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REPUBLIC OF KENYA

MINISTRY OF WATER DEVELOPMENT

THE STUDY

ON

THE NATIONAL WATER MASTER PLAN

SECTORAL REPORT (N)

ENVIRONMENTAL CONSERVATION

JULY 1992

JAPAN INTERNATIONAL COOPERATION AGENCY

LIST OF REPORTS

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PREFACE

Interpretation of Report

The original objective of this NWMP Study is to propose a nationwide framework for orderly planning and development of water resources in the country. The Study also deals with the formulation of individual development schemes. However, it should be noted that the plans formulated in this Study remain at a national level and do not provide complete details at local level. Further details should be examined in subsequent studies on each river basin, district, and project basis which are separately recommended in this Study.

Administrative Division of Districts

In this Study, the original 41 districts were considered and various statistical data, particularly socio-economic information, were collected for these districts. During the progress of the Study, six districts were detached from the original ones and established as new districts. In the report, the data on these new districts are grouped together with the corresponding original districts as shown below.

	Original Districts	New Districts	Data included in:
1.	Machakos	Makueni	Machakos/Makueni
2.	Kisii	Nyamira	Kisii/Nyamira
3.	Kakamega	Vihiga	Kakamega/Vihiga
4.	Meru	Tharaka-Nithi	Meru/Tharaka-Nithi
5.	Kericho	Bomet	Kericho/Bomet
6.	South Nyanza	Migori	South Nyanza/Migori

(Note: The last three Districts were established very recently.
The report refers only to the names of the original 41 districts.)

The administrative boundary map used in this Study is the latest complete map set covering the whole country (41 Districts, 233 Divisions and 976 Locations), prepared in 1986 by the Survey of Kenya, Ministry of Land, Housing and Physical Planning.

Data and Information

The data and information contained in the report represent those collected in the 1990-1991 period from various documents and reports made available mostly from central government offices in Nairobi and/or those analyzed in this Study based on the collected data. Some of them may be different from those kept in files at some agencies and regional offices. Such discrepancies if any should be collated and adjusted as required in further detailed studies of the relevant development projects.

Development Cost

The cost and benefit estimate was based on the 1991 price level, and expressed in US$ equivalent according to the exchange rate of US$1 = KShs25.2 prevailing at that time. The same exchange rate was used in calculating the development cost in K£/KShs currency.

ENVIRONMENTAL CONSERVATION REPORT

REPORT CONTENTS

PART I. THE STATE OF THE KENYA ENVIRONMENT.

PART II. INITIAL ENVIRONMENTAL EXAMINATIONS OF SELECTED WATER DEVELOPMENT PROPOSALS.

Note: The following are presented in separate Sectoral Reports:

(a) Environmental aspects of flood control works in Sectoral Report G

(b) Environmental aspects of water transfer schemes in Sectoral Report M

PART I

THE STATE OF THE KENYA ENVIRONMENT

PART I THE STATE OF THE KENYA ENVIRONMENT

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N1. INTRODUCTION

1.1 Report Format

The Environmental Conservation Section of the Kenya National Water Master Plan Study Report was originally proposed to conform in format with the other sections of the Final Report in that the basic study units were to be either administrative boundaries, namely Districts, or water catchments. This approach was envisaged since it is along these lines that a majority of the data available in Kenya is arranged as a result of previous studies having been conducted by the several River Basin Authorities or following the establishment of the District Focus plans to produce District Reports on the environment.

It is apparent, however, that the various environmental problems to which this report is addressed do not recognize these boundaries and the proposed approach, therefore, has been abandoned in favour of a problem orientated format.

To a very large extent the majority of the environmental problems experienced in Kenya today are "natural" environmental consequences resulting from the inter-play of climate, geology, soils and topography within Kenya; examples of such problems include soil erosion, infertile soils, land degradation, various diseases and drought (Figure N1.1). The present distribution the human population in Kenya reflects the distribution of these problem areas, in which especially water resources and soil fertility have played a major role. Thus high population densities occur in the environmentally favourable areas of the country eg. western Kenya and the coastal strip, whereas low and very low populations exist in the arid and semi-arid areas (ASAL) of the country.

The, so-called, `environmental crisis` this country is experiencing at present and will continue to increasingly experience in the future is mainly a consequence of the exacerbation of these "natural" problems by the rapidly increasing human population. As the population has grown and continues to grow the pressure on, and demand for, natural resources (principally land and water) will further increase within the high potential areas resulting in over-use of resources and overspill (emigration) into marginal and arid areas once considered uninhabitable. Adverse environmental impacts which are not exacerbations of naturally occurring problems are not currently of major significance in Kenya but may soon become so, and include water and soil pollution as existing problems. This report does not cover social problems associated with urbanization even though these could be included in a wider definition of environment.

The Environmental Conservation Report is presented in two Parts:-

Part I: The State of the Environment in Kenya : 1991.
An Assessment of Environmental Issues Relating to Water Resource Development,

Part II: Initial Environmental Examinations of selected water development proposals.

Part II contains Initial Environmental Examination (IEE) report summaries of 16 damsites short-listed for further investigation. The information necessary to carry out similar investigations on proposed irrigation projects has not been possible since a short-list of sites was not available. In place of IEE reports on irrigation proposals a broader review of the environmental impacts of irrigation projects based on experience from other regions of the world has been prepared and forms Chapter 3 of Part I of this report.

As explained in Interim Report 1, environmental examinations of proposed dam sites can be carried out at a much earlier stage in project development and planning because the environmental impacts are very site specific. In addition, details about the type of dam, that is whether it is to be a run-of-river or diversion type, or whether intended for continuous or peak power generation operations, are better known and decided upon early in the projects history, and these also have considerable influence upon the impacts to be anticipated.

In contrast, irrigation development impacts stem from not only from planning/ implementation stage but also from stem from the management and operation of the scheme and especially with regards the types of fertilizers and biocides used, their mode of application and associated water management practices. Often the decisions of the latter issues are not made until later stages in project planning after hydrological, land suitability and economic aspects have been considered and evaluated. Exceptions to this generalization include certain site specific impacts such as resettlement of population, water abstraction impacts on downstream users, and perhaps impacts on sites of cultural significance, among others. It is these reasons that are the rationale for the review forming Chapter 3. It is, of course, recommended that environmental investigations are undertaken when irrigation development planning reaches a more advanced stage.

1.2 Defining the Environment

The natural environment is the whole outer physical, chemical and biological system in which man and all other organisms live and co-exist. It is a complex and dynamic system often changing cyclically over various periods of time: constant change is thus a characteristic feature of the natural environment.

The physico-chemical components of the environment include the climate, atmosphere, the seas and oceans of the world, all inland waters and the surface soils and rock strata into which animals and plants penetrate. The physical and chemical properties of these components greatly influence the abundance and restrict the distribution of all living organisms on earth.

Biological inter-actions such as predation, competition and disease also influence the abundance and distribution of organisms and biological activities in conjunction with physico-chemical reactions extensively modify the physical environment. A particularly important example of such inter-action is the formation of soils in which water, temperature, micro and macro-organisms (both animal and plant) combine to create the top-soils upon which all land-based life is ultimately dependent through the terrestrial food chains.

An understanding of "environment" is necessarily based on an understanding of the complex of interrelationships which exist between the organic and the inorganic components of the biosphere and a brief introduction to the more important of these ecological relationships and principles is given in the following section.

Interactions also exist between environmental issues and the development and management of natural resources: these interactions are two way and examples are illustrated below.

1.3 Environmental Principles

1.3.1 Carrying capacity

The carrying capacity of an ecosystem is usually defined in terms of the numbers or biomass (live weight) of the animal populations living within the system. It implies that a given area of rangeland, for example can *sustainably* support a given quantity of wildlife or livestock and that if this quantity is exceeded then the rangeland will become degraded by overgrazing and/or trampelling. It should be noted that although intuitively this seems a logical consequence the determination of what the actual carrying capacity of a particular habitat might be is extremely difficult. More often than not the carrying capacity is said to have been exceeded when deterioration is noted.

None-the-less it is obvious that a given land resource cannot support an ever increasing population indefinitely without damaging the environment beyond repair and the over-stocked populations crash through starvation and disease. Equally obvious is the fact that the stock or wildlife carrying capacity of a rangeland, for example, varies seasonally with rainfall and subsequent vegetation growth. This concept thus applies equally to cattle, goats or wildlife confined to a limited grazing range, as it does to people confined within national boundaries or, indeed, mankind on earth.

1.3.2 Limiting factors

To sustain the growth and production of plants and animals (including man) several essential inputs are required; these include water, oxygen, carbon dioxide and a long list of inorganic compounds called nutrients (which animals consume as "food"). Plant and animal production depends on an adequate supply of these inputs in the correct proportions. Whichever of the vital inputs is deficient in quantity it is the one which limits the rate of organic production and the total amount of organism or biomass produced. This item is referred to as the limiting factor. Increased availability of the limiting factor raises both the rate of production and the total amount that can be produced, while increase in the availability of other non-limiting constituents has little if any effect. Conversely, reduction in the supply rate of the limiting factor reduces production. For example, phosphorus as phosphate is essential for plant growth and its low availability often restricts crop yields; the addition of fertilizers containing phosphate makes up this shortfall. The more fertilizer that is added the greater the crop yield until the point is reached when another vital ingredient for growth (often nitrogen) becomes limiting.

1.3.3 Nutrient cycling

Nutrients are chemicals which are essential for plant growth but required only in small or trace amounts. As noted above their absence will prevent plants production and reduce crop yields. Phosphate and nitrate are the two principal plant nutrients which most often limit crop yields; other trace elements include boron and molybdenum.

In natural ecosystems such as a forest or grassland nutrients occur naturally in the soils and have originated from the bed-rock that was broken down in soil genesis. During the growth and development of plants these nutrients are taken up by the plant root system and incorporated into the plant tissues. Here they remain until the plant dies. After death the processes of decay and decomposition, mediated by microbial action, begin to chemically and biologically break down the plant tissue previously manufactured by photosynthesis. As decomposition proceeds the mineral nutrients in the plant tissues are released back into the soil or water. Here they remain until absorbed by the next generation of plants when they begin their next cycle of growth and development. Thus the atoms of phosphorus and nitrogen (and many other elements) move between the soil, water and the plants in a potentially endless cycle.

Some leakage occurs even in natural systems; this may be via water or wind transport from one system into another, but these losses are usually slow and complemented by the release of more minerals from the underlying rock strata and the incorporation of more nitrogen, carbon and oxygen from the atmosphere. Thus natural systems are sustainable in the long-term through the recycling of nutrients, water and atmospheric gases; only the energy from the sun which drives the whole system is not recycled; but this source of energy is considered to be an unlimited resource even in the most long-term planning scheme.

The natural situation of nutrient cycling described above contrasts with that found in agricultural systems or fisheries where the crop is harvested and removed from the point of production to a distant point of consumption. In this way the fertility of the soil, in Kiambu for example, is exported to Nairobi in a consignment of vegetables or in fish from Kisumu. In Nairobi the vegetables and fish are consumed and a portion of the resulting waste finally enters the Nairobi River. From here, via the Athi-Sabaki River the nutrients, once in Kiambu, enter the Indian Ocean near Malindi. Thus the ocean is enriched with the exported fertility of Kiambu soils. To counter the accumulative loss of nutrients from agricultural areas fertilizers are normally applied to the land, if they are not then the soil becomes increasingly infertile and unproductive.

Intensively cultivated agricultural systems are, therefore, linear and not cyclic systems and as such are only sustainable in the long-term by the replacement of lost minerals by the continuous application of imported fertilizers.

1.3.4 Population dynamics

The number of individuals comprising a population living within a defined area is controlled by the interaction of two sets of opposing forces. Birth and death, and immigration and emigration are the two sets and birth and immigration add to the size of the population and are countered by death and emigration which reduce population numbers.

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                         Birth rate
                             |
                             ↓
Immigration ----> POPULATION SIZE ----> Emigration
                             |
                             ↓
                         Death rate
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In the Kenya context immigration and emigration have been less significant factors in population control since Kenya is neither able nor willing to "export" any population which may be considered to be in excess of some perceived carrying capacity for the country; and immigration is not encouraged, though the current illegal inflow of refugees is forming a major threat to increasing the real population in the country. Kenya population size has been, in general, controlled by the balance between the birth rate (fertility) and the death rate (mortality) within the country. As will be discussed in a later chapter movement of population within the country is an important population parameter and is especially significant when expressed as a mass movement of people from the rural into urban areas, and when population emigrates from the high potential agricultural areas into the arid and semi-arid lands (ASAL) due to over-crowding and land shortage in the high potential areas.

1.4 An Introduction to Kenya

1.4.1 Geography and topography

The Republic of Kenya is located approximately between latitudes 4°21' N and 4°28' S and between longitudes 34° and 42°E. It is almost bisected by the equator and by longitude 38°E. Kenya is bordered by five neighbouring countries, Uganda to the west, Ethiopia and the Sudan to the north, Somalia and the Indian Ocean to the east, and Tanzania to the south.

The land area is approximately 582,646 km^2 of which 11,230 km^2 are inland waters. The country is about 800 km wide and 940 km from north to south. To the east the coastline extends 536 km from Somalia to Tanzania. Kenya is characterised by enormous physical and ecological diversity. The country is divided longitudinally by the central Rift Valley which is over 60 km wide and upto 330 metres deep. To the east of the Rift Valley the highlands rise to over around 2000 metres and the region is dominated by Mount Kenya (5199 metres) and the Aberdares (4000 metres).

The general relief of Kenya is dominated by a gentle dome shaped asymmetrical shield which divides the country into two distinct physical regions; upland (over 900 metres altitude) and lowland.

The *upland area*, centred around Mount Kenya extends westward to the Lake Victoria basin and north to Mount Elgon. This area comprises mainly volcanic rocks, has fertile soils and good to plentiful rainfall; it is consequently heavily populated and developed.

The *lowland area*, with the exception of the coastal plain and Lake Victoria basin, comprise a less favourable environment, due mainly to low rainfall and poorer soils and are consequently lightly populated and less well developed.

There are a series of plateaus at various altitudes extending across the country from the central highlands to the north and east. The Rift Valley, as mentioned, divides the country from north to south and in conjunction with the mountain masses of Mount Kenya the Aberdares, and the Mau Escarpment greatly influence the drainage pattern of the country (see Subsection 1.4.3).

1.4.2 Climate

(a) The monsoon seasons

The climate of Kenya is controlled by the seasonal northward and southward movement of the Intertropical Convergence Zone (ITCZ). The influence of the ITCZ is then greatly modified by differences in altitude within Kenya to produce the very regionally varied climate. From December to March the country is mainly influenced by the north-east monsoon system which produces a predominantly north-easterly flow of dry air in the north of the country. To the south of the equator the direction changes to northerly and eventually to the north-west. From March to May the winds become easterly in both hemispheres and maritime air from the Indian Ocean moves across the country bringing with it the long rains. Later in the year in June through August the south-east monsoon strengthens over much of the country; north of the equator the winds are generally north-easterly. During this period little rain falls but over higher ground the weather, although stable, is dull and often cold.

The north-east monsoon re-establishes during October to December; in October-November the short rains occur and these are usually followed by a return to warmer dryer conditions over most of Kenya.

(b) Temperature

Although there is no appreciable change in mean temperature throughout the year in Kenya there is considerable variation in temperature geographically, diurnally and seasonally as a consequence of altitude. In the highlands temperatures may fall to below freezing while maximum temperatures recorded at Magadi and Garissa exceed 40°C. Annual mean temperatures are shown on the isohyetal map (Figure N1.2).

(c) Rainfall

Rainfall in Kenya is strongly seasonal. The seasons are most pronounced in the dry lowlands, the north and the east; they are weakest in the more humid highlands of the Central Rift areas where altitude modifies the pattern.

Three broad rainfall regions are recognized:

1) *the Indian Ocean coastal region:* here January to March is usually dry with the long rains falling between the end of March to May, rainfall decreases from June to August. Short rains occur in October and November. Late December through to late February are generally dry and hot.

2) *the east, north-east, south-east and central region*: two distinct rainy seasons occur in this region from March to May (long rains) and from October to December (short rains). June to September are generally dry months. The short rains often fail, but also frequently contain the most intense rainfall.

3) *the western Rift Valley and Lake Victoria basin region*: this region effectively has no dry season; rainfall is generally higher from March to September but some rain falls throughout the year especially in the highlands. At lower altitudes April and May tend to be the wettest months.

The overall distribution of rainfall in Kenya is shown in Table N1.1; which indicates that over two-thirds of the country receives less than 500 mm of rain per year and 79% has less than 700 mm annually. Only 11% of the country has more than 1000 mm per year. Mean annual rainfall distribution is illustrated in Figure N1.3.

(d) Droughts and floods

These natural disasters are an integral part of the climate of Kenya and both occur as anomalies in rainfall pattern. Records indicate that serious drought has occurred twelve times during the past 50 years in the following periods: 1928, 1933-34, 1939, 1942-44, 1952-55, 1960-61, 1965, 1971, 1973, 1975, 1981, and 1984. Major floods which periodically afflict the Winam Gulf area of Lake Victoria and the lower Tana basin have occurred in 1937, 1947, 1951, 1957-58, 1961 and 1990.

(c) Evaporation

Mean evaporation from free water surfaces in Kenya ranges from 1250 to 3120 mm per annum. Mean monthly figures range from 85 to 260 mm (NWMP-1). Few areas in Kenya have evaporation rates below 100 mm/month.

1.4.3 Surface water resources

(1) River basins

The surface water resources of Kenya are distributed in five major river catchments or drainage basins; some basic details of these basins are given in Table N1.2. Three basins, the Tana, Athi and Lake Victoria basins dominate the water resources of Kenya and contribute over 13 km^3 (90%) out of the total of 14.8 km^3 of water discharged from Kenyan rivers each year. With the exception of the Lake Victoria and Rift Valley basins which contains numerous rivers flowing into Lake Victoria, the remaining basins are single river systems.

Although Kenya is well endowed with rivers only eight are permanent and flow regularly throughout the year; the vast majority are seasonal and cease flowing in the dry season; a few flow continually in their upper reaches but either disappear downstream in the dry season or drain into inland closed basins as is the case of the Ewaso Ngiro North and South rivers. The permanent rivers are the Tana and Athi flowing eastward into the Indian Ocean and the Nzoia, Yala, Nyando, Sondu, Sio and Mara which flow into Lake Victoria.

(2) Lake basins

With the exception of Lake Victoria the majority of Kenya lakes are located within the Rift Valley. Most are small and saline; details of the principal lakes are given in Table N1.3.

A majority of Kenyan lakes are either saline or brackish and unsuitable for use in water supplies. They may, however, be valuable tourist attractions as exampled by Lake Nakuru, or provide valuable fishery resources as does Lake Turkana. Lake Magadi although quite useless as a water resource is a renewable supply of soda ash which is exported world-wide. These saline lakes are all closed basin lakes, that is they have no surface or sub-surface outlets. They are sumps in their drainage basins and lose water solely by evaporation and a little seepage. All of these soda lakes are found in the Rift Valley in volcanically active areas which accounts for their high salt concentrations. Lake Naivasha is also located in the Rift and is also in a volcanic area adjacent to Mount Longonot and also has no surface outlet and yet, anomalously it is fresh. This freshness can only be accounted for by presupposing an active subterranean outlet which probably flow southward through Hells Gate towards Olkaria.

Since the soda lakes exist in closed basins they are especially prone to the adverse impacts of development since once a polluting substance enters it will remain trapped in the lake or its sediments indefinitely. Developments which introduce the threat of water pollution into closed basin need very careful planning or the adoption of precautions to avoid contamination of the lake and the destruction of its ecology. A particularly pertinent example is the proposal to transfer water from the Naivasha basin into the Lake Nakuru basin. The possible consequences of this action are considered in detail later in this report. A similar situation exists in the Winam Gulf of Lake Victoria; for although the Gulf is "open" to Lake Victoria the degree of water exchange between the two seems very limited, though hard data are not available. Pollutants, especially from Kisumu Municipality, which enter the Gulf will, therefore, accumulate and remain in the Gulf for long periods with uncertain consequences. This situation also is discussed further in a later section of this report. It is sufficient at this point to stress that closed basin lakes are extremely vulnerable to pollution and abuse and developments which affect these valuable resources should proceed with caution only after extensive studies on the potential adverse impacts of the proposed development.

1.5 Agricultural and Ecological Zoning

The division of the land area of Kenya into five river basins is one form of regional zoning which can be used for resource planning and management purposes. Other zones based on ecological and agricultural potential of the land are also used and are of considerable importance since population distribution tends to conform more closely with these zonal systems than with river basins or political and administrative boundaries as mentioned in previous sections of this report.

1.5.1 Ecological zones

On the basis of vegetation cover characteristics, the amount and reliability of rainfall and the ecological potential of the land six eco-climatic zones have been recognized. These area described briefly:-

Zone I: Afro-alpine; comprises high altitude (>3000 m) grassland, moorland and barren areas above the upper tree line and extends to an area of about 900 km^2. Rainfall varies from 1100 to 2700 mm per annum. The development potential of such areas is very limited because of the cold and high elevation and suitable for water catchments and tourism. Examples of this zone are found on Mount Kenya and Mount Elgon.

Zone II: Humid to dry sub-humid (tropical climate); this also is a high altitude zone ranging from 1976 to 2736 metres occurring as isolated areas on the lower slopes of the afro-alpine mountains and on the Aberdares, Mau, Cherangani and Marsabit mountain ranges. Rainfall ranges from 889 (eastern slopes) to 2286 mm on western slopes. Vegetation includes forests and derived grass and bush lands. The potential for forestry and intensive agriculture is high and includes coffee, tea and pyrethrum at higher elevations. Live-stock can be supported at one stock unit per 1 to 1.5 hectares. The moisture index is >10 and the zone extends to nearly 56,900 km^2.

Zone III: Dry sub-humid to semi-arid; this zone comprises medium to high altitude grasslands with scattered trees and scrub and occupies the southern and eastern slopes of Mount Kenya at elevations between 912 and 1824 metres. Annual rainfall varies from 88 to 1524 mm. Vegetation cover is variable including moist woodland, bushland and savannah. Agricultural potential is high where soil and topography permit with an emphasis on ley farming; extensive areas of this zone are under rangeland use (< 2 hectares per stock unit) with high densities of wildlife. The moisture index is from 10 to 30, and the zone covers 53,434 km^2.

Zone IV: Semi-arid (marginal lands); the natural vegetation in this zone is dry woodland, scrub and savannah where *Acacia* and *Themeda* tend to dominate. Rainfall varies from 508 to 762 mm and the altitude ranges from 1216 to 1976 metres. The zone has considerable potential for productive rangeland (< 4 hectares per livestock unit) or dry-land farming and is excellent wildlife habitat with good potential for tourism. The moisture index is 30 to 42; the zone occupies 54,009 km^2.

Zone V: Arid; this is the largest zone and covers 297,800 km^2. The natural vegetation is dry woody scrub dominated by *Acacia*, *Commiphora* and related genera. Its potential is for low density rangeland use since its soils are very subject to degradation if badly managed. The range can only support livestock at densities below 1 unit per 4 hectares. Wildlife is a significant asset in this zone where dry thorn-bush exists. Management by controlled burning is necessary to slow regeneration of thorn-bush. The moisture index is 42 to 51.

Zone VI: Very arid: this is desert or semi-desert land of very low agricultural potential. The vegetation consists of stunted scrub and thorn-bush again represented by *Acacia* spp. though trees are usually confined to temporary water courses; barren land is abundant. Grasses are mainly annuals with patches of perennials in-between. Rainfall is limited and very unreliable with figures ranging from 254 to 381 mm per annum. Wildlife and livestock grazing is possible under nomadic-migration systems; settlements are scarce and difficult to sustain.

1.5.2 Agro-potential zones

To facilitate the translation of the ecological zones described above into a suitable framework for development planning the NMWP-1 divides the country into three zones defined by their agricultural development potential. The agricultural potential of these zones is determined by the interplay of geology and climate - which influences the formation of soils, and their fertility and quality; altitude - which determines temperature that in turn influences plant growth rates; and rainfall which also determines plant growth and production. The three zones are as follows:-

1. **High potential zone:** comprises ecological zone II,

2. **Medium potential zone:** comprises ecological zone III,

3. **Low potential zone:** comprises ecological zones IV to VII.

The distribution of the agricultural potential zones in Kenya is very uneven and a majority of Districts contain some of each zone. Of the 41 Districts (now 47 Districts in 1992) in Kenya 22 have arid or semi-arid land (ASAL) and 6 Districts are entirely ASAL; these Districts are Isiolo, Marsabit, Garissa, Mandera, Wajir and Turkana. These Districts comprise 62% of the total ASAL area (439,000 km^2) which in turn comprises 83% of the land area of Kenya.

N2. KENYA POPULATION

2.1 Deographic Trends

The population of Kenya has been characterized by very rapid growth over the past 40 years (Table N2.1). During this period the population increased from 5.4 million in 1948 to 16.1 million in 1979. The future population is officially projected to increase to between 32.6 and 34.7 million by the year 2000. At present (January 1991) it is estimated to be in the region of 24 to 25 million. (NB: These figures are based on Tables N2.1 and N2.2. See footnote of Table N2.2 for explanation.)

During this same period the rate of growth has also significantly increased from 2.5 to over 4 percent per annum giving Kenya one of the highest growth rates in the world (Table N2.1). To put these figures into perspective a 2.5% growth rate implies the population will double in 28 years, while growth rates of 3, 3.5 and 4% will double the population in 23, 20 and 17.5 years respectively. Assuming a present (1991) population size of 24.5 million and a growth rate of 4% per annum nearly one million people will be added to Kenya's population this year; all of whom will require land, food, water, shelter, clothing, education, employment and access to health and other social services.

This rapid growth in population has resulted from the combined effect of increases in fertility coupled with declining mortality. The effects of immigration or emigration on population change have been insignificant. The question now to be addressed is what factors have influenced the rates of change in fertility and mortality? These factors are summarized in Figure N2.1

2.1.1 Rising fertility

The total fertility rate (TFR) rose from 6.7 in 1948 to nearly 8 children per female by 1979 (Table N2.1) before levelling off and subsequently falling substantially during the mid 1980's (Table N2.2). Through this period the crude birth rate remained almost constant at a high level of 50 births per 1000. The single most significant and influential change affecting population growth has been the reduction of the crude death rate by nearly 45%, from 25 to 14 per thousand. This reduction in mortality was brought about through the interaction of improvements in the nutritional status of the population, higher standards of hygiene associated with better sanitation and the provision of safe water supplies, and through the benefits derived from an expanding modern health service.

These factors were particularly effective in drastically reducing infant mortality which fell from 184 to 104 per thousand between 1948 and 1979 (Table N2.1). Better hygiene, medicine and food supplies have also had their effect on life expectancy which has increased from 35 to 54 years over the same period.

2.1.2 Declining fertility

Evidence from the 1989 Kenya Demographic and Health Survey indicates that a turning point in Kenya's population growth was reached sometime in the 1980's with a marked decline in the fertility rate and that a new phase of the demographic transition was begun. However, the population of Kenya will continue to grow rapidly for some time because of the still large number of women entering their childbearing years. This baby boom will have to pass through the fertility cycle before the population growth rate begins to fall appreciably. Thus although the number of children produced per mother is now falling, because the total number of mothers will continue to increase, the present rate of population growth will be sustained for some time.

It should be noted that the reduction in fertility has occurred in all eight Provinces (though results from Western Province are equivocal) and that the extent of the decline is large by international standards.

2.1.3 Causes of fertility decline

1. *Family planning:* changing attitudes to birth control brought about by education programmes and an increasing perception of the economic burden and pressures of large families have resulted in a growing proportion of women using contraceptive methods to prevent or plan their pregnancies (Table N2.2). Thus the proportion of married women using modern methods of contraception has increased from 7.2% in 1977/8 to 27% in 1989 while the proportion of married women pregnant has declined from 13% to 8.9%. Similarly the desired or perceived ideal family size has fallen from 6.2 to 4.4 children over the same period with the major changes taking place in the second half of the 1980's. These changes in attitudes have been complemented by the expanded availability of contraceptives and family planning counselling through the activities of various government and non-government organization projects which provide training courses and supply services. There is, however, room for improvement in these services as shown by the fact that although 27% of married women in Kenya are currently using a contraceptive method, 60% expressed the need for family planning either to prevent further pregnancies or to space the births of their children.

2. *Female education*: increase in the proportion of women receiving some formal education has been one of the most significant factors contributing to the decline in fertility rates world-wide and Table N2.3 shows this to be the case in Kenya also, where the proportion of women in the 15-19 age group with some education increased from 33 to 95% between 1962 and 1989. Table N2.3 shows that the fertility of women with secondary education or higher, declined from 7.3 to 4.9 children (a 33% reduction) in the decade 1979-1989 compared with an 18% reduction from 8.8 to 7.1 children in women with no education. Women who completed primary school education experienced a reduction in fertility of 20% from 8.1 to 6.5 children. Intermediate levels of education gave proportional reductions in fertility.

3. *The cost of education*: the high parental costs of educating the children in a family have risen dramatically in the 1980's and these costs coupled with a general appreciation of the importance of education in terms of future employment opportunities is considered to be a further important influence and constraint on the desired family size.

4. *AIDS:* The rapid spread of AIDS in the East Africa region adds a further dimension to the complex of factors influencing population growth. On the one hand the recorded increase in contraceptive use may be in partial response to fears of this disease and on the other mortality may be increased as the disease follows its course. However, any impact of AIDS on fertility is very unlikely to have contributed to the reported decline in fertility but may do so in the future so as the fear of contracting the disease would increase.

5. *Urbanization*: the changes in fertility and mortality rates discussed above are not equally in evidence throughout the country and vary principally between rural and urban populations as well as between women of different educational standards as noted above. For example, results from the 1984 Kenya Contraceptive Prevalence Survey show that in Nairobi and Mombasa the total fertility rate was 4.7 children, almost 42% lower than that of women from rural areas (8.1 children). The practical significance of the combination of urbanization and higher education in reducing population growth rate is well illustrated by these figures.

6. *The age of marriage*: also influences the child bearing potential of a woman, though the rising numbers of unmarried mothers masks this effect. Kenyan women tend to marry early, but the mean age of marriage has been rising steadily over the past 20 years. The most recent published data indicate that the median age of marriage varies significantly among the eight Provinces, ranging from 16.3 and 16.6 years in Coast and Nyanza Provinces to 20.0 and 19.8 in Eastern and Nairobi Provinces, respectively.

7. *The shortage of resources/infrastructures:* another reason may be the shortage of land, housing and other assets necessary to support the family, though this is a very minor reason.

2.1.4 The dependency load

The combination of high fertility and declining mortality has produced a population in Kenya with a very high proportion of young people who in turn guarantee further increase in population size once they reach their child-bearing years. These youngsters, therefore, represent a built-in population growth or growth momentum factor ensuring further increase well into the future. Consequently present predictions indicate that Kenya's population growth rate is unlikely to fall much below 3 percent per annum before the year 2010 when the population will number 45 to 50 millions on current estimates (Table N2.2).

The results of the 1979 census indicate that about 52% of the Kenya population was under 15 years of age and a growing number of people were surviving beyond 65 years of age. These two ends of the age spectrum constitute the dependent population (Table N2.2), that is those who do not contribute to the formal cash economy. The number of dependents is thus greater than the population who have to support them and the burden on the supporters is growing annually.

2.1.5 Population projections

Projections of the Kenya population size (based on the 1979 census data) from 1980 to the year 2000 and based on three alternative growth scenarios are given in Table N2.4. Table N2.2 gives further details concerning other population parameters and is based on the assumption of a moderate reduction in fertility and a moderate increase in the contraceptive prevalence rate.

Which-ever series of projections one chooses to accept the overall picture is very similar; the population is growing rapidly though the rate of growth would appear to be slowing down as family planning becomes more readily acceptable and practiced. None-the-less the 1979 Kenya population size will double or more than double by the end of the century bringing with it many challenges and consequence for the future and development of the nation.

2.2 The Consequences of Rapid Population Growth

2.2.1 Population density

When a growing population is confined within set boundaries as is Kenya within her national borders then increasing population translates into an increasing population density within those borders. Today population density in Kenya is, in absolute terms, still very low by international standards at around 38 people per square kilometre (see Table N2.5). This national average, however, is misleading since the distribution of population within Kenya is very uneven. In the urban conurbations of Nairobi and Mombasa densities are 1,968 and 2,224 per km2 respectively and rising. In rural Districts figures range from less than 2 to 3 per km2 in Garissa, Wajir, Marsabit, Isiolo, Turkana and Tana River to over 300 in Kiambu, Murang'a, Kisii, Kisumu and Kakamega. In Western Province, the provincial mean density is now over 789, making this the most populous Province in the country.

It is obvious that continuing population increase, resulting in ever increasing population density cannot continue indefinitely since the country area is finite and has a carrying capacity albeit that this limit cannot be quantified and is unknown. Fortunately the recent data presented in the previous section indicate that the fertility rate is now in decline which should result in a slowing down of population growth within the next few decades. In the meantime, the population is projected to rise to nearly 45 million by the year 2010 (Table N2.2) and it is the consequences and implications of this continued growth which are discussed in the following paragraphs.

2.2.2 The pressure on resources

An expanding population requires that the country provides an equally rapidly expanding supply of essential resources if the quality of life of the people is to remain constant; the usual aim of government development projects, however, is generally an endeavour to raise rather than maintain the existing living standards of its people which places a proportionately higher demand on national resources.

The resources which are basic to the maintenance of human life are listed in Figure N2.2, and it is these natural resources which are coming under ever increasing pressure for exploitation through development.

2.2.3 The land and food supply

The need for an increase in the food supply is often the most immediate and pressing demand on resources and the one which has the most direct impact on other essential resources; it is the need for an expanded food-base which causes the greatest degree of resource conflict and the one which poses the greatest problem for Kenya today. Since food is the most basic daily requirement, high expenditure on this item in relation to other needs reflects the degree of deprivation suffered by the rural communities and is now a commonly used indicator of poverty; recent estimates indicate that 64% of the total expenditure of small-holder families in Kenya goes on food and non-alcoholic drinks.

Agriculture is the mainstay of the Kenyan economy and smallholders are the backbone of Kenyan agriculture. Smallholders holding 20 hectares or less of land account for nearly 75% of the total agricultural output, 55% of the marketed yield, over 60% of the land devoted to arable farming, around 85% of total employment in the agricultural sector and 70% of those in employment in Kenya. By 1980, 1.7 million smallholders were farming less than 2 ha plots on average, with 50% cultivating less than 1 ha. These smallholders were responsible for the following proportions of marketed produce:-

100% cotton (almost)
60% coffee and beef,
50% milk,
45% maize and sugarcane
35% tea

Central to the whole issue of food production is, of course, LAND. Land and the conflicting demands and competition for the limited area of agriculturally suitable land which must also provide several of the other land-based essential resources listed in Figure N2.2. The same area of land is simultaneously needed, and expected, to provide not only space for crop production, but also - grazing for livestock, trees for fuel, fencing and construction timber, and also forests for water catchment conservation and space for infrastructure such as housing, schools, clinics and roads. The conflict of resource requirements is, therefore, becoming intense over large areas of the country.

The land problem is further complicated and exacerbated by the traditional inheritance practices which divide the parental land equally between the male offspring resulting in an ever decreasing size of land holding per person in successive generations. As noted above, over 850,000 smallholders are farming less than one hectