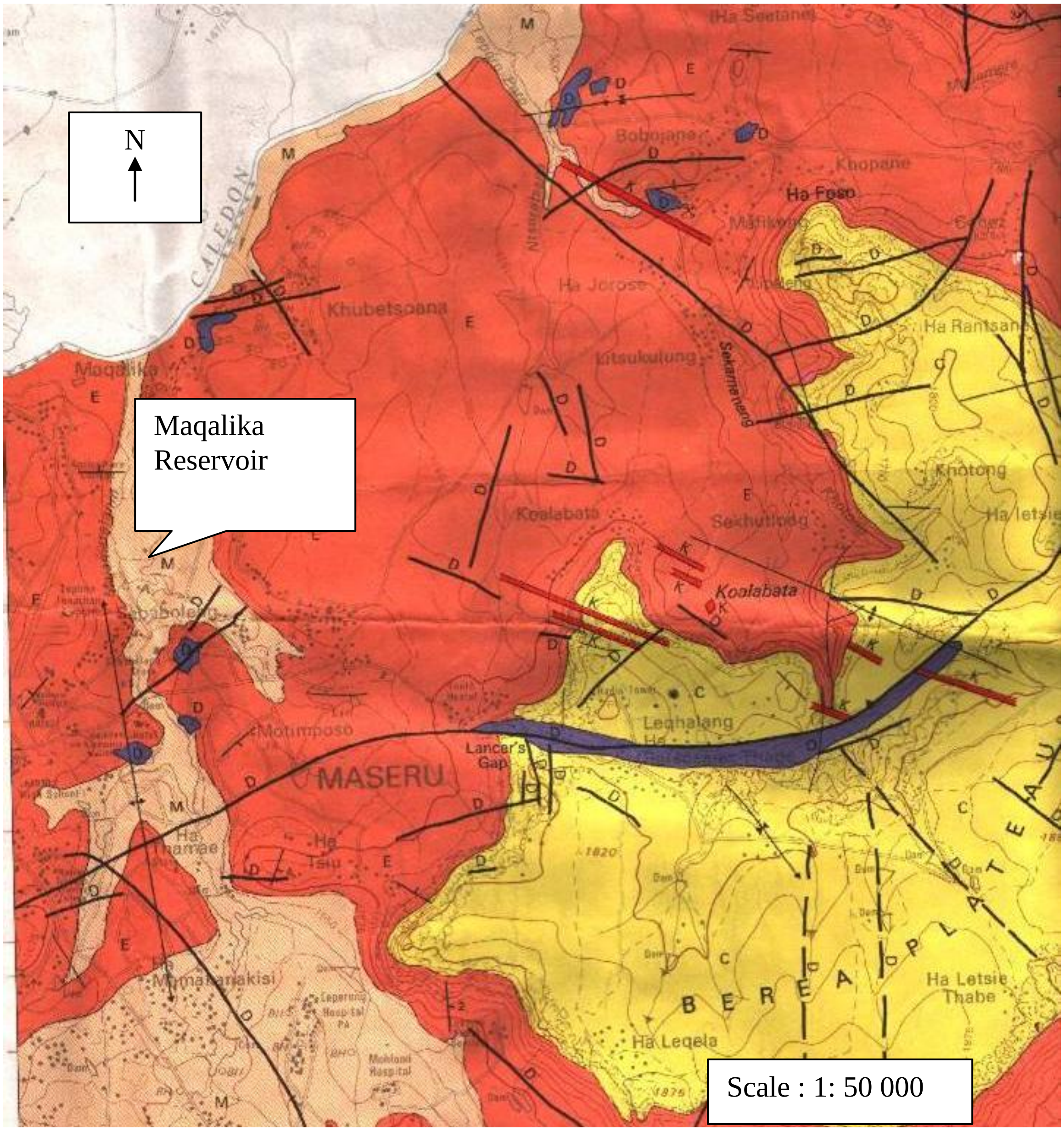
4.1.1 Vegetation

The vegetation of the study area falls within the *Cymbopogo-Themeda* Southern Variation Veld (Wieland, 1982 cited by DWA, 1990). It is predominantly *Themeda triandra* grassland. According to Chakela *et al*. (1986) the population explosion of the twentieth century has had a strong impact on flora and vegetation in Lesotho including that of the Maseru urban area. With increasing pressure on the land, the flora underwent a general impoverishment and the vegetation ceases to exist as a protective soil cover, leading to an acceleration of the natural erosion and land denudation. As a result, dongas are becoming common features of the area. The little vegetation which is left in the slope debris (*Clematis brachiata*) is in danger of vanishing due to increasing occupation by man.

4.1.2 Geology

The geology of the study area consists of igneous rocks of the Lesotho Formation; that is, dolerite dykes e.g Lancers Gap and intrusions and sedimentary rocks of the Stormberg Group, the Molteno, Elliot, and Clarens formation. The sandstones are generally more resistant to weathering than the mudstone and shales resulting in benches where there is a change from sandstone to mudstone or shale terrain (Chakela *et al*. 1986). Towards the periphery of the catchment lie the Qoaling plateau, Berea plateau and Lithabaneng hills which are all covered with Clarens sandstone escarpments while in the centre the prevalent formation is the Molteno series which is overlaid by Elliot horizons especially towards the north. The reservoir is located on the Molteno Formation (see map 4.1).

Map. 4.1 Geological location of Maqalika (source: Geological map of Lesotho, 1981)



KEY

Molteno Formation

Clarens Formation

Elliot Formation

4.1.3 Soils

According to the Soils of Lesotho (1979) cited by Chakela *et al*.(1986), the soil series of the area belongs to the Sephula-Maseru-Berea Gullied Land Association. These soils have typically brown friable to very dark brown and light greyish sandy loam and are firm and sticky. There is a somewhat poor to very poor internal drainage; surface run-off of external drainage is moderately rapid to slow depending on slope and degree to which the soil above the clay-pan has become saturated. Permeability of the loamy surface soil is moderate and that of the clayey subsoil is slow to very slow. On the contrary, Berea series have moderately rapid permeability and run-off is medium to moderately slow. The erosion hazard is very high.

CHAPTER 5

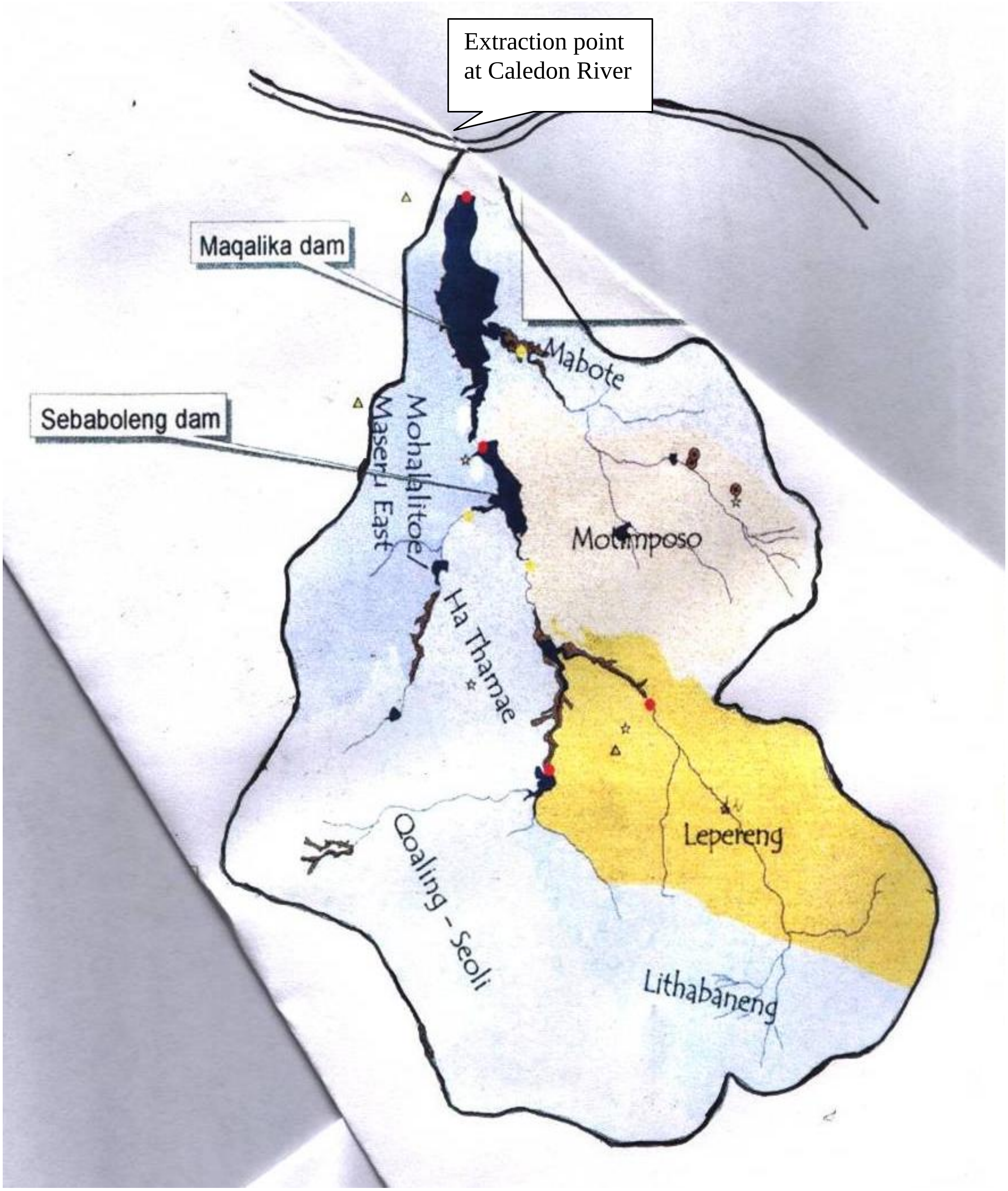
5.0 SEDIMENT CONTRIBUTION THROUGH PUMPING

Accumulation of sediment through pumping was derived from the cumulative mass concept by Wilson (1990), which states that the volume of water passing a point can be determined together with its sediment loading. This can be achieved by sampling that point several times for a long period of time, then plot hydrograph against time. By adding each new volume to the previous total a cumulative mass of discharge can be obtained together with sediment quantity.

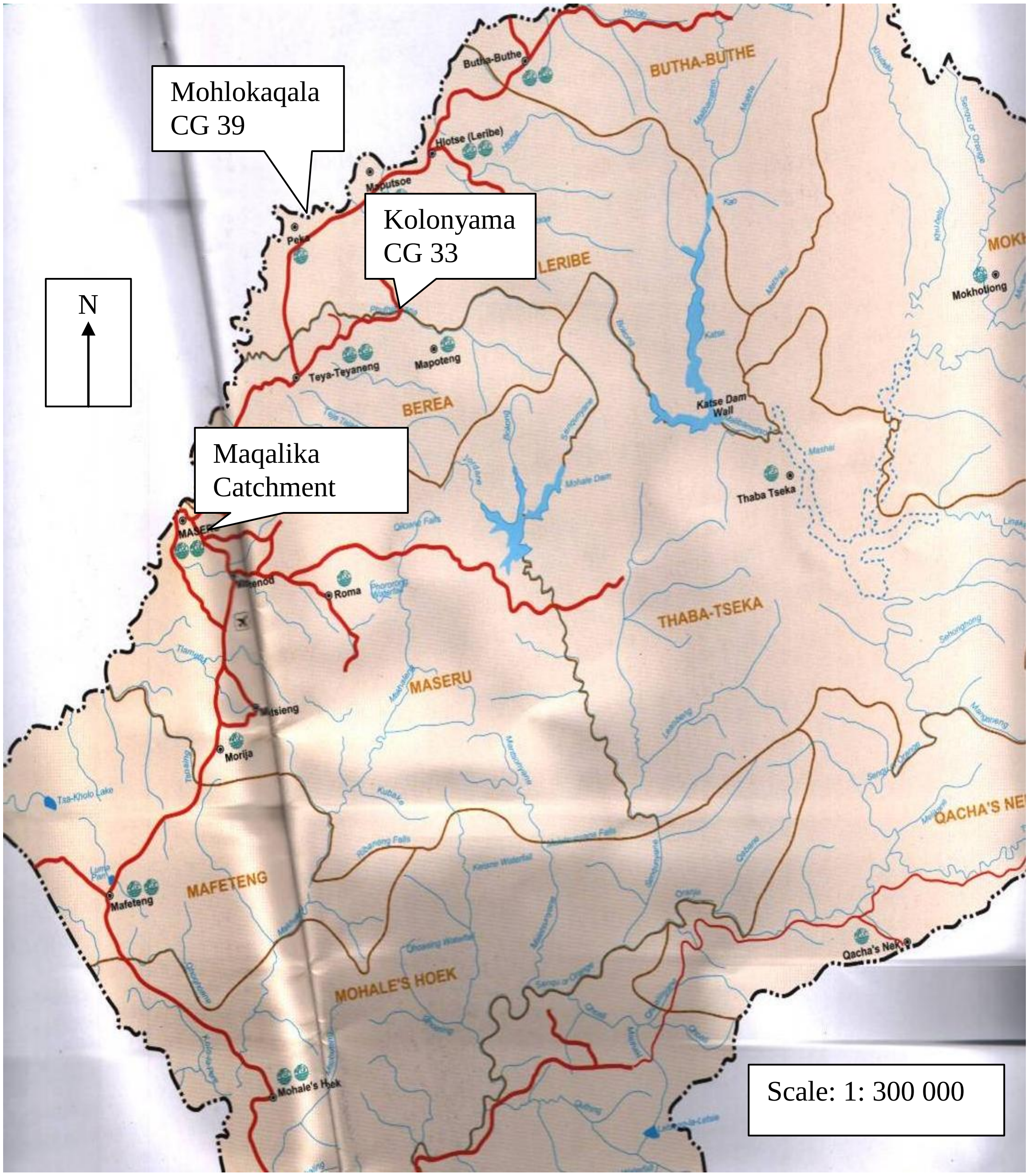
Raw water from the river is pumped daily into the reservoir during low river flows from April to September before (WASA engineer, pers. comm, 2003), making the reservoir act as a settling pond and having a negative impact on its capacity (see fig.5.0). To verify this, data from two hydrometric stations were analysed. The first was Mohokare at Mohlokaqala (CG 39) and the second was North Phuthiatsana at Kolonyama (CG 33) see map 5.0.

North Phuthiatsana is one of the major tributaries of the Caledon River and is heavily sedimented according to previous studies by Jacobi (1977) and Makhoalibe (1984), cited by TAMS (1996). It joins Caledon in the Berea district which is about 50 km upstream of Maseru and is a major supply of potable water. Kolonyama station (CG 33) is one of the reliable stations with satisfactory data, hence it as been utilized in numerous studies.

Fig 5.0 Maqalika Catchment   (Source:NES, 2001)



Map 5.0 Location of gauging stations (Source:WASA 1999/2000)



5.0.1 North Phuthiatsana at Kolonyama

Fig. 5.1 shows the comparison of average annual sediment yield to that of total discharge passing the station, which was found to be: 27985/1521485.6 (tons/day) /(m^3/day) x 100 = 1.84 % .Fig 5.2 shows North Phuthiatsana River at Kolonyama Bridge about 10 kilometers before it joins Caledon River.

Fig 5.1: Phuthiatsana flow vs. time (source: Author, 2004)

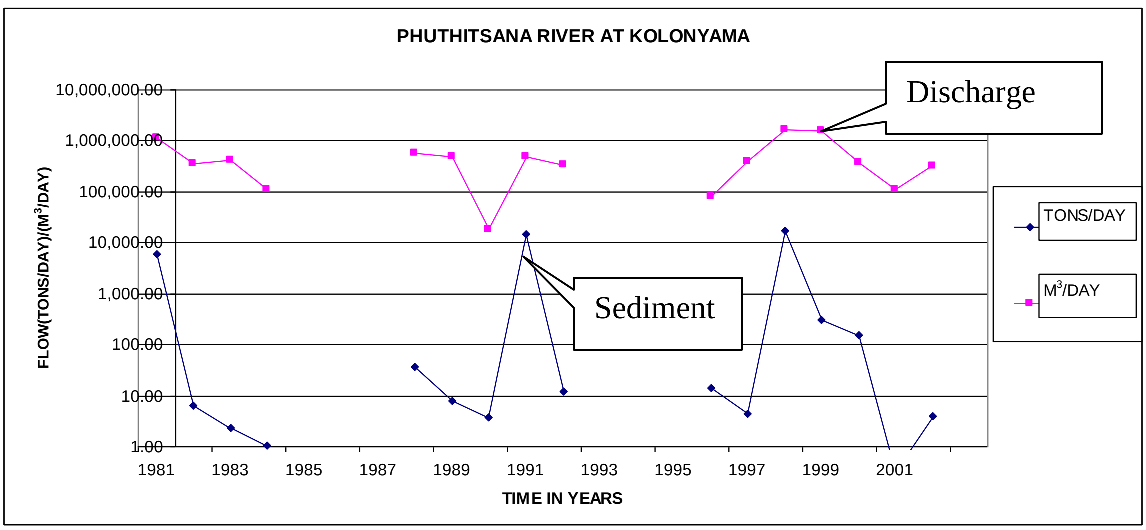


Fig 5.2 : North Phuthiatsana River at Kolonyama Bridge (Source: Author, 2004)

Fig. 5.3 depicts sediment concentration against river discharge for the years 1982-1997 giving the linear regression equation (y = 0.0002x – 0.0004). It is a common practice to draw a rating curve of sediment as a function of discharge based on short term planning and to use a rating curve in conjunction with long term discharge records. A rating curve on limited data may also be used where a singular relationship does exist between sediment concentration and discharge.

The correlation coefficient for Phuthiatsana river is 0.63 (see table 5.0 for results) and this was deduced from equation: $r = S_{xy} / (S_{xx} * S_{yy})^{0.5}$ (Dowdy and Wearden, 1999).

where : $S_{xy} = \sum x^2 – (\sum x)^2 /n$

$S_{yy} = \sum y^2 – (\sum y)^2 /n$

$S_{xy} = \sum xy – (\sum x) (\sum y) /n$

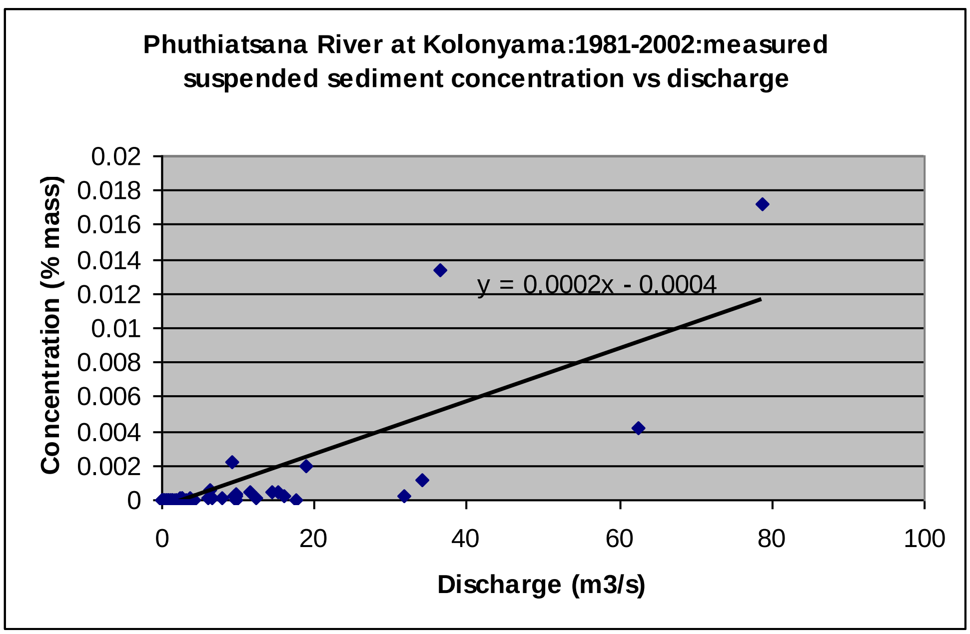
See appendix 4 for data consideration.

Table 5.0 Phuthiatsana summation results

X	X^2	Y	Y^2	XY
$1.22 * 10^6$	$2.73 * 10^{11}$	$1.89 * 10^8$	$3.66 * 10^{15}$	$2.67 * 10^{13}$

When r = -1 there is a perfect negative relationship, when r = 1 there is a positive relationship. As "r" gets closer to zero, there is less association between variables with a sample correlation coefficient. When "r" = 0.89, there is positive and relative strong linear association (Dowdy and Wearden, 1999).

Fig 5.3 Phuthiatsana River measured suspended sediment vs discharge



5.0.2 Mohokare (Caledon) at Mohlokaqala

Fig. 5.4 shows a comparison of average annual sediment yield to that of total discharge was found to be: (tons/day)/(m^3/day) x 100 = 0.54 %. Fig 5.5 shows Caledon River 1 km downstream of a pumping station.

Fig. 5.4: Caledon flow vs time

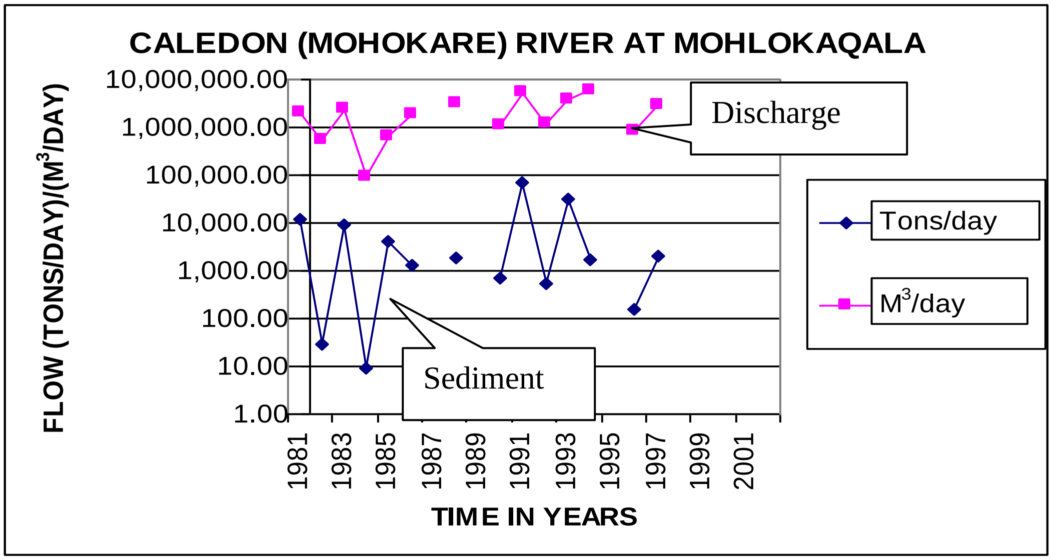


Fig 5.5 Mohokare (Caledon) at Maseru Bridge (Source:Author, 2004)

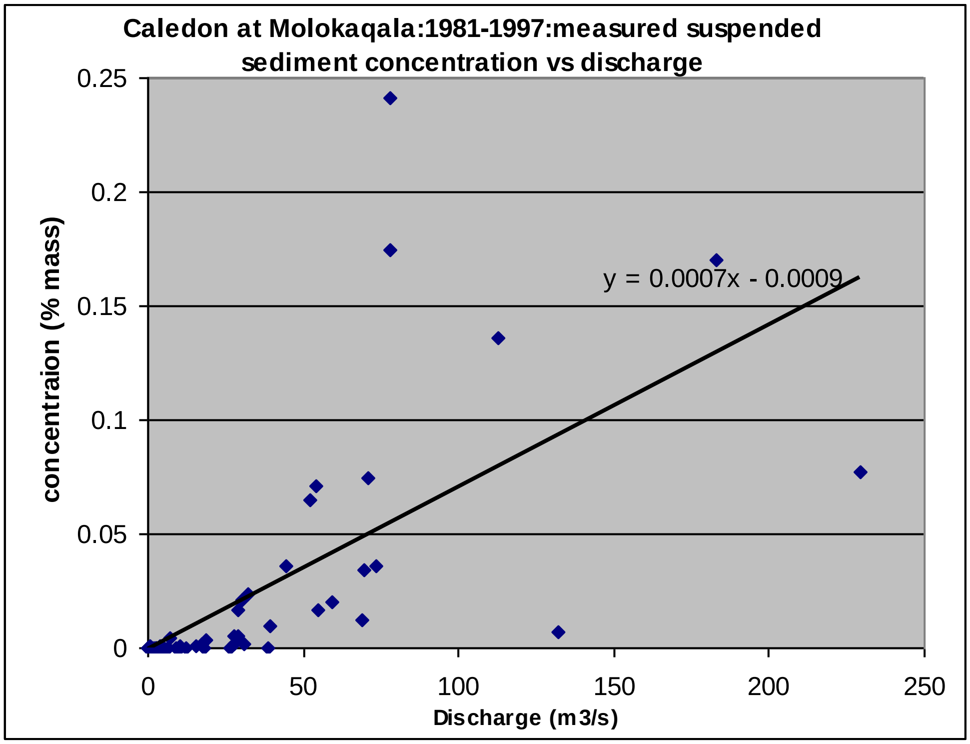
Fig 5.6 shows a graph depicting the sediment concentration against river discharge of the years 1982- 2002 yielding an equation of ($y = 0.0007x – 0.0009$). Rooseboom (1992) suggested that the rating curves based on scattered data may only be used in conjunction with flow records which cover the same period as the recorded sediment concentrations.

Mohlokaqala river correlation coefficient was calculated based on the previous equations mentioned on pages 66 and 68 and it was found to be 0.82 (see table 5.1 showing summation results) showing a greater link between variables. See appendix 3 for data consideration.

Table 5.1 Mohlokaqala summation results

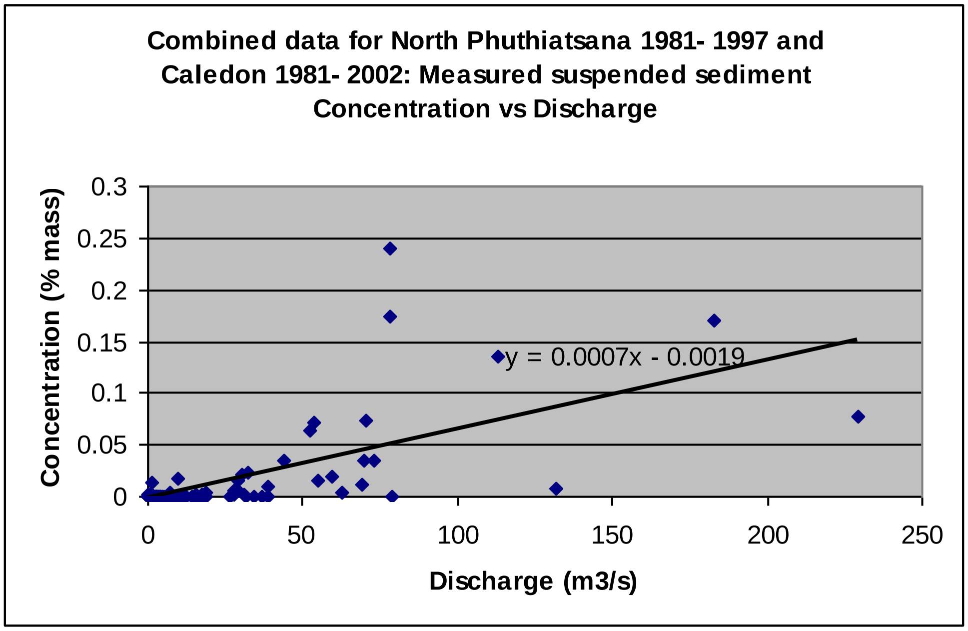
X	**X^2**	**Y**	**Y^2**	**XY**
$2.079 * 10^5$	$1.52 * 10^{10}$	$2.6 * 10^7$	$6.0 * 10^{13}$	$6.26 *10^{11}$

Fig. 5.6 Caledon measured sediment concentration vs. discharge



Since North Phuthiatsana River is a tributary of Caledon River both equations that were found above could not be used as they did not give the right concentration at the point where pumping is occurring. Therefore, data for both stations was combined in one graph to give at least the closer concentration equation at the pumping station as reflected in fig. 5.7. The obtained linear regression equation y = 0.0007x – 0.0019 was used throughout to attain the volume of sediment (see appendix 1 and 2 for spreadsheets used to plot fig 5.7).

Fig 5.7 Combined data for Phuthiatsana and Caledon



Pumping from Caledon River into Maqalika Reservoir is 14Ml/day = 14 000 m^3/day = 0.162 m^3/s.

Assume the specific volume of 1.35m^3/t

Normally a conservative value of 1.0m^3/t is used for a duration of 10 years period but since a 21 years period of data is considered in this study, Basson (2004) suggested that the value of 1.35m^3/t is appropriate (as per communication).

As the volume: time relationship is highly non-linear even though the mass of sediment within the reservoir may accumulate linearly with time, it is best to calculate the total mass entering the reservoir and convert this to volume by means of a function of time (Pitman *et al*. 1981).

From equation $y = 0.0007x – 0.0019$

Where y = Concentration from the river

x = Discharge from the river

"x" was kept constant at 0.162 m^3/s

and therefore $y = 0.0007 \times 100 \times 0.162 – 0.0019 = 0.00944$ kg/s

convert to tonnes : $y = 0.00944/1000 = 9.44 \times 10^{-6}$ t/s

convert to days: $y = 9.44 \times 10^{-6} \times 86400 = 0.815616$ t/day = 297.70 t/a

to find an annual volume considering a specific volume of 1.35 m^3/t.

Volume = 0.815616 t/day x 365 days x 1.35 m^3/t = 401.895 m^3

Roosebom (1980) suggested the following equation for trap efficiency.

$V_t/V_{50} = 0.376 \ln t/3.5$

(source : WRC report no 9/81, 1981)

Therefore the volume occupied for 21 years is: V_{21}= 50 years x 401.895 = 20 094 m^3

V_t = 20 094 x 0.376 ln (21.3.5) = 13 537 m^3

For simplification it was conservatively considered that pumping continues throughout the whole year whereas it occurs during low flows for minimization of high concentration of sedimentation during the rainy season as mentioned before. Therefore, quantity obtained was then divided by 2 to get 6 789 m^3 showing that pumping is only done during six months of the year (April – September). But, it should be considered that climate change has its own contribution to human reaction, therefore if there is no rainfall during the rainy season pumping still continues and vice versa.

The study by Jacobi (1977) cited by TAMS (1996) estimates the following annual sediment yield (see table 5.2).

Table 5.2 Annual sediment yield

River name	**Area km^2**	**Tons/Km^2/yr**
North Phuthiatsana (CG 24)	386	2968

The other study was done by Makhoalibe (1984) cited by TAMS (1996). Table 5.3 shows estimate of sedimentation.

Table 5.3 Estimates of sedimentation

Name of the river	**Area (km^2)**	**Tons/Km^2/yr**
North Phuthiatsana (CG 33)	905	740
Caledon at Mohlokaqala (C 39)	5600	930
North Phuthiatsana Mapoteng (CG 34)	386	2050
Caledon at Mashili	1560	730

In August 2002, Stephenson and Associates was commissioned to carry out a sedimentation impact study on the Maqalika Reservoir. A hydrographic survey was done by means of a Garmin GPSMAP 185 depth sounder. The instrument was mounted on an inflatable boat and the dam was traversed backwards and forwards picking up bed level beneath the water using a depth sounding devise. The data was downloaded into a computer from which “x-y” coordinates and water depths of each point were computed. The results were then used for plotting new contour maps and cross-sections of the reservoir at regular intervals (WASA, 2002).

The new contours were then compared with those that existed before the construction of the reservoir. From a comparison of plotted cross-sections it was deduced that 100 000m^3 of sediment deposition was estimated. It was found to be evenly distributed over the reservoir floor. It was concluded that catchment erosion was the main contributor. Nevertheless, deposition around the tower intake was found to be very considerable because of pumping from Caledon River (WASA, 2002) (indicating that the river was a likely source).

5.1 Sediment contribution through Maqalika catchment run-off

In modelling sediment yields from small catchments, the yields are normally linked to the run-off transporting capacity (Roosebooom, 1992). Not only are daily loads of rivers extremely variable but even on an annual basis the variability is such that long term records are required in order to establish accurate estimates of average annual loads. It is therefore extremely risky to draw conclusions from limited records.

Following many attempts in trying to use the Pitman model for the estimation of sediment yields using rainfall data for the Maqalika catchment, a simplified statistical analysis adopted by Rooseboom (1992) was used. The method entails sub-dividing the area of interest (Maqalika catchment) into higher, medium and lower sediment yield potential, whereby one has to consider:

(i) A basic yield index map based primarily on soil types and slopes prepared by Prof. E. Vester cited by Rooseboom (1992).

(ii) Land-use.

(iii) Availability of recorded data.

(iv) Boundaries of river catchments.

Fortunately, the area of interest is only 44 km^2, hence there was no need for sub-dividing it any further and it has only two regions to be considered; Elliot formation for higher and Molteno formation for medium sediment yield potential. There is only a small fraction of Clarens formation which was never considered since it was considered insignificant.

Constant ratios between yields from the sub-regions were assumed. This was implied from all the available calibrated maps. By using these ratios, a standardized yield value could be calculated for each reservoir (Rooseboom, 1992).

For determination of sediment yield values in the Maqalika catchment, the following tools were used.

(i) A map of Southern Africa, on which nine distinct sediment yield regions are indicated. Dividing the regions into three categories, higher, medium and lower sediment yield potential (Annexure 1).

(ii) A table containing mean standardized sediment yield value for each of the nine sediment yield regions (Annexure 2).

(iii) Graphs showing, for each region, the variability displayed by existing data, linked to the catchment size.

(iv) A table with sediment yield factors for each region, by means of which the standardized sediment yield values for any given catchment (Annexure 2).

5.1.1 Methodology for applying the map

Rooseboom (1992) suggests that the first step is to determine the regional standardized sediment yield value, which is applicable to a catchment with a specific size and location, and then convert this value into the actual yield potential of the different soils in the catchment.

The method consists of the following steps: Source: (WRC report no. 297/1/92)

(i) Determine the location and size of the catchment for which the estimated sediment yield is to be determined; 44 km^2 was used in this regard.

(ii) Obtain from the sediment yield region map, the yield region (from 1 to 9) for the catchment as well as the sizes of sub areas within the catchment that consists of soil with different yield potential (higher, medium and lower yield potential) (Annexure 2). Maseru falls within Region 6 hence this region was selected.

(iii) For the given region, use the regional standardized mean yield given in Annexure 2. From the table 335 t/km^2.a was found to be appropriate and a sediment yield factor (F_H) of 1 was selected.

(iv) From the graph for the region, (Annexure 3-8) select the multiplying factor with due consideration to catchment conditions. Note that the factors given are envelope values and are expressed as multiples of the regional average standardized yield. Annexure 7 (for region 6) was utilised considering the 95% confidence limit which yielded 7 as a multiplying factor.

(v) Convert the standardized sediment yield values to site specific yield values with the formula: $Y_C = Y_S (F_H A_H/A_T + F_M A_M/A_T + F_L A_l/A_T)$

Whereby:

Y_C = estimated catchment sediment yield value (t/km^2.a).

Y_S = standardized sediment yield value (t/km^2.a).

F_H = high yield potential factor.

F_M = medium yield potential factor.

F_L = low yield potential factor.

A_H = size of area consisting of soils with high sediment yield potential (km^2).

A_M = size of area consisting of soils with medium sediment yield potential (km^2).

F_L = size of area consisting of soils with lower sediment yield potential (km^2).

A_T = total cathment area (km^2).

Since the lower yield potential was excluded, $F_L\ (A_L/A_T)$ was excluded from formula. Therefore the calculations were:

Y_S = 335 x 7.0 = 2345 t/km^2.a

Therefore Y_C = 2345 (1(22/44) + 1(22/44)) = 2345 t/km^2.a

Which is 2345 t/km^2.a x 44 km^2 = 103.18 * 10^3 t/a

Rooseboom (1980) suggested that in determining sediment trap efficiency, Brune's diagram as depicted in his report, should be used. From this diagram trap efficiency is about 98%.

Average silting rate will therefore be = 98/100 x 103. 18 x 10^6 = 101.12 x 103 t/a

At a specific volume of 1.35 m^3/t, sediment accumulation is = 136.51 x 10^3 m^3/a

Assuming sediment accumulation from 1982 –2002, the storage volume capacity will be calculated by equation $V_t/V_{50} = 0.376\ ln\ t/3.5.$

Where V50 = 50 x 136.51 x 10^3 m^3 = 6.826 x 10^6 m^3

$V21 = 6.286x\ 10^6 \times 0.376 \ln 21/3.5 = 4.598 \times 10^6\ m^3$.

NB: from both pumping and catchment run-off contribution the total volume is 4.605 MCM and Maqalika reservoir capacity is 3.7 MCM therefore, 0.905 MCM has been accumulated beyond capacity.

CHAPTER SIX

6.0 EFFECTS OF LAND USE PRACTICES ON THE WATER QUALITY

6.1 Introduction

This chapter discusses the results obtained when analyzing the procured data. The results are presented in tables and graphs in order to show trends. For comparative purposes WHO, RSA and the Proposed National Domestic Water Quality Guidelines for Lesotho will be used. The difference between the individual results and the recommended guidelines gives an indication of how polluted Maqalika is, hence the amount of energy and the chemicals needed to treat the raw water to the acceptable standards. The two requirements in turn have a bearing on the treatment costs.

6.2 Physico-chemical data

This section discusses the results for both physical and chemical analysis of the data obtained. The determined parameters are nitrates, phosphates, conductivity, turbidity, temperature, pH, iron, alkalinity, hardness and faecal coliforms.

6.2.1 Nitrates

The United Kingdom’s Department for Environment Food and Rural Affairs(DEFRA) (1992) sited by Stentiford *et al*.(1994) pointed out that the enrichment of water by nutrients produce an undesirable disturbance to the balance of organisms present in water. It was also stated that it is necessary to control nitrates from discharges to freshwaters especially where the 50 mg/l nitrates concentration has been exceeded and where water is abstracted for human consumption. From obtained results there is a clear indication that, as mentioned before regarding phosphates, the main contributor of nitrates within the catchment are poor treated sewage from the Makoanyane barracks and the National Health Training Centre (NHTC), leaking pit latrines, leaking septic tanks and the two dumping sites mentioned before (one at Tsosane (active) and the other at Lower Thamae (inactive)). Another contributor is the use of dongas for defaecation by some other members of the local community.

From table 6.0, maximum values are way above the limits of three guidelines except for February, June and July of 2001, but for mean values almost 70 % are within the range of WHO but 60 % are above SABS and National Standard guidelines. Excessive nutrients, such as nitrates and phosphates cause pollution primarily because they stimulate the growth of micro organisms, increasing the Biological Oxygen Demand (BOD) of the water and reduce the dissolved oxygen available for aquatic organisms. These nutrients stimulate growth, lead to plankton blooms which produce obnoxious taste and odours in water, and disrupt aquatic ecology (Evangelou, 1998).

Table 6.0 Concentration of nitrates (2001-2002)

2001												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max	39.0	6.1	14.0	28	19.7	3.1	3.5	-	14.6	24.4	-	-
Min	1.9	2.0	4.5	2.0	1.7	1.1	1.9	-	0.1	0.4	-	-
Mean	11	3.13	9.9	11.3	6.8	1.9	2.7	-	5.3	5.0	-	-
2002												
Max	35.8	14.0	48.2	-	-	-	-	13.9	12.0			19.0
Min	1.8	2.4	1.3	-	-	-	-	1.1	5.0			7.0
Mean	13.8	6.3	11.8	-	-	-	-	3.4	7.1			1.3

WHO < 10 mg/l National std. < 6 mg/l SABS < 6mg/l

Fig. 6.0 Nitrates vs. Time

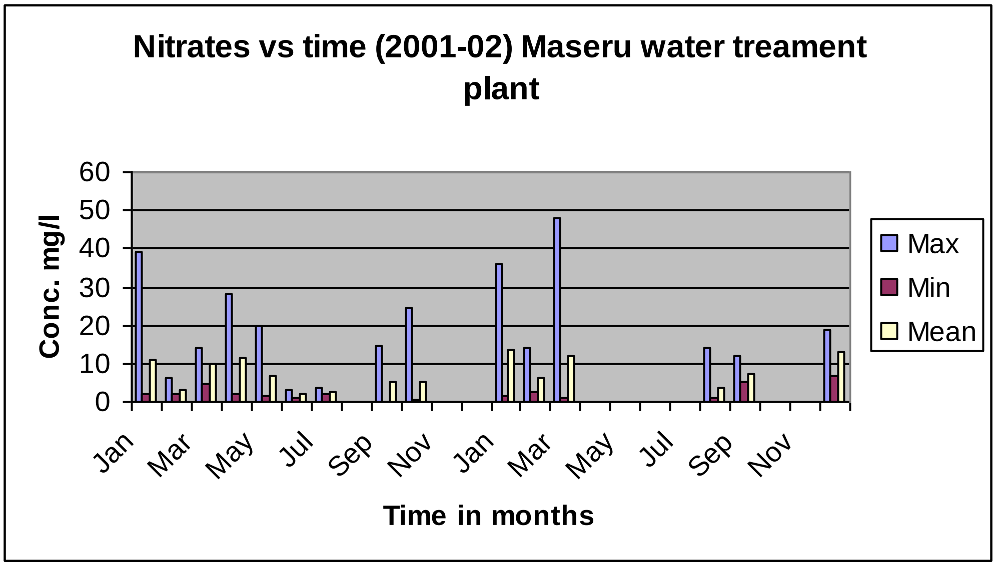
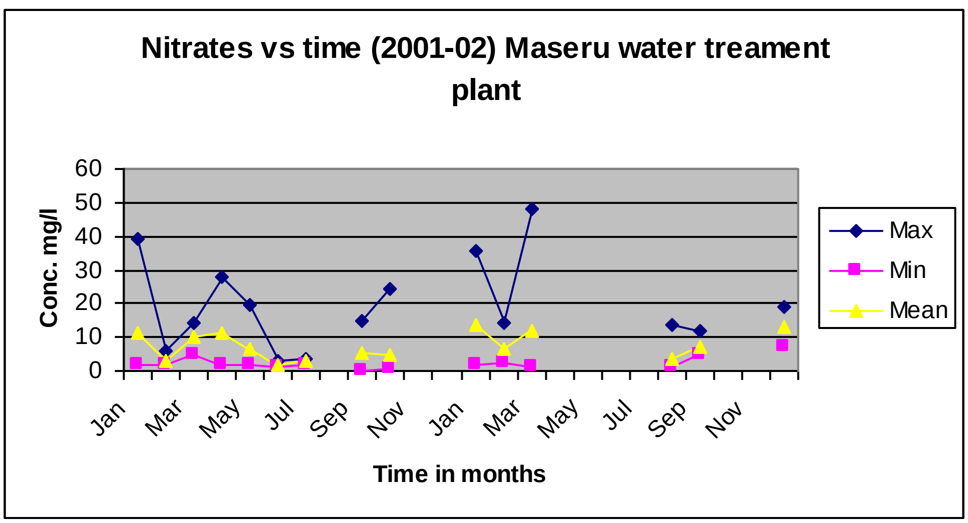


Fig. 6.1 Nitrates vs. Time



6.2.2 Alkalinity

Table 6.1, fig 6.2 and fig 6.3 show that all the recorded results are within the guideline limit of WHO, with the highest maximum value of 217 mg/l recorded in June, 2001.There are no guideline limits in place for SABS and National standards. The contribution of high alkalinity might be leaching from Molteno, Elliot and Clarens formations since they are comprised of siltstone and mudstone. They may contain high $CaCO_3$ due to high clay content. Detergents from domestic effluent may also contribute a significant amount of alkalinity. Thokoa (1996) sited by Molapo (1998) stated that high alkalinity has a bearing on the amount of chemicals required for purification processes.

Table 6.1 Concentration of alkalinity (2001-2002)

2001												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max	155	98	129	160	138	217	135	17	170	160	-	-
Min	23	79	67	72	73	118	80	8	65	44	-	-
Mean	111	87.7	104	89.6	110	138	113	11	87	110	-	-
2002												
Max	98	105	110	147	150	110	171	170	97	133	188	198
Min	39	70	76	89	70	73	93	77	68	74	2	89
Mean	83.3	90	93.6	116	109	88	117	135	83	104.6	104	120

WHO < 500mg/l
National std. none
SABS. None

Fig. 6.2 Alkalinity vs. Time

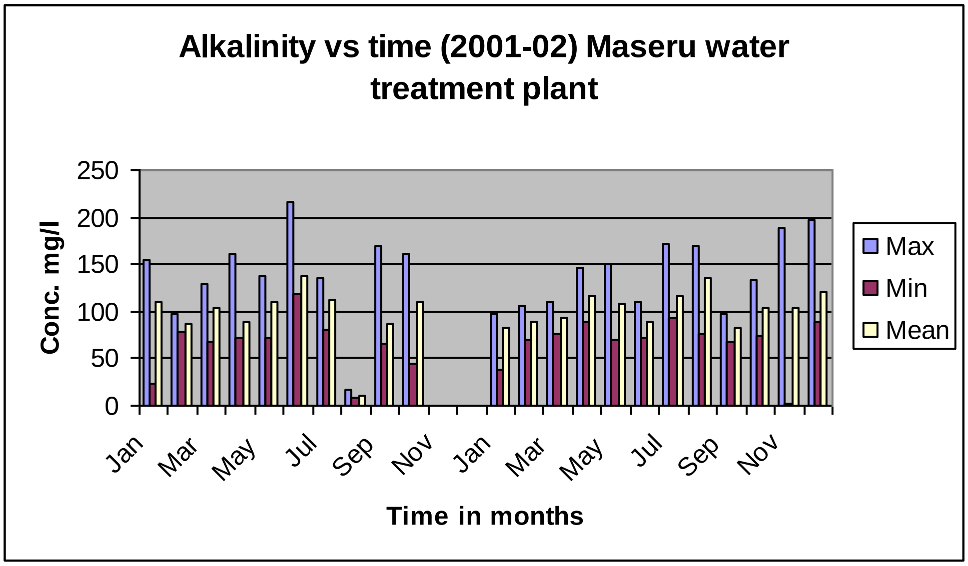
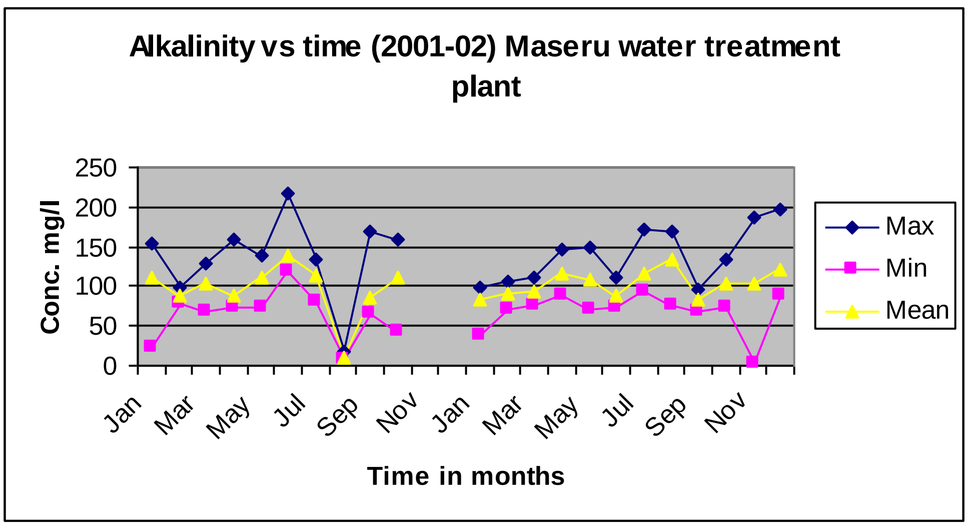


Fig. 6.3 Alkalinity vs. Time



6.2.3 Conductivity

Table 6.5, fig. 6.4 and fig.6.5 illustrate a sudden fall of concentration from October, 2001 to December, 2002. It is difficult to suggest the cause of the fall but one may assume that concentrations were high due to direct effluent (sewage) discharge into the reservoir from local communities or high leachate concentration from the solid waste disposal sites. This can also be affected by problems with the data or a change in units.

Table 6.2 Concentration of conductivity (2001-2002)

2001												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max	234	240	442	298	242	244	295	351	194	38	-	-
Min	204	114	101	115	123	118	231	129	131	7	-	-
Mean	225	173.8	187.3	173	187	209	265	270	171	22	-	-
2002												
Max	28	37	35	38	42	38	46	44	33	41	41	39
Min	13	18	15	13	19	20	21	18	13	21	16	10
Mean	22	24	23	26	28	29	33	29	22	27	25	24

WHO < 150 mS/m
National std. < 70 mS/m
SABS < 70 mS/m

Fig. 6.4 Conductivity vs. Time

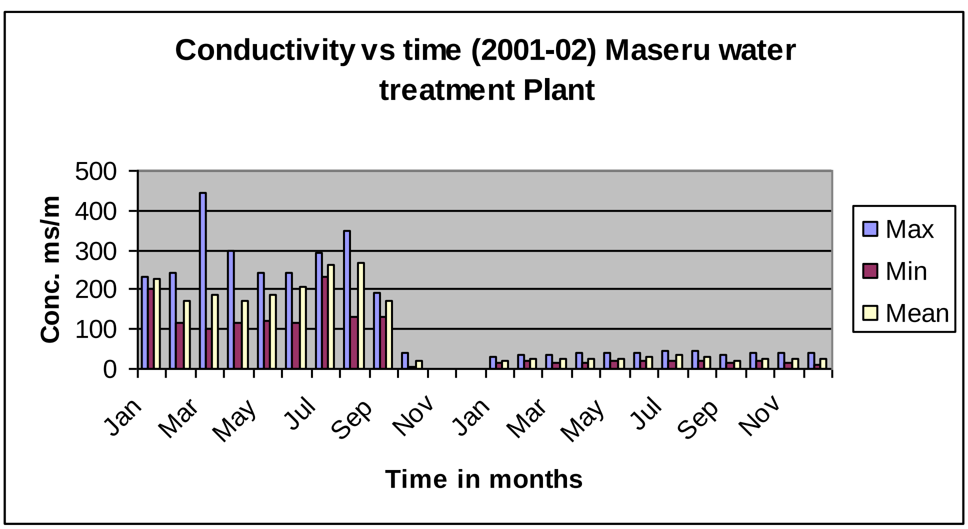
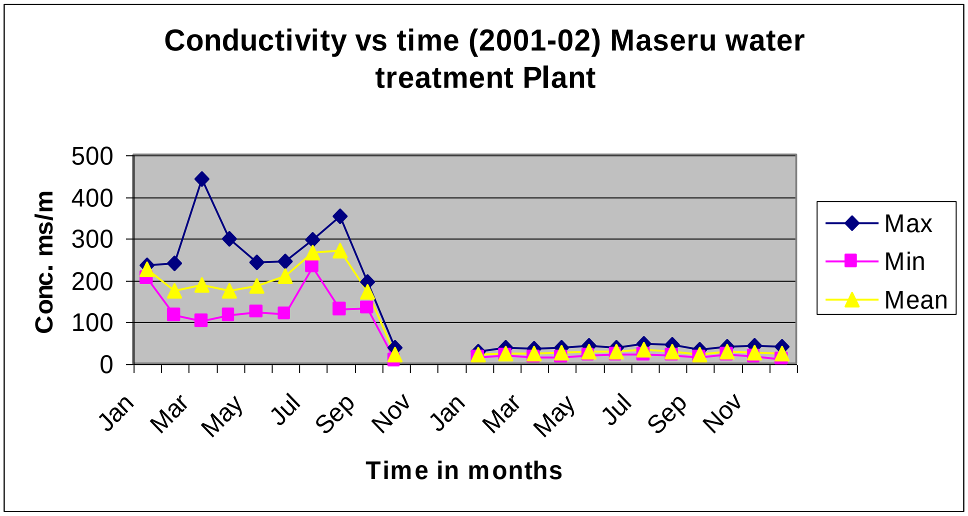


Fig. 6.5 Conductivity vs. Time



6.2.4 Hardness

Table 6.3 shows that all the values are lower than the recommended standards in the WHO guidelines and SABS. However, they are slightly higher than the proposed national standard which is 100 mg/l. From the recorded results, the highest ever in two year was 195 mg/l recorded in October 1991. Hardness in water requires more lime which is expensive (Sundstrom and Klei, 1979). Considering table 6.3, figure 6.6 and figure 6.7 hardness ranges from moderately soft (50 -100 mg/l) to moderately hard (150 – 200 mg/l) and, as a result, does not pose much danger to human beings. McGhee (1991) stated that hardness is not harmful to health, in fact; there is some evidence that soft water may be a contributing factor in some ailments, particularly cardiovascular diseases. Undesirable precipitates from other divalent cations in water with organic radicals can produce solid deposits in pipes and equipment which is very expensive to maintain.

Table 6.3 Concentration of hardness (2001-2002)(mg/l)

2001												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max	118	82	102	79	102	133	126	192	93	195	-	-
Min	68	60	58	55	54	63	77	112	64	71	-	-
Mean	96	70.1	77.1	68.2	82.7	110	102	148	78.1	105	-	-
2002												
Max	118	103	105	134	123	123	125	137	111	143	112	119
Min	63	71	72	66	86	79	92	68	59	90	77	67
Mean	90.2	90.2	90.2	98.7	99.7	98.7	109	110	80.8	113	96.4	88.5

WHO < 500 mg/l
National std. <100 mg/l
SABS < 650mg/l

Fig. 6.6 Hardness vs. Time

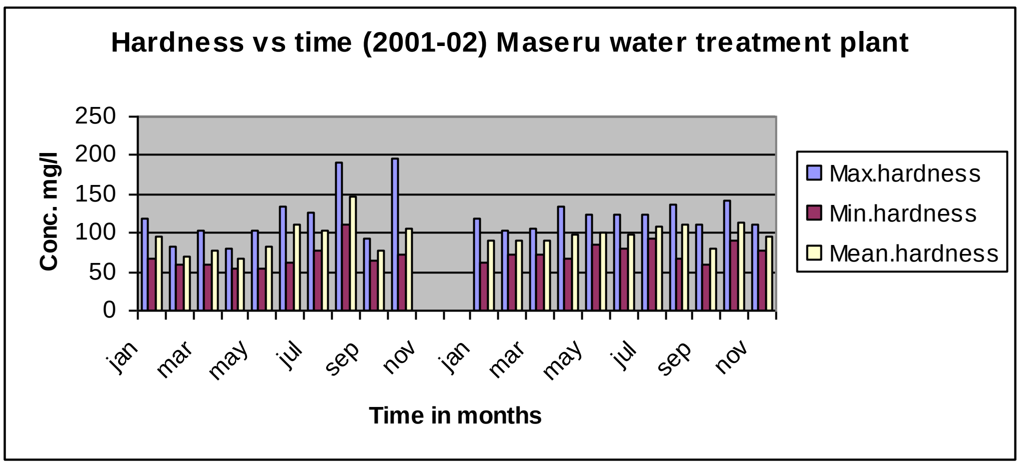
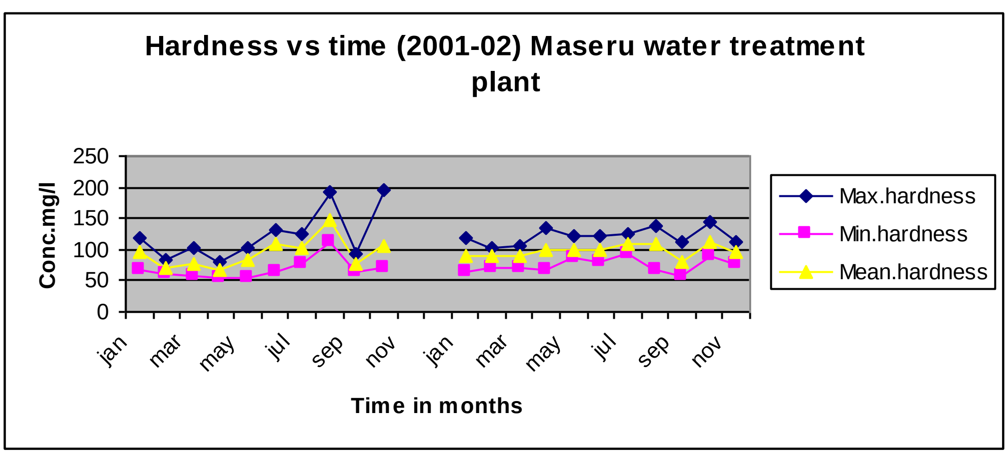


Fig. 6.7 Hardness vs. Time



6.2.5 Phosphates

There are two forms of phosphorus in the soil system – organic and inorganic. The organic form of phosphorus in many soils represents more than half of the total phosphorus. It appears in three different sinks/ sources. The first is nucleic acids, second is phosphate esters of inositate and third is phospholipids (Evangelou, 1998).

The inorganic form of phosphate in soils exists in various forms: (1) oxide-phosphate complexes such as clay mineral and (2) minerals of apatite (Evangelou, 1998). According to field observations (2003) the main contributors of phosphorus within Maqalika catchment are sewage effluent from poorly treated Makoanyane Barracks effluent, and the National Health Training Center (NHTC) upstream of the catchment and also, leacheate from two dumping sites, one (active) at Tsosane and the other (inactive/buried) at Lower Thamae. Furthermore, leaking sewage pipelines, septic tanks and leaking pit latrines aggravate the situation.

The contribution of detergents containing anionic surfactant phosphate (sodium tripolyphosphate (STPP) from domestic effluents discharged into open pits worsen the situation. According to Stentiford *et al*.(1994) the average concentration of STPP in domestic detergent formulation is around 22%. Looking at table 6.4, fig 8 and fig 6.9, tests were done in only 9 months out of the 24 months, which is not representative. From the results, however, one could easily see that all the mean values are above the eutrophication threshold of 0.02 to 0.053 mg/l indicating high nutrient concentration (Vollerweider 1968, Heckrath *et al*. 1995 cited by Molapo 1998). The increase in phosphates in October of both years may be attributed to the onset of runoff (“first flush” effect), since October is the beginning of the rainy season.

Table 6.4 Concentration of phosphates (2001-2002)(mg/l)

2001												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max	-	-	-	-	2.0	1.0	1.0	1.0	1.0	26.7	-	-
Min	-	-	-	-	0.18	0.32	0.1	0.1	0.29	0.07	-	-
Mean					0.54	0.58	0.68	0.32	0.50	1.86	-	-
2002												
Max	-	-	-	-	-	-	-	2.0	1.0	15	-	-
Min	-	-	-	-	-	-	-	0.04	0.24	0.01	-	-
Mean	-	-	-	-	-	-	-	0.5	0.5	0.8	-	-

NB: there are no guideline limits from three standard guidelines being compared here.

Fig.6.8 Phosphates vs. Time

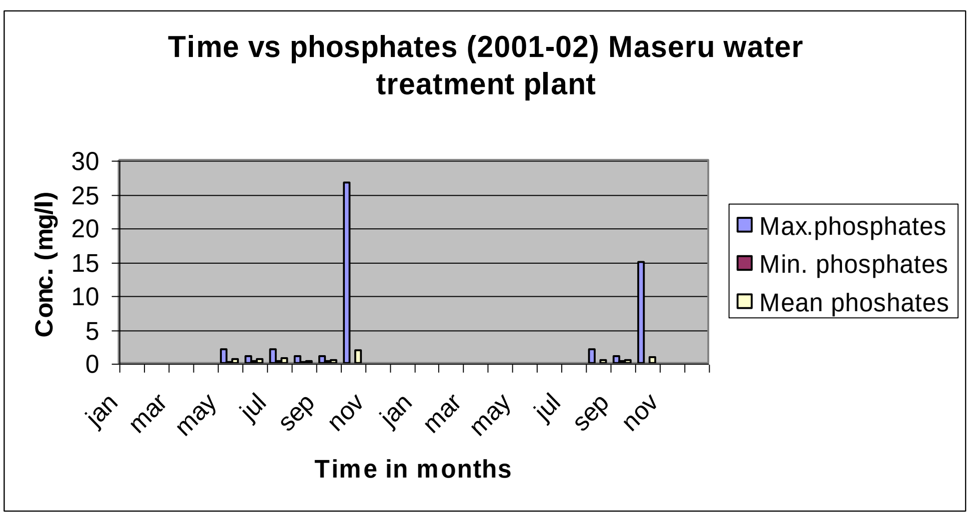
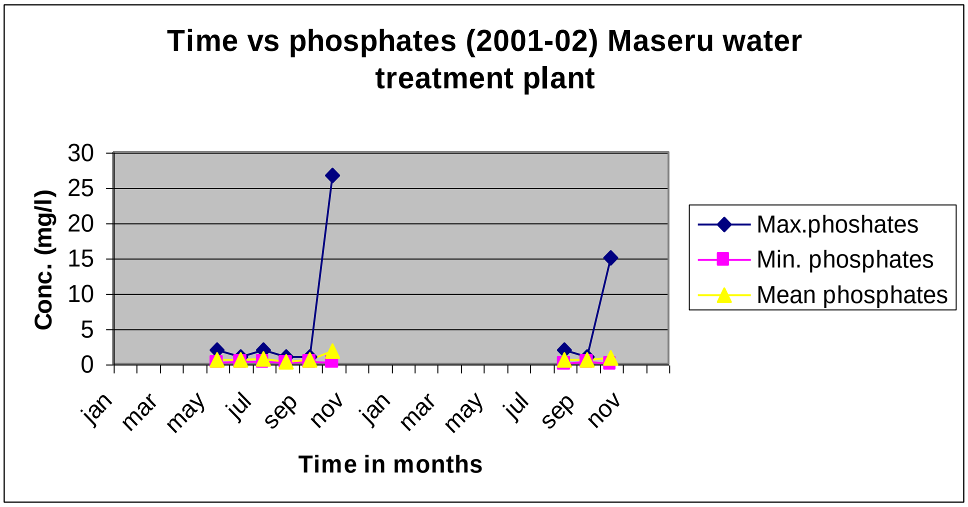


Fig. 6.9 Phosphates vs. Time



6.2.6 Turbidity

Turbidity in water is caused by the presence of suspended matter. Removal of suspended contaminants from water is a necessary step to the achievement of economic and environmental objectives. Water turbidity in nature generally results from colloidal clay dispersion and most of the natural colour comes from decayed wood, leaves etc., and organic soil matter. In addition to these contaminants, there are viruses, algae, bacteria, starches, metal oxides, oils and other pollutants that can significantly increase levels of suspended solids (Cheremisinoff and Young, 1981).

The primary importance attached to turbidity relates to its role in water treatment. The amount of chlorine required for disinfection of water increases as turbidity increases. Low turbidity therefore minimizes the required chlorine dose, and reduces the formation of chlorinated organics and taste and odour problems (Smith *et al*.1985 cited by DWAF 1993).

The adsorptive properties of some suspended particles may lead to the entrapment of undesirable inorganic compounds in water, including metal-humate complexes and herbicides, hence these could protect bacteria and viruses against disinfection. This could pose an indirect health risk associated with turbidity, WHO (1984) cited by DWAF (1993).

From obtained results, the maximum concentration attained in two years was in October 2001(see table 6.4**)** which was 8205 NTU- way above the limit (0-1 NTU). This gives a clear indication of the threat imposed by siltation and the high costs incurred during purification. According to Zimmie (1983), 90 % of all problems in a cooling system come from mud and sediment; pumps erode, shafts and packings fail, valves and controls stick because of plugged strainers or sedimentation on the stems. Fig 6.10 and 6.11 show clearly that high concentrations are during the rainy season starting from October to March.

Table 6.5 Concentration of turbidity (2001-2002) (NTU)

	2001			2002		
months	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Jan	**24**	**2992**	**674**	**89.3**	**3884**	**1115**
Feb	**84**	**5684**	**1183**	**45**	**765**	**261**
Mar	**63**	**2807**	**1183**	**80**	**1806**	**477.5**
Apr	**56**	**4375**	**1355**	**19.8**	**3389**	**398**
May	**25**	**748**	**140**	**0.5**	**1859**	**363**
Jun	**6**	**63**	**21.4**	**0.943**	**1920**	**182**
Jul	**3**	**70**	**19.9**	**8.12**	**30.8**	**14.9**
Aug	**5**	**1124**	**49.8**	**5.19**	**2123**	**229**
Sep	**20**	**3960**	**240**	**17**	**566**	**160**
Oct	**7.42**	**8205**	**1256**	**1.74**	**154**	**28.4**
Nov	**-**	**-**	**-**	**6.7**	**1371**	**257**
Dec	**-**	**-**	**-**	**3.1**	**2852**	**726**

WHO < 5 NTU
National std. 0-1 NTU
SABS < 0-1 NTU

Fig 6.10 Turbidity vs. Time

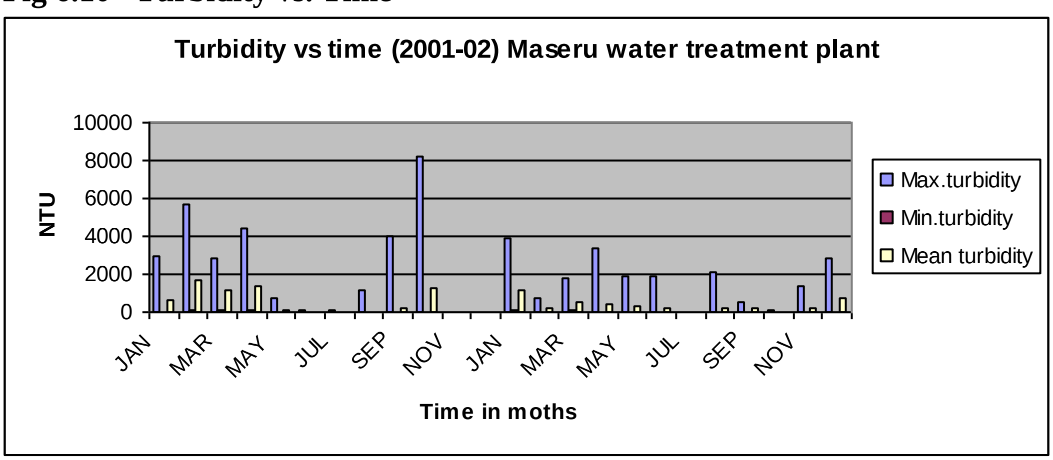
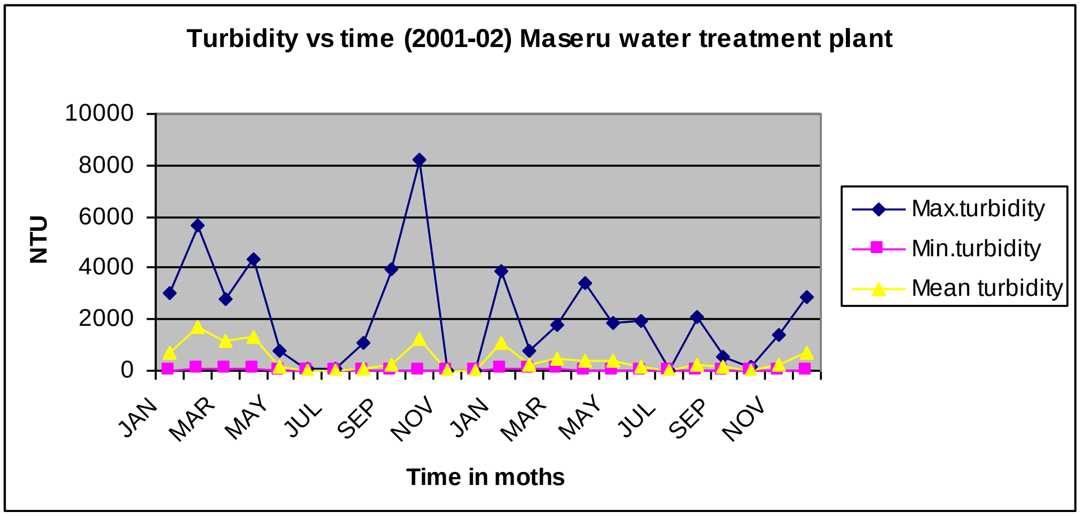


Fig. 6.11 Turbidity vs. Time



6.2.7 Temperature

If large gradients are reported in temperature changes, then stratification may occur between the upper warmer water body and lower colder water body. With no mixing between both layers, the upper warmer layer may become susceptible to eutrophication. High temperatures reduce the amount of oxygen in the water, thereby making the river/dam less desirable for fish (Kiely, 1997).

From obtained results (see table 6.5, fig. 6.12 and fig. 6.13) temperature values varies accordingly with seasonal changes and do not seem to pose any danger to aquatic life as they fall between 7.7 ^{0}C to 25 ^{0}C.

Table 6.6 Temperature in degrees Celsius (2001-2002)

2001												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max	27.6	23.2	24	21	17	17	14	17	21	26.8	-	-
Min	23.4	23.1	22	16	9.0	9.0	8.6	9.0	10	15	-	-
Mean	25.6	23.1	22.8	19	14.2	12.9	10	13.2	15.4	19	-	-
2002												
Max	25.2	26	25	22.7	19.9	13	10	20	19.5	23	24	26
Min	19.9	21.5	20	15.5	10.3	6.0	3.0	9.0	11.5	16.5	19	15
Mean	22.6	23.6	22.4	18.5	12.9	9.1	7.7	11.5	15.3	19.6	21.6	22.2

NB: no guideline limits for temperature.

Fig 6.12 Temperature vs. Time

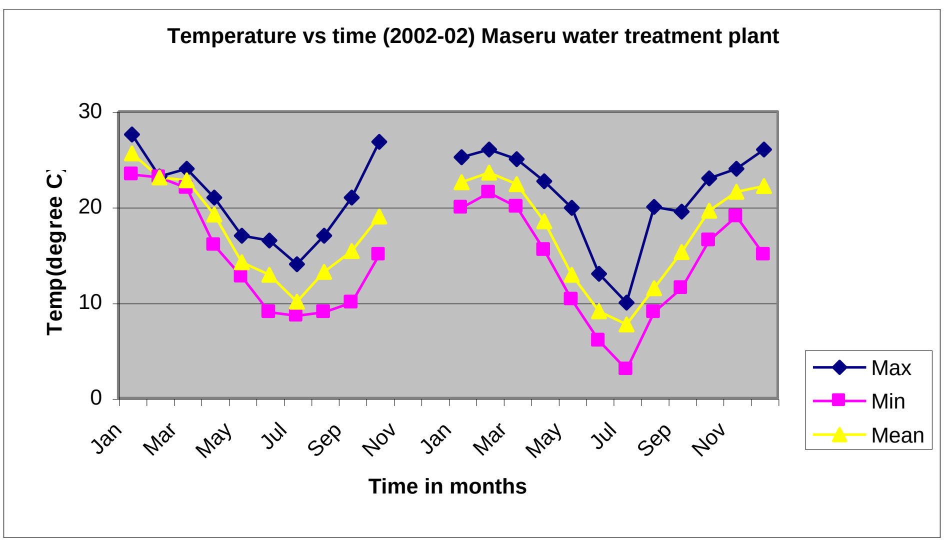
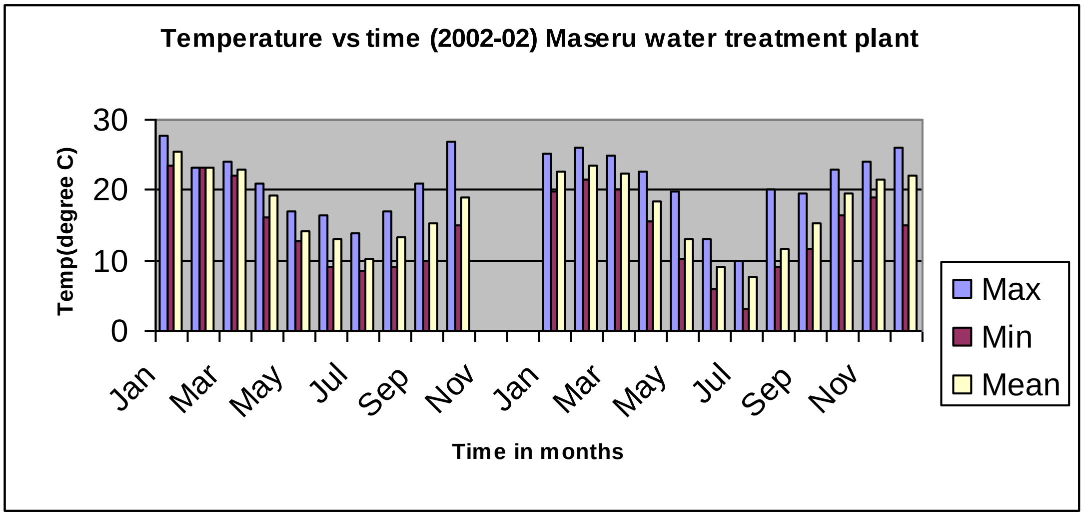


Fig 6.13 Temperature vs. Time



6.2.8 pH

The pH of most fresh water is 6 to 9. The pH remains reasonably constant unless the water quality changes due to natural or anthropogenic influences, adding acidity or basicity (Kiely, 1997). The pH values from table 6.6, fig. 6.14 and fig.6.15 are indicative of alkaline conditions. Most of the mean values fall within acceptable limits of the three compared guidelines, except 9.1 recorded in November, 2002.

The main contributors may be coal ashes from nearby surroundings, geological conditions (since all formations within the study area contain clay deposits) and wastewater discharges from domestic effluents. Kiely (1997) pointed out that influent above pH 8 may kill off active microbiological population and as a result impart tastes and odour problems.

Table 6.7 pH (2001-2002)

2001												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max	8.61	8.76	8.67	8.32	8.89	8.89	8.75	8.58	8.53	8.61	-	-
Min	7.96	7.48	7.86	5.42	7.66	8.16	7.98	8.1	7.69	7.45	-	-
Mean	8.3	8.07	8.2	7.71	8.31	8.54	8.4	8.44	8.12	8.2	-	-
2002												
Max	8.1	8.43	8.54	8.61	8.99	8.88	9.05	9.08	8.94	9.64	8.94	8.84
Min	7.61	7.74	7.65	7.83	8.12	8.13	8.13	8.14	8.15	8.39	7.93	7.84
Mean	7.7	8.0	8.0	8.27	8.4	8.6	8.7	8.7	8.5	9.1	8.5	8.2

WHO – (6.5-8.5)
National std.-(6.0-9.0)
SABS –(6.0-9.0)

Fig 6.14 pH vs. Time

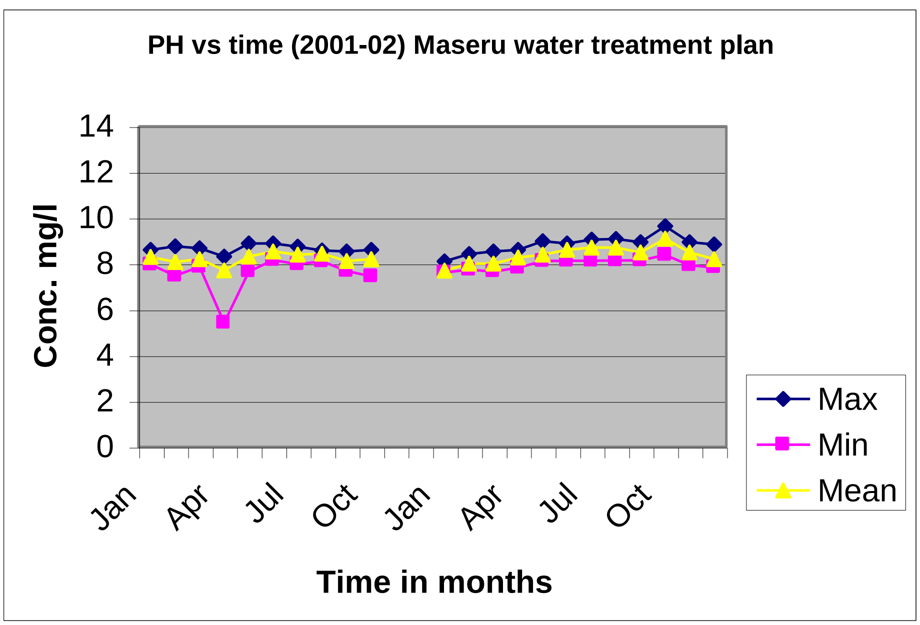
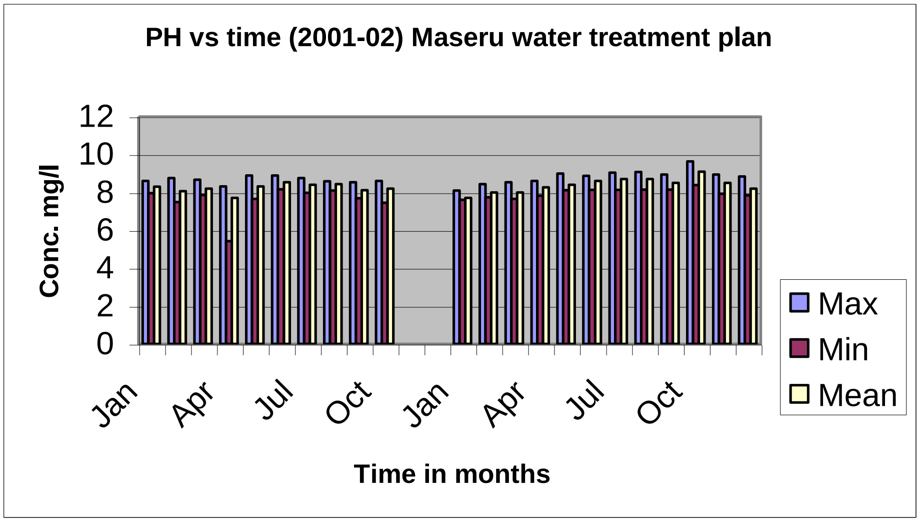


Fig 6.15 pH vs. Time



6.2.9 Iron

According to Otieno (1998 cited by Molapo, 1998) the taste threshold of iron is about 1.0 mg/l. Steel and McGhee (1979) stated that undesirable tastes, discolouration of clothes and plumbing fixtures are expected to happen when the concentration of iron is just above 0.3 mg/l. Table 6.7, fig. 6.16 and fig 6.17 show that all mean values are above 0.3 mg/l (except for 0.24 mg/l recorded in June, 2001) which shows that Maqalika is experiencing aesthetic problems.

Excess concentrations of iron do not usually cause health problems but are of concern for aesthetic and taste reasons (Kiely, 1997) but huge amounts of costs for purification are usually incurred. The source of iron can be iron minerals in the rocks or soils especially shales and sandstones, poor disposal of scrap metals and leachate from landfills.

Table 6.8 Iron concentration (2001-2002)(mg/l)

2001												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max				2.4	0.6	0.6	0.9	8.8	1.8	5.1	-	-
Min				0.1	0.2	0.1	0.1	0.03	0.2	0.01	-	-
Mean				1.23	0.39	0.24	0.3	0.68	0.59	0.88	-	-
2002												
Max	3.41	7.08	3.15	6.38				2.13	1.6	1.34	9.81	12
Min	0.25	0.06	0.25	0.37				0.02	0.26	0.06	0.23	0.25
Mean	1.34	1.6	1.5	2.04				0.32	0.78	0.3	2.66	5.26

WHO – 0.3
National std. –(0-0.1)
SABS – (0-0.1)

Fig 6.16 Iron vs. Time

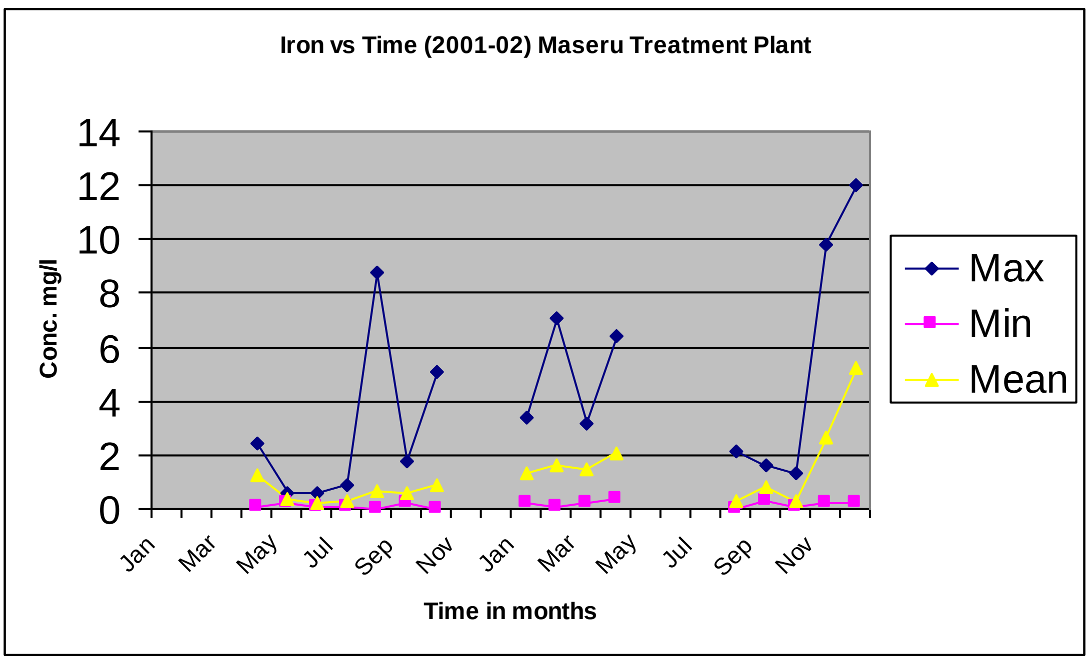
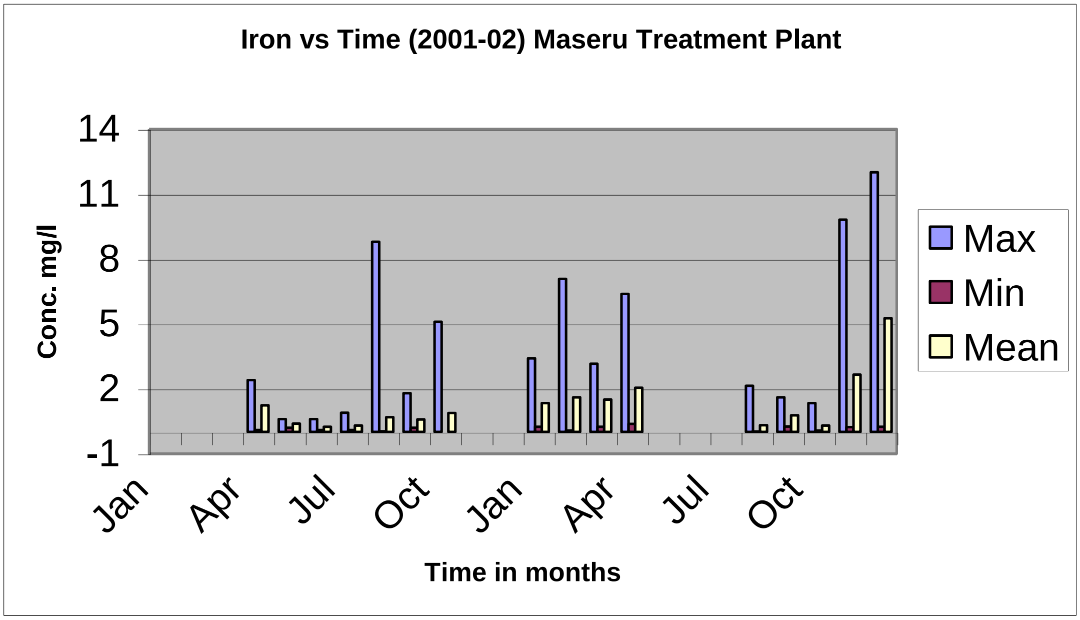


Fig 6.17 Iron vs. Time



6.2.10 Faecal coliforms

Higher concentrations of faecal coliforms in water indicate a higher risk of contracting waterborne diseases such as dysentery, cholera, typhoid fever etc; even if small quantities of water are consumed. Water quality guideline limits for SABS is 0, WHO is 0-1 and the National Standard is 0 – 1 count/ 100 ml. When considering table 6.9, fig 6.18 and fig 6.19 on the next pages, one would recognize that all mean values are far above guideline limits with the highest mean value being 77200 counts/ 100ml and the lowest of 25 counts/ 100ml. This is the clear indication of high sewage contamination requiring a high volume of chemical used for disinfection during purification.

Table 6.9 Faecal coliforms (2001-2002) (counts/100 ml)

	2001			2002		
months	**min**	**max**	**mean**	**min**	**max**	**mean**
Jan	100	7000	1740	300	600000	77220
Feb	450	11000	4488	200	800000	11704
Mar	2100	10000	5014	300	80000	9350
Apr	12	18000	5401	70	100000	14880
May	60	7000	1366	140	40000	7027
Jun	13	1420	242			
Jul	2	1200	121	20	1000	422
Aug	20	700	186	20	10000	1434
Sep	100	36000	4046	150	3000	1046
Oct	17	700000	65027	4	6000	528
Nov	-	-	-	20	15000	1506
Dec	-	-	-	20	40000	25

Fig 6.18 Feacal coli vs. Time

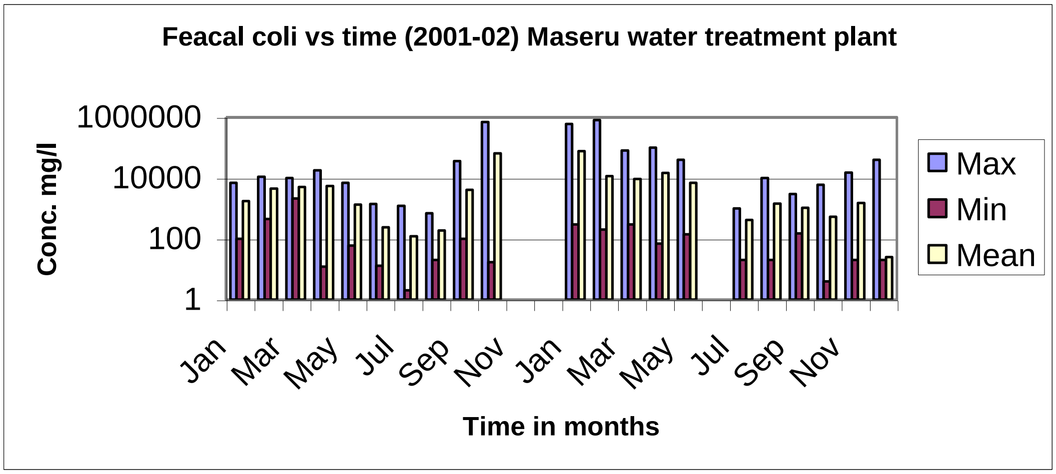
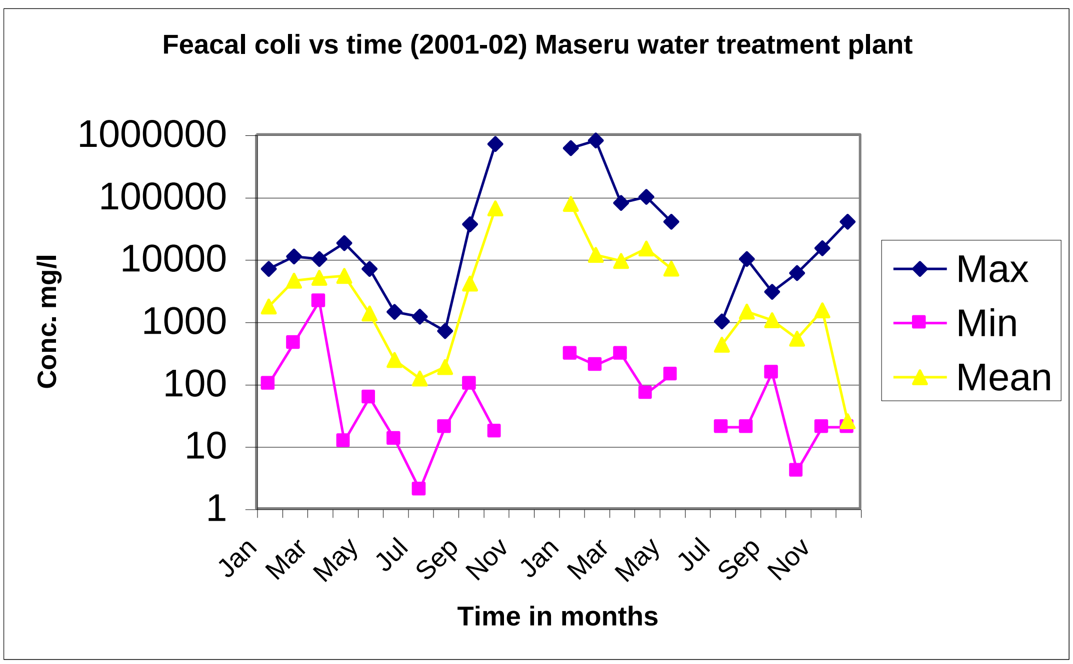


Fig. 6.19 Faecal coli vs. Time



CHAPTER 7

7.0 INTRODUCTION

Water quality has a major impact on all forms of life. In modern approaches, water quality is defined in terms of the uses for which the water is intended. There are therefore differing water qualities tied to various uses such as domestic, industrial, irrigation, stock watering and conservation of the of the aquatic ecosystem. The treatment of raw water or untreated water allows for the use of surface or groundwater of a quality that would otherwise not be acceptable. At the other end of the water use cycle, the treatment of sewage and effluent is intended to restore the quality of the wastewater so that it is environmentally acceptable (TAMS, 1996).

Umgeni Water (2004) point out that sewage disposal without treatment can lead to severe downstream pollution and public health problems where receiving waters are used for drinking-water supply or for recreation, irrigation and fisheries. This was seen in the cholera outbreaks in Peru and neighbouring countries in recent years; cholera and typhoid outbreaks in KwaZulu-Natal and Mpumalanga in RSA. Lesotho fortunately, because of its location and climate, does not appear to experience water borne diseases such as cholera, etc. Water quality has a negative bearing on cost treatment of potable water.

The unreliability of urban potable water supply presents a disproportionate burden to the poor. The poor are likely to pay higher informal market rates for water. Studies show that poor households are paying the highest unit rates (over 4 times as much per cubic meter as those who have a house connection). Over the medium-term, the most effective strategy for helping the poor is to expand the present formal system by having tariffs which allow WASA to cover its costs and perform as an efficient utility, and adopting flexible standards of service that make service to the poor technically and financially viable (Aide memoir, 2001).

7.1 Water charges in Lesotho

7.1.1 Domestic customers

Water charges differ with quantities it is priced as follows:

A. 0 to 5 kilolitres costs R 1.56/m^3
B. 6 to 10 kilolitres costs R 2.61/ m^3
C. 11 to 23 kilolitres costs R 4.37/m^3
D. Above 23 kilolitres costs R 6.50/m^3

7.1.2 Non domestic customers

All consumptions R 3.78/ m^3 source: (WASA, 2001) Notice for new water tariff structure announcement. The standing charge for all customers is R2.40/month.

7.2 Maseru water production

Table 7.0 and fig. 7.0 depicts the pumping rates from Maqalika Reservoir and the Caledon River. The average daily demand is around 21Ml/day and has been marginally consistent throughout the year except for a slight seasonal variation (WASA, 2000).

Table 7.0 Production of water

Raw water abstraction	Minimum daily (Ml/day)	Maximum daily (Ml/day)	Average daily (Ml/day)	Total monthly (Ml/month)	Actual
Maqalika	1.587	18.265	9.926	449.081	48
Caledon 1	0.775	15.719	8.247	294.209	32
Caledon 2	4.414	10.269	7.3415	189.866	20
Total raw water abstraction.				933.156	100%

7.3 Water Quality

Table 7.1 below shows raw water quality from Maqalika reservoir and the final product after treatment. The pH levels seem to be normal but the turbidity of 4180 NTU in summer was recorded with only the minimum of 11.20 NTU in winter. 80% of turbidity between 1 NTU and below was achieved as per records, with highest score in winter and lowest in summer (WASA, 2000).

Table 7.1 Measured water quality parameters

Raw water	**Parameters**	**Minimum**	**Maximum**	**Average**	**Range**
	pH	7.80	7.98	8.03	7.80
	Turbidity	11.20	4180	2095.60	11.2
Final water	**Parameters**	**Minimum**	**Maximum**	**Average**	**Range**
	pH	7.21	7.98	7.60	7.21
	Turbidity	0.80	3.90	2.35	0.80

7.3.1 Chemical usage

Table 7.2, fig. 7.0 and fig 7.1 depict information pertaining to the use of chemicals for purification purposes. Three chemicals are used in the treatment plant namely, sudfloc 3456, sudfloc 3TL and chlorine. Table 7.2 and 7.1 give more detailed information pertaining to cost per kiloliter. Fig 7.0 shows the production of clean water as compared to raw water for the year 2002/2003.

Table 7.2 Chemicals used

Chemical	Litres/Kg	Rands/Ml
Sudfloc 3456 (litres)	1347	12.81
Sudfloc 3TL (litres)	4862	63.11
Chlorine (kg)	1850	18.16
Total unit treatment cost		94.09 (9 cents /kl)

Fig 7.0 Raw water vs production

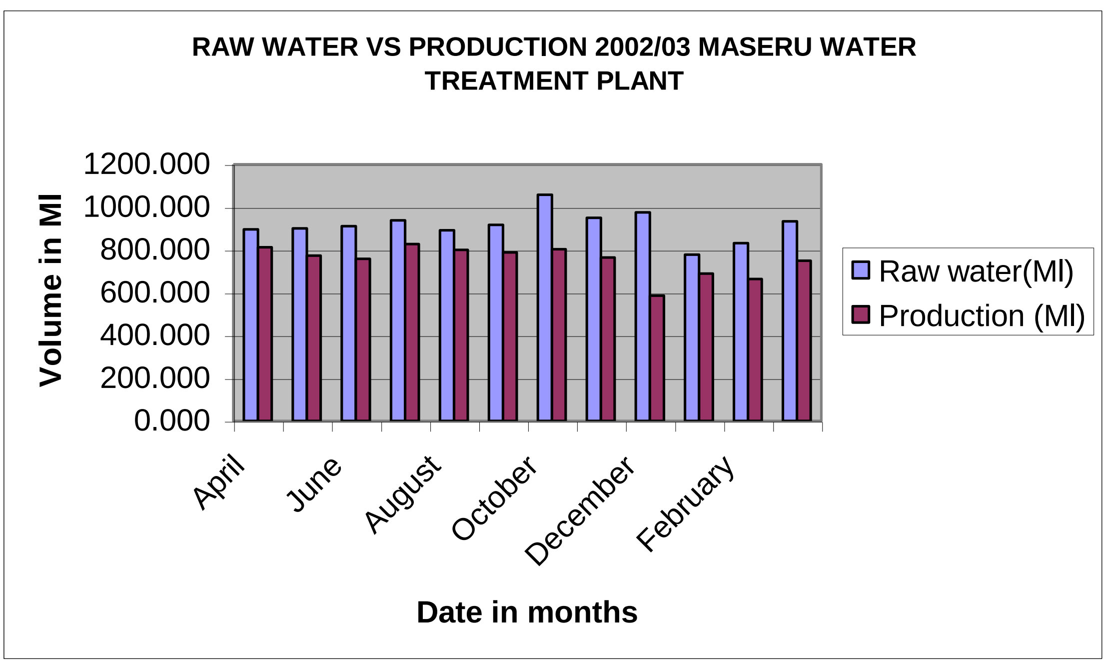
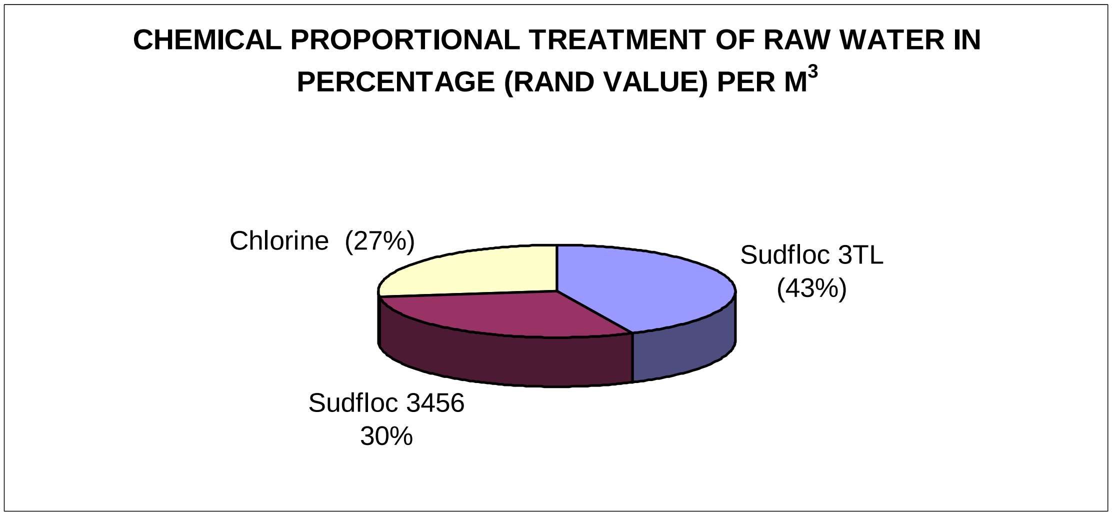


Fig. 7.1 Chemical proportional treatment of raw water in percentage per m^3



7.4 Water charges in Umgeni Water: KwaZulu-Natal

Umgeni Water's primary business and core customers and clients are located in KwaZulu-Natal, RSA. Its primary function as defined in the Water Services Act of South Africa (Act 108 of 1971), is to provide water services to other water service institutions within its supply area for which it charges them R1.787/kl. Water services include both (i) water supply services – which refers to the abstraction, conveyance, treatment, and distribution of potable water intended to be converted to potable and (ii) sanitation services – which refers to the collection, purification and disposal of domestic waste water, sewage and effluent, including industrial effluent (Umgeni report, 2002). Fig. 7.2 shows treated water sales and fig. 7.3 shows details of water supplied to customers for the year 2001 -2002**.** fig. 7.4 depicts water works total chemical costs and water works unit chemical costs.

The white paper issued by DWAF states that it is government policy to ensure that all South Africans have access to basic water supply and sanitation services by the year 2002. And one of the targets set for minimum standards is:

- twenty-five litres of safe treated water per person per day at a maximum distance of 200m from the dwelling (Umgeni Water, 2004).

Fig 7.2 Treated water sales for 2001- 2002 (source: Umgeni report, 2002)

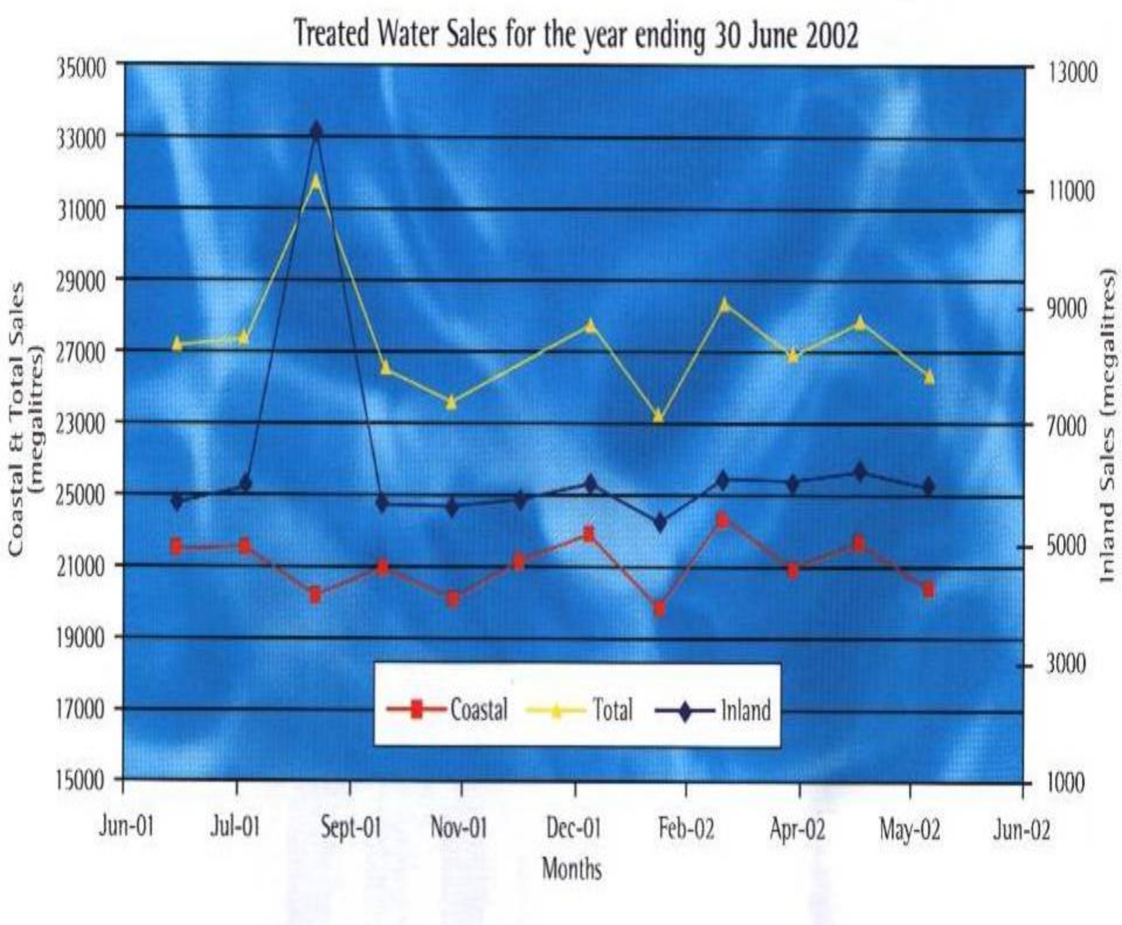
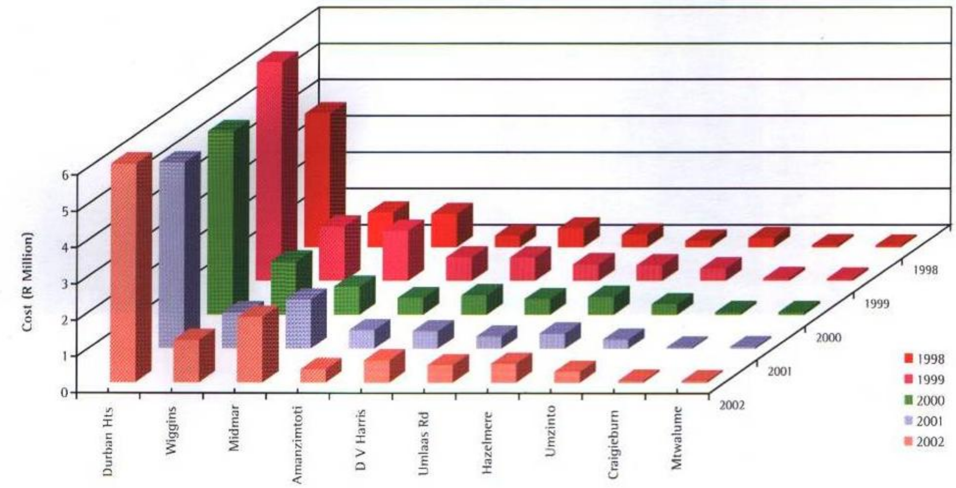


Fig. 7.3 Details of water supplied 2001-2002 (Source: Umgeni report, 2002)

Details of Water Supplied to Customers

Customer	Total Annual Sales (kl)
Durban Metro – Inland	17 609 204
Durban Metro – Central	228 294 622
Durban Metro – South	6 963 046
Durban Metro – North	2 868 407
Pietermaritzburg Msunduzi TLC	39 664 831
Howick TLC	3 017 847
Hilton TLC	839 723
Ashburton TLC	301 374
Camperdown TVC	134 204
Wartburg TLC	147 681
New Hanover TLC	47 063
Dalton TLC	85 611
Ixopo TLC	535 092
Cool Air TLC	161 105
Siza Water	2 255 835
KwaDukuza Municipality	116 539
Ugu Regional Council	4 848 640
Development and Services Board	105 140
Reticulation – Inland	2 593 723
Reticulation – North Coast	1 359 263
Reticulation – South Coast	410 745
Others	3 010 274
Total	315 369 969

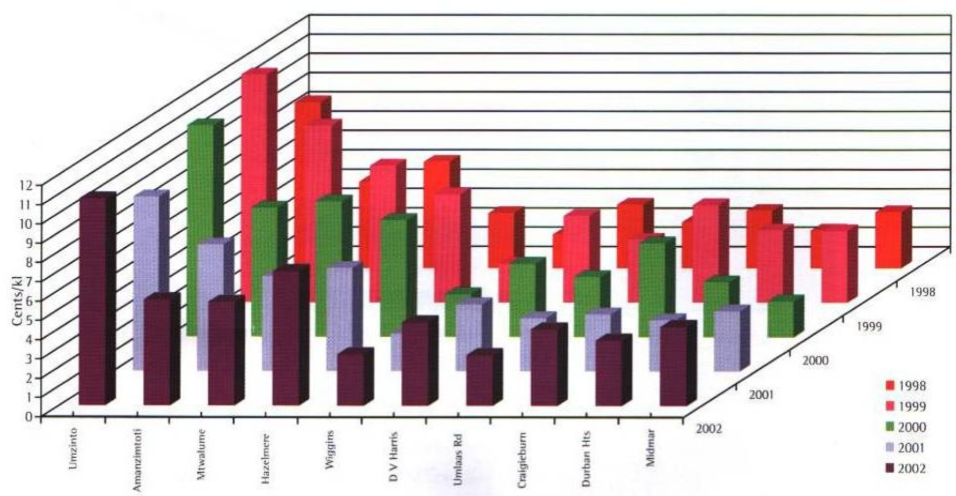
Fig 7.4 Waterworks Total Chemicals Treatment Costs (R million) (Source:Umgeni report, 2002)



Waterworks - Total Chemical Treatment Costs (R Million)

	Durban Hts	Wiggins	Midmar	Amanzimtoti	D V Harris	Umlaas Rd	Hazelmere	Umzinto	Craigieburn	Mtwalume	Total
1997	4.33	1.38		0.28	0.92	0.33	0.32	0.16	0.04	0.03	7.79
1998	3.66	0.95	0.91	0.32	0.52	0.35	0.18	0.25	0.06	0.05	7.24
1999	6.05	1.50	1.38	0.65	0.64	0.46	0.43	0.34	0.08	0.07	11.59
2000	5.03	1.46	0.77	0.46	0.53	0.43	0.49	0.29	0.07	0.07	9.60
2001	5.10	0.99	1.34	0.51	0.48	0.33	0.42	0.25	0.04	0.05	9.52
2002	6.46	1.16	1.80	0.36	0.61	0.47	0.52	0.30	0.05	0.04	11.76

Waterworks Unit Chemical Treatment Costs (cents/kl)



Waterworks - Unit Chemical Treatment Costs (cents/kl)

	Umzinto	Amanzimtoti	Mtwalume	Hazelmere	Wiggins	D V Harris	Umlaas Rd	Craigieburn	Durban Hts	Midmar	Average
1998	8.5	4.43	5.45	2.82	1.72	3.26	2.36	2.94	1.93	2.88	3.94
1999	11.72	9.09	7.03	5.56	1.99	4.45	3.23	5.01	3.71	3.68	6.01
1990	10.87	6.64	6.97	6.01	2.19	3.77	3.08	4.81	2.81	1.84	5.54
2001	8.98	6.52	4.92	5.33	1.95	3.45	2.75	2.94	2.65	3.11	4.60
2002	10.66	5.46	5.35	6.94	2.66	4.31	2.62	3.95	3.39	4.09	5.24

When comparing the two organizations, that is WASA and Umgeni Water, one could clearly see that despite the fact that Durban is highly industrialized with much of its population around the Umgeni River the water costs were less. In contrary, Maqalika Catchment does not have as much industry but has a higher population density. It costs WASA 9 cents per cubic meter to treat a cubic meter of raw water, whereas it only costs 5.24 cents per cubic meter for Umgeni water in the same year.

7.5 Augmentation of bulk water supply.

Proposals have been put in place to raise the spillway of Maqalika Reservoir by 1,5m so as to provide increased storage for sustaining supplies during periods of low flow in the Mohokare River, as well as upgrading the pumping station, expanding the water distribution network and the construction of a new water treatment plant with a capacity of 20Ml/day. The whole package includes the following components (see table 7.3).

Table 7.3 Cost estimates for upgrading Maqalika Reservoir Source: (Aide memoir, 2001)

Project component description	**Technical specifications**	**Estimated cost in Rands**
Upgrade pumping from Mohokare River to Maqalika Reservoir	New pump, 500mm dia. Pipeline	4,000,000.00
Raise the level of Spillway	Raise spillway by 1.5 meters	5,000,000.00
New water treatment plant	20 Ml/day water treatment plant	22,254,000.00
Treated water pumping station	Capacity 20 + Ml/day	1,090,000.00
Treated water transmission line	New 400 mm dia, 1.7 km pipeline	3,012,000.00

New reservoir at medium North at Naleli	Capacity 1,100 kl	2,769,000.00
Upgrade pumping at medium North	Mechanical and electrical installations	640,000.00
Expansion of water network and new connections	Complements work	25, 000,000.00
	TOTAL COST	63, 765,000.00
	Inflate by 15%	79,700,000.00
Priority sewerage system extension	To minimize pollution	
	Engineering (15%)	96,000,000.00

FINAL COST	**96,000,000.00**

7.6 Environmental Issues

7.6.1 Impact Assessment

More capital will be required to provide for conducting an environmental impact assessment (EIA) to evaluate the sustainability of the project. This will also assist in the decision making Process. EIA evaluates the project, the potential environmental risks and the impacts on its area of influence. It examines project alternatives, identifies ways of improving project selection, siting, planning, design and implementation by preventing and minimizing environmental damage.

7.6.2 Flora

The Current situation (barren/overgrazed) is likely to improve with the implementation of the project because plans would be implemented to control overgrazing. Vegetation that has negative impacts can be eradicated e.g. low water consumption could be promoted through introduction of indigenous species.

7.6.3 Fauna

There are no indigenous animals since the catchment is in a residential area. However, with the removal of people and promoting the area's flora to revert to its original status, such actions would enhance the indigenous fauna to flourish, thus attracting birds and small mammals. Control of pollutants into the water body could decrease BOD and COD hence decreasing the risk of killing aquatic fauna to the benefit of all.

7.6.4 Socio-economic factors

The society in the proximity of the project area could be classified as low to medium in terms of their economic affluence. In this regard the project would benefit the local people in terms of temporary jobs during the construction. In the long term, there is also a positive impact on the growth of Maseru, since more available water encourages industrial development in the city.

7.6.5 Culture and Aesthetics

The catchment has an urbanised society therefore; no cultural activities or benefits will be endangered by the project. Traditionally the Basotho use rivers not man made water bodies for their ceremonial activities. The project would have no significant aesthetic value since it will not enhance or worsen the view of both the residents and passer-bys. However, through proper flora management aesthetics would be improved.

7.6.6 Water Resources

During the construction of the project no disruption to the existing water supply system is anticipated. Diversion tunnels will be constructed to divert incoming water from the construction area to minimise the amount of eroded material. Other precautions will be undertaken to minimise pollution, etc.

7.6.7 Biophysical Environment/ Topography

The topography of the project area encourages erosion because of steep slopes. Since the existing soil is highly erodable the project would have to be constructed during the winter season (dry period), otherwise there would be a significant impact on the water quality of the existing reservoir. Before the area can be modified, preservation of top soil will be carried out for relaying at the completion of the project. During the construction, dust from constructional activities will be controlled by water sprinkling. Sound barriers will be used to minimise noise levels.

7.7 Natural habitats

More capital may also be needed in order to conserve natural habitats, thereby taking measures to protect and enhance the environment, which is essential for long -term sustainable development. This money will also support the protection, maintenance, and rehabilitation of natural habitats. Nevertheless, this issue might not be a “banning issue” in this regard since Maqalika and Caledon are areas of less importance when it comes to the natural environment because it is already a developed area.

7.8 Involuntary resettlement.

Any resettlement policy should ensure that the population displaced by the project receives benefits from it. Involuntary resettlement is an integral part of project design and should be dealt with at an early stage of the project. This is going to be one of the difficult parts of the project. However, public gatherings would be conducted to hear the views of the public. Fortunately, there is no cemetery or any monument in the project area. However, relocation may pose, among others, the problems of inhabitants moving away from ancestors and friends.

CHAPTER 8

8.0 CONCLUSION AND RECOMMENDATIONS

8.1 Conclusion

According to Basson and Rooseboom (1997) many factors are taken into consideration before the selection of a reservoir location and some of them are:-

(1) it should be a low sediment yield catchment

(2) no major cities, towns or infrastructure should be located near the headwater region of the reservoir

(3) topography suitable for sediment bypassing should be utilised, if available

(4) the reservoir surface area should be as small as possible, deep rather than shallow to minimize evaporation

(5) off-channel storage options should be considered and

(6) the storage capacity should be optimised to give suitable capacity – inflow ratio in order to operate for sediment sluicing/flushing or storage reservoir. Of these only "4"and "5" apply to the Maqalika catchment.

Normally, the storage reservoir is located where the supply is greater than the local demand but Maqalika was designed to meet demand up to 1995 only. The source of water is unreliable since it is constructed on a seasonal stream that depends on rainfall and also depends on pumping from the Caledon River. The river is heavily sedimented, which is demonstrated by siltation of the Welbedacht Dam (downstream of Maqalika) that has silted to capacity. RSA farmers and towns upstream heavily exploit Caledon River and north-eastern towns in Lesotho also depend on it.

In general terms there are no light or heavy industry within the Maqalika catchment that would modify the quality of water bodies; hence the only pollution that exists is through domestic activities. Leaking oil from garages/filling stations, domestic effluent from kitchens (characterized by high levels of detergent containing phosphorus), leaking sewage (nutrient rich) and littering from the catchment all reach the “Reservoir”.

Leachate from the two dumping sites (i.e Tsosane and Lower Thamae) and leaking sewerage from NHTC and the Makoanyane barracks have had a significant impact on water quality as can be deduced by excessive levels of feacal coliforms, phosphates, nitrates, turbidity and iron. Eutrophication is hence, now a serious issue for the reservoir. Turbidity levels are aggravated by high sediment loads within the catchment and from pumping, having a bearing on the cost of purification.

Other tested parameters like pH**,** temperature, alkalinity, hardness and conductivity do not pose much danger to the reservoir water quality, but excessive levels result in high purification costs.

Human activities within the catchment and the type of geology and steep slopes of the catchment encourage both rill and sheet erosion during heavy rainfalls, leaving Maqalika effectively acting as a settling pond. Cascade earth dams constructed upstream of Maqalika play a major role in trapping sediment but most of them are now full of sediment.

Studies by Jacobi (1977) and Makhoalibe (1984 cited by TAMS, 1996) show that North Phuthiatsana (CG 24) yields a sediment load of 1.14 x 10^6 tons/annum, (CG 33) yields 0.669 x 10^6 tons/annum respectively, and the Caledon at Mohlokaqala (CG 39) yields 5.2 x 10^6 tons/annum, showing that the catchment looses much sediment. Therefore, the procured results through pumping from the Caledon River yielded 297.70 t/annum, which is rather low when compared to the two studies mentioned above, but reasonable when considering the fact that water is pumped through sumps with a lower yield of 0.162m^3/s.

From the catchment run-off, the sediment yield of 101 x 10^3 tons/annum is still acceptable but the conservative multiplying factor of 7 might just be too high. A sediment volume of 4.605 MCM, which is 0.905 MCM beyond the capacity of Maqalika is high because the reservoir still has some recognizable capacity. This is supported by a study conducted by Stephenson and Associates (2002) who found that only 100 000 m^3 has been occupied by siltation but this value of 100 000 m^3 seems to be too low from personal observation. This is because during the drought of the 1990's the reservoir was virtually dry and one could clearly see that siltation has really taken its toll.

The other reason why Maqalika might still have a recognizable capacity is the fact that cascade dams upstream and Sebaboleng Dam had played a major role in trapping sediment from the catchment, hence prolonging the life span of Maqalika.

From the cost analysis one could see that more money is spent in purifying water in Maseru than it is in Kwazulu-Natal; 9 cents/kl and 5.24 cents/kl respectively indicating that water in Maseru is very dirty. On the other hand, this might not be necessarily the reason for difference in charges and other factors such as the type of chemicals used, suppliers charges, proximity of suppliers, transport, etc. may have contributed to this but the research indicated that it was more likely the costs of purification. More money could also be spent in trying to raise the spillway of Maqalika by 1.5m thereby increasing the capacity from 3.7 MCM to 4.5 MCM which does not solve the prevailing situation because more water is being utilised by clothing industry which was not planned for during the construction of Maqalika and it is a booming industry at the moment (2004).

8.2 Recommendations

- Construction of a hydrological station at Lower Thamae and a flume at the same place for data collection on discharge and sediment concentrations for future studies.
- Efforts being made for upgrading (raising of spillway by 1.5m) of Maqalika should be abandoned and Maqalika should be sidelined in the on-going preliminary study of the Lesotho Lowlands Water Supply which is charged with finding solutions for development of water supply in the lowlands.
- A permanent release of water from Katse Dam should be allowed into the Caledon River which will alleviate the deteriorating situation to meet the water demand along the border region; hence the two countries RSA and Lesotho should negotiate a compromise in this regard.

- Guidelines regarding water resources planning and development for control of reservoir sedimentation in selection of measures as well as guidelines for operation should be established.
- Dredging can be considered as a last resort for Maqalika. Disposal of dredged material, however, remains a problem.
- A geotechnical method should be employed to stabilise cut areas where developments have taken place.
- Re-vegetation of eroded areas would help in reducing surface run-off and enhancing the rate of infiltration of water into the soil, thereby lowering the rate of soil erosion and subsequent suspended matter in water (Molapo, 1998).
- It should be appreciated that there are some segments of populations, particularly in developing countries including Lesotho, who are living far below the poverty line. In such cases subsidy by the government would really go a long way in improving sanitation within the catchment hence increasing water quality and public health for all.
- Policing of leaking sewerage, illegal dumping, etc should be practised and culprits prosecuted.
- Introduction of constructed wetlands upstream of Maqalika which would alleviate levels of nutrients.
- Molapo (1998) suggested that while it is generally agreed that there is no substitute for an effective regulatory framework, the involvement of NGO's and local communities in the dissemination of environmental information and

implementation of clean up campaigns can play a vital role in ensuring compliance with set environmental standards and regulations.

- Metal screens should be placed in water channels especially close to the dam so as to trap plastics, cans and other solid waste. The entrapped waste should be removed at least once a month. The frequency should be increased during periods of high flow.
- The Tsosane dumping site located on the dolerite dyke supplying the Teacher's College with water should be buried and abandoned since it is a source of leachate imparting excessive phosphate, nitrates and iron to Maqalika during heavy rains. An alternative site should be established beyond the boundaries of the catchment.
- Maqalika is a typical example of reservoirs that were constructed without proper environmental investigation. No studies concerning the likely impacts of settlement on the water quality were undertaken. For future dams, Environmental Impact Assessments (EIA) should be a priority.
- Integrated water resources management of the catchment should be introduced.
- Government policies and strategies between the Ministry of Trade and Industry and Ministry of Natural Resources should be integrated so that the interest of the other must not be the worry of a third party. For example, more clothing firms are being established, which are water hungry but existing water facilities cannot cope.

8.3 Areas for further studies:-

- The use of rainfall data to determine the impact of sediment within the catchment using computer models.
- Investigating the presence of heavy metals in water bodies and their sources within the catchment.
- The risk of pollution of groundwater through leachate from dumping sites especially Tsosane dumping sites.

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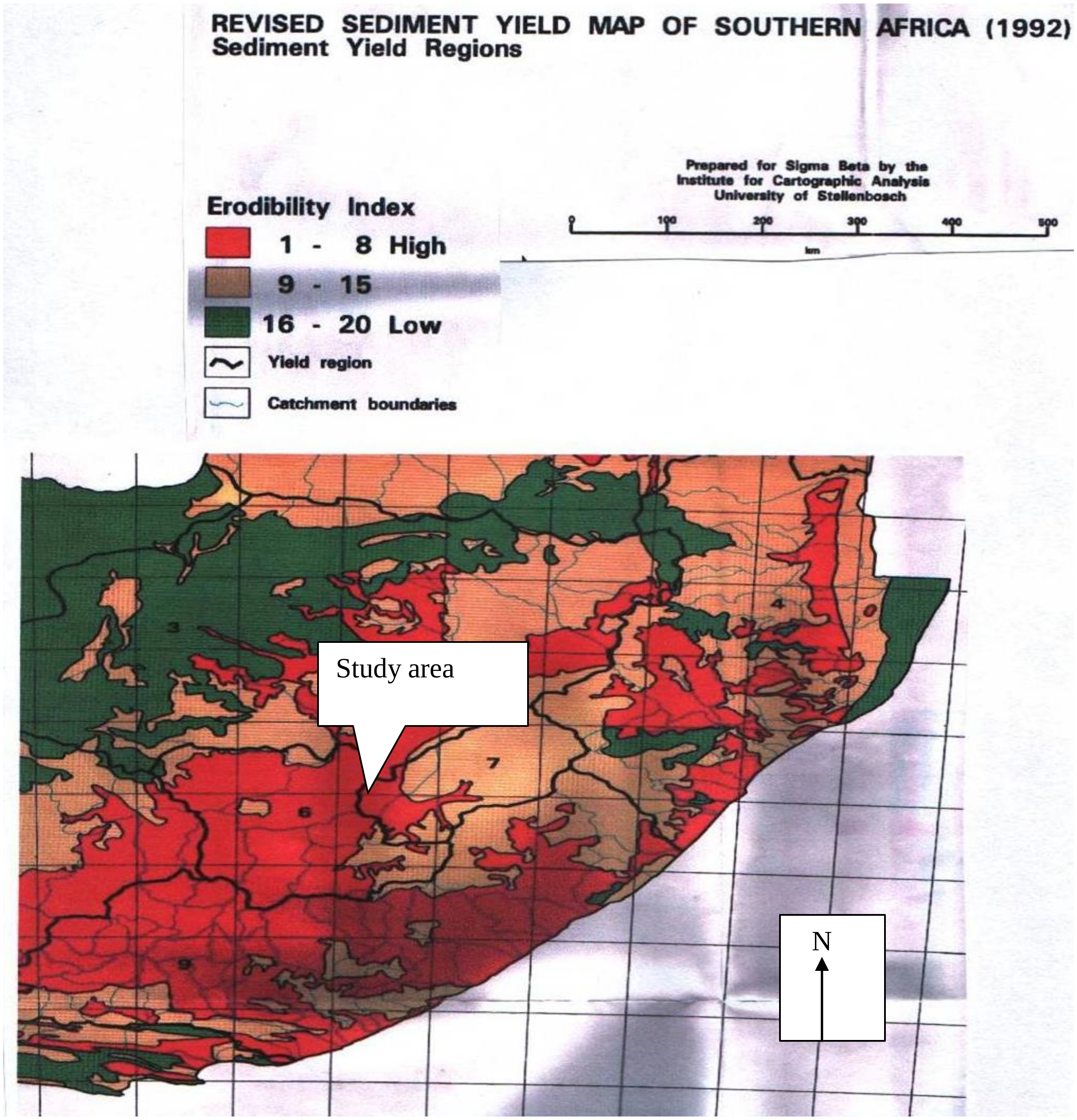
ANNEXURE 1

Standardized average yield values and yield factors

Region	Standardized average Yield (t/a.km^2)	Sediment yield factors		
		F_H (High)	F_M (Medium)	F_L (Low)
1	49	2.23	1.00	0,92
2	N/A	N/A	N/A	N/A
3	82	1.87	1.00	0.35
4	155	1.44	1.00	0.18
5	30	2.69	1.00	N/A
6	335	1.00	1.00	N/A
7	203	N/A	N/A	1.00
8	35	1.00	1.00	0.23
9	185	1.00	1.00	N/A

Source: (WRC report no. 297/1/92)

ANNEXURE 1



Source : (WRC report no. 297/2/92)

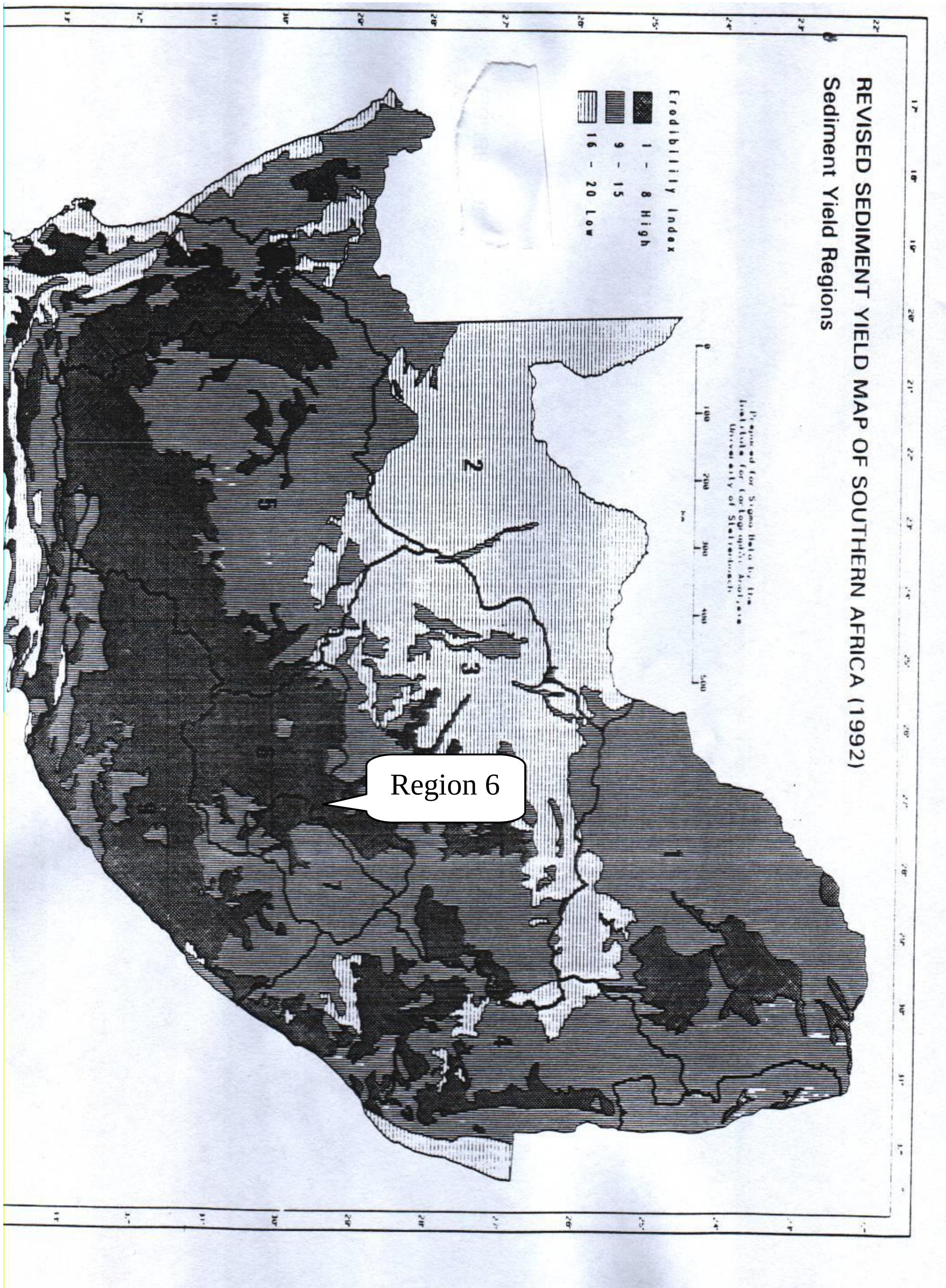
ANNEXURE 2

Standardized average yield values and yield factors

Region	Standardized average Yield (t/a.km²)	Sediment yield factors		
		F_H (High)	F_M (Medium)	F_L (Low)
1	49	2.23	1.00	0,92
2	N/A	N/A	N/A	N/A
3	82	1.87	1.00	0.35
4	155	1.44	1.00	0.18
5	30	2.69	1.00	N/A
6	335	1.00	1.00	N/A
7	203	N/A	N/A	1.00
8	35	1.00	1.00	0.23
9	185	1.00	1.00	N/A

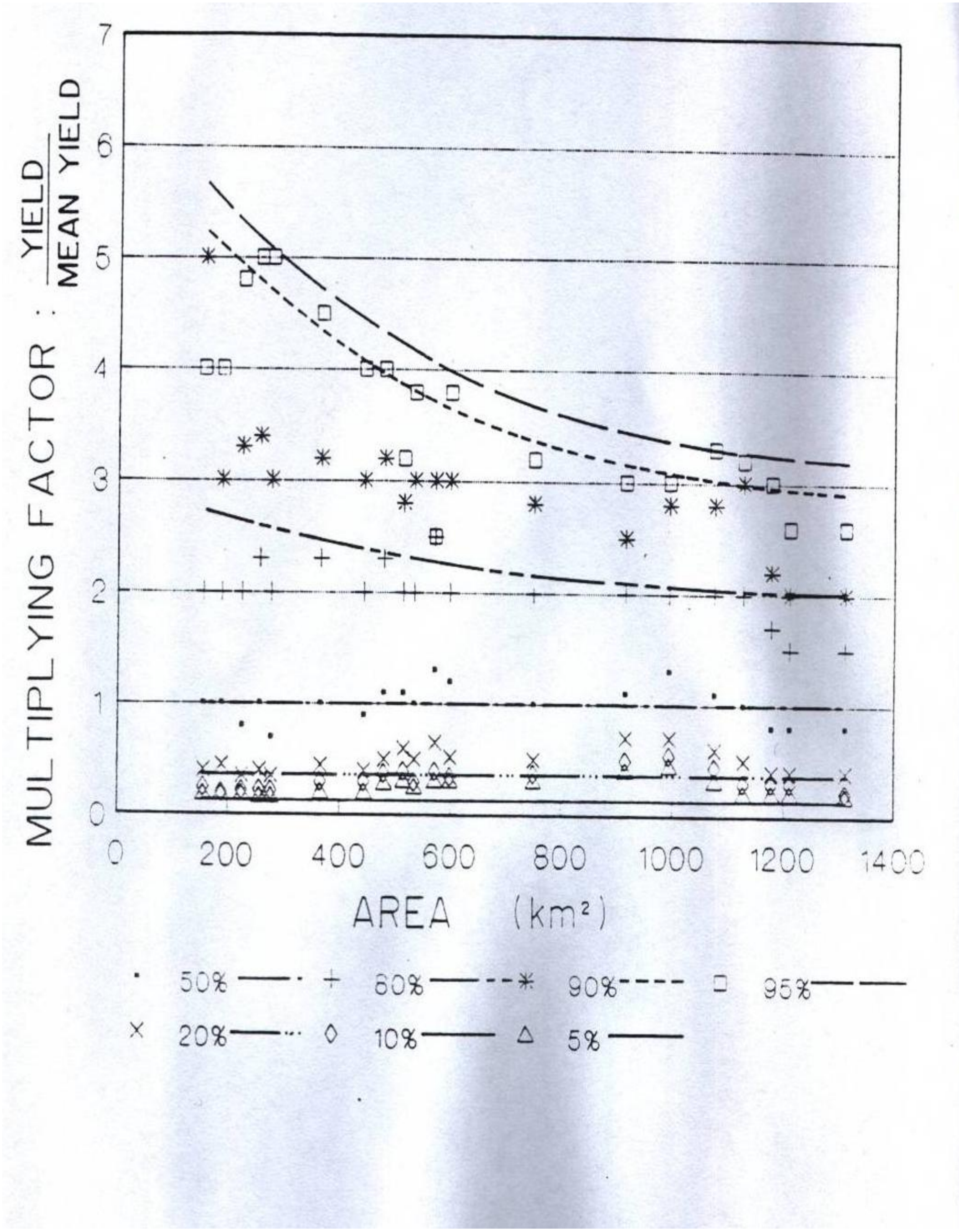
Source: (WRC report no. 297/1/92)

ANNEXURE 2


REVISED SEDIMENT YIELD MAP OF SOUTHERN AFRICA (1992)
Sediment Yield Regions
Erodibility Index
1 – 8 High
9 – 15
16 – 20 Low
Region 6

ANNEXURE 3

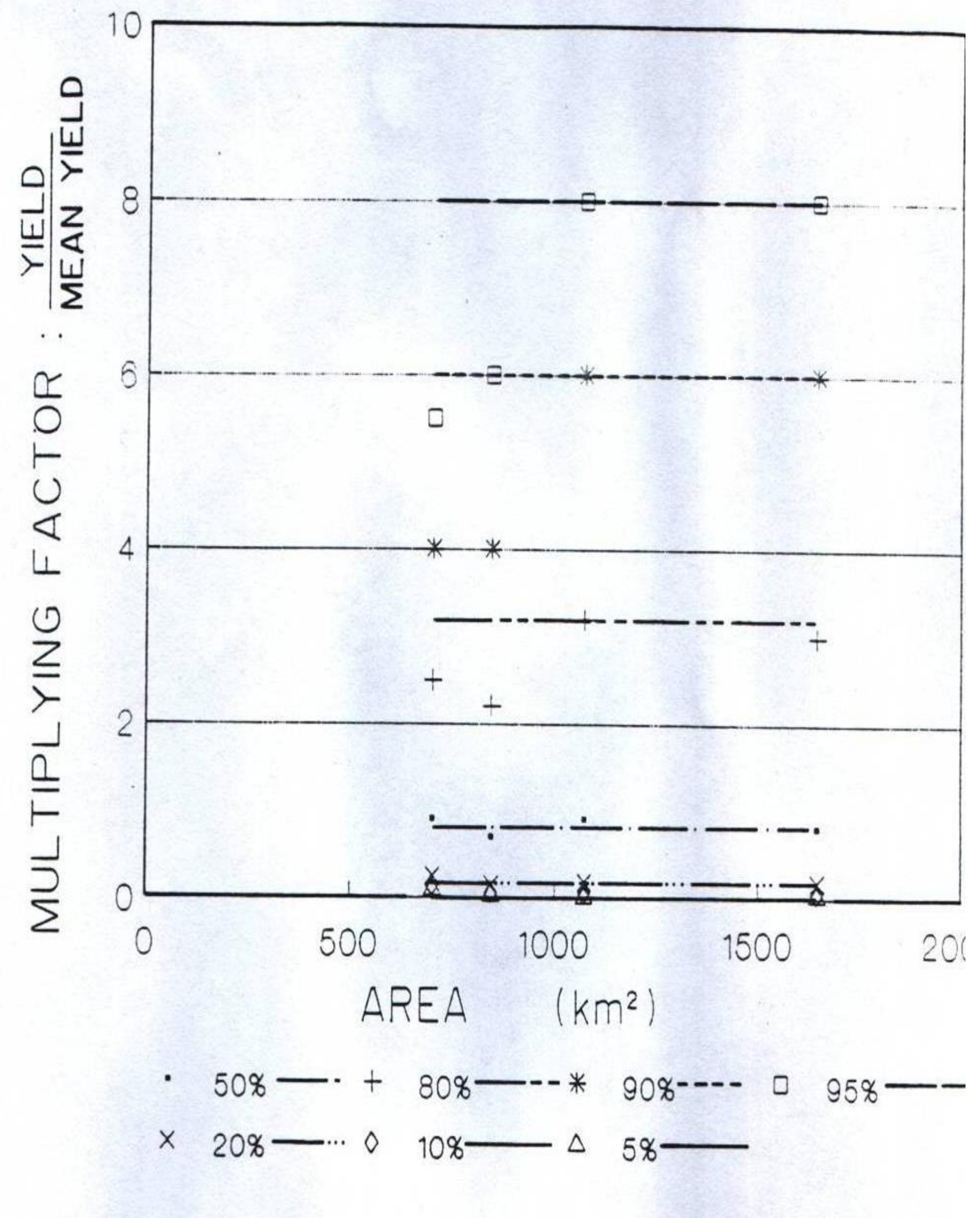
Sediment yield confidence bands (region 1)



Source: (WRC report no. 297/1/92)

ANNEXURE 4

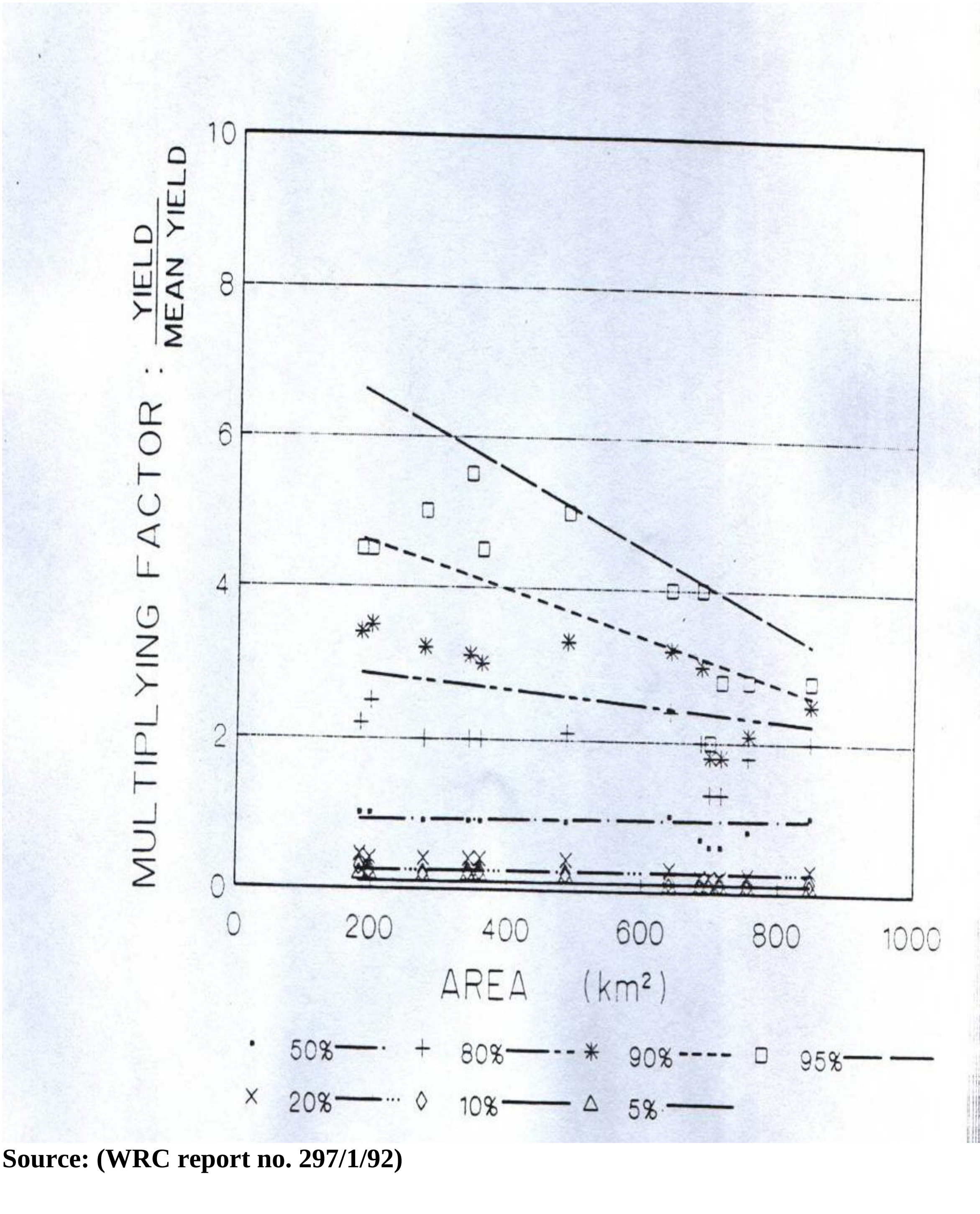
Sediment yield confidence bands (region 3)



Source: (WRC report no. 297/1/92)

ANNEXURE 5

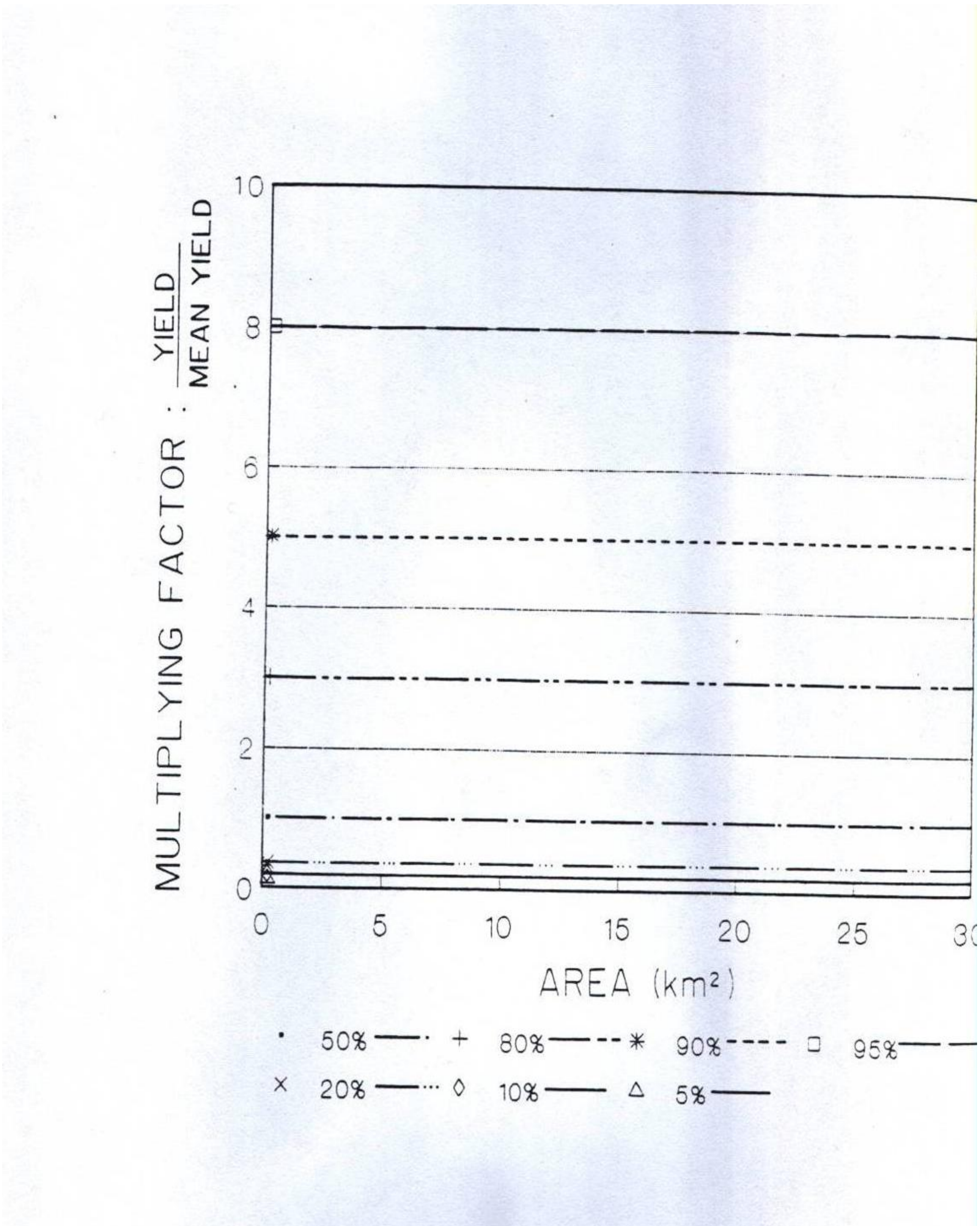
Sediment yield confidence bands (region 4)



Source: (WRC report no. 297/1/92)

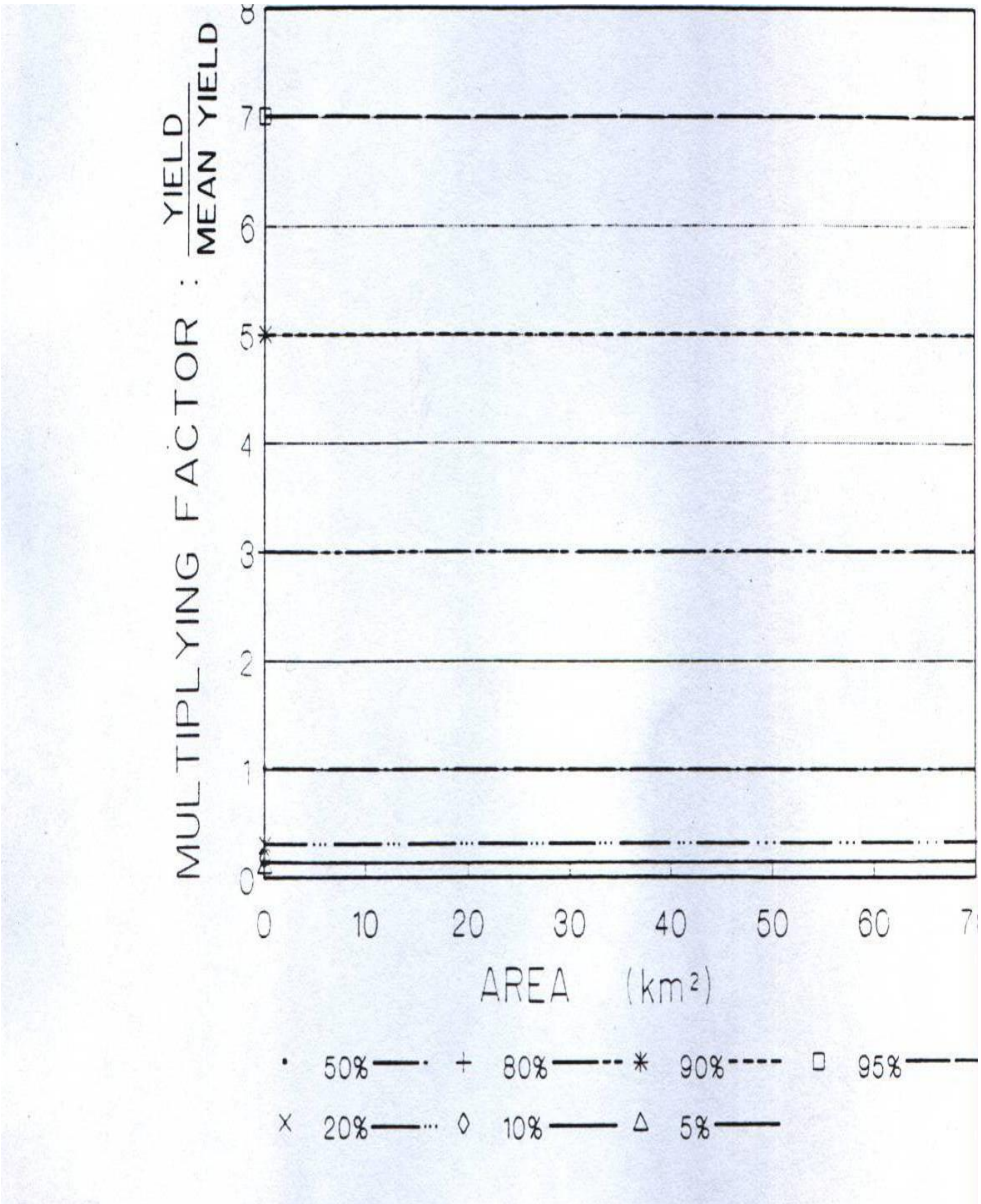
ANNEXURE 6

Sediment yield confidence bands (region 5)



ANNEXURE 7

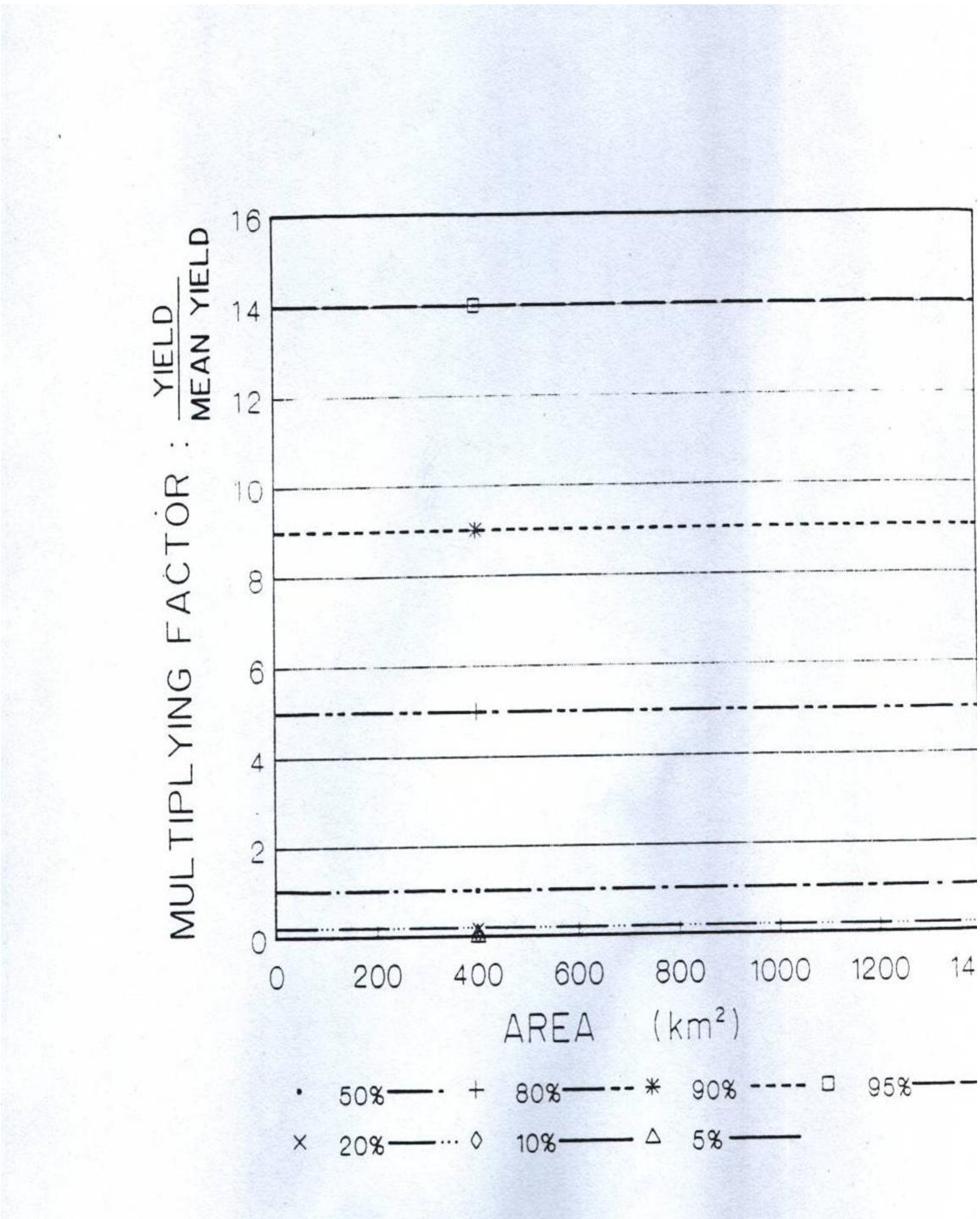
Sediment yield confidence bands (region 6)



Source: (WRC report no. 297/1/92)

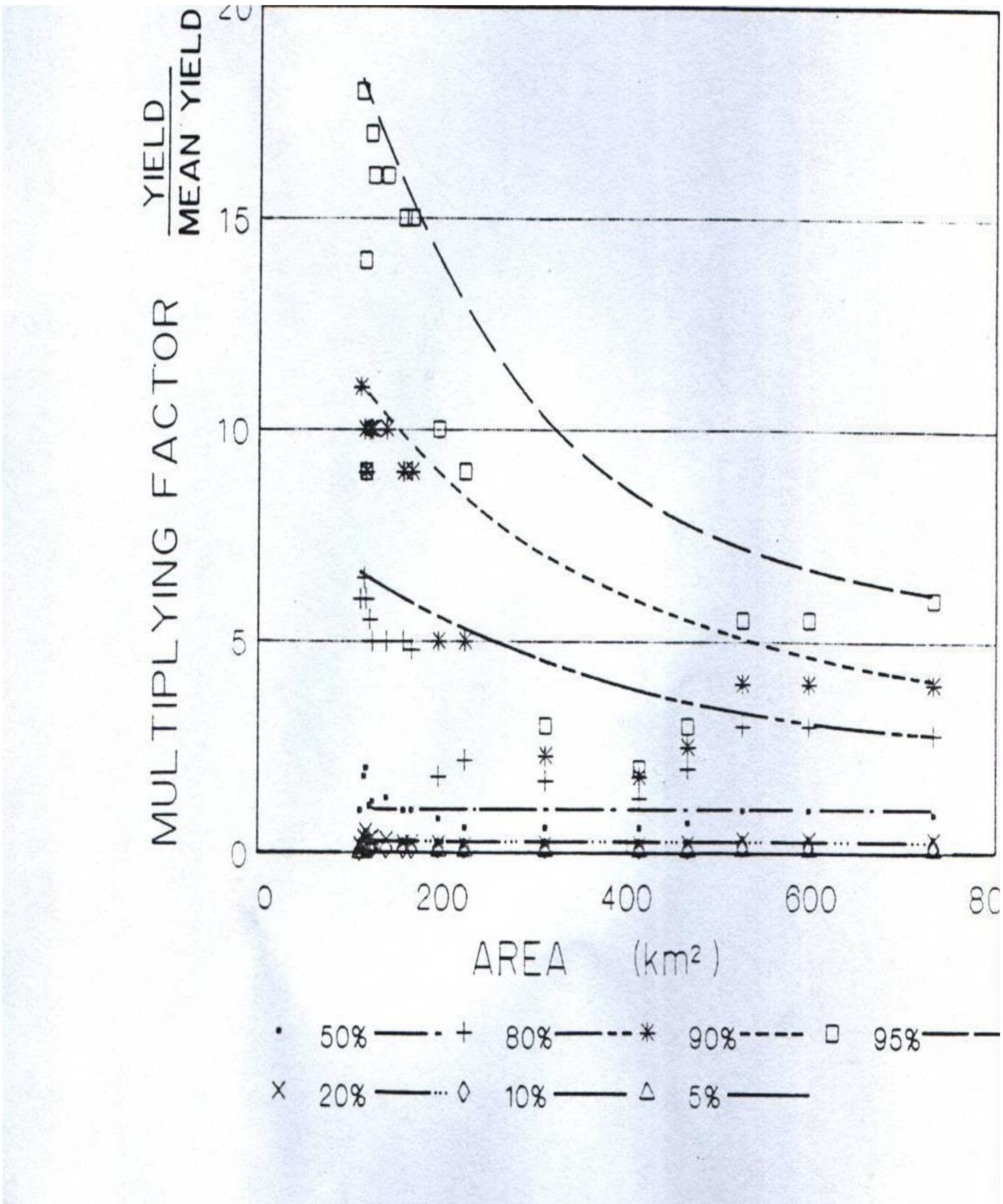
ANNEXURE 8

Sediment yield confidence bands (region 7)



Source: (WRC report no. 297/1/92)

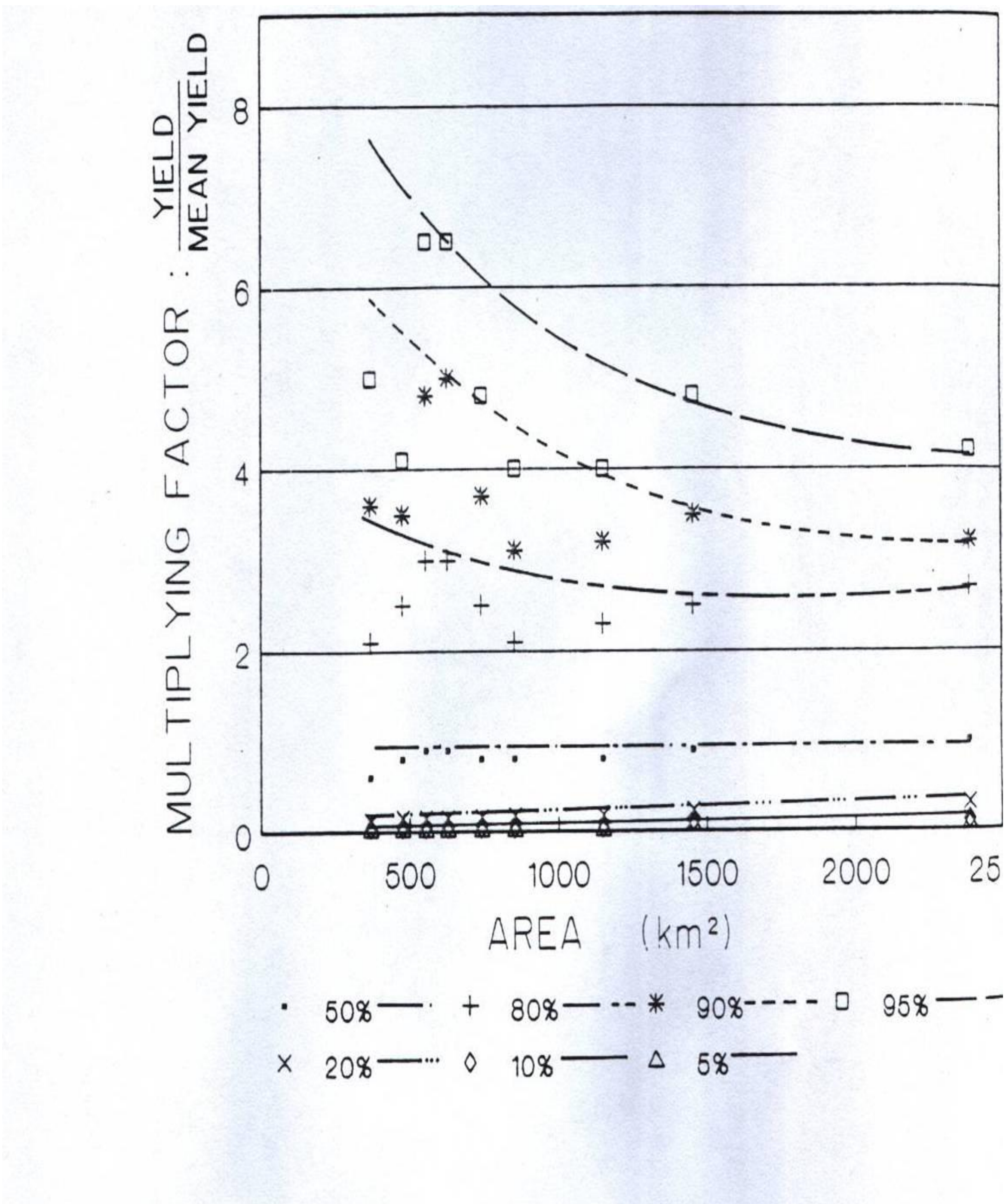
ANNEXURE 9
Sediment yield confidence bands (region 8)



Source: (WRC report. no 297/1/92)

ANNEXURE 10

Sediment yield confidence bands (region 9)



Source: (WRC report. no 297/1/92)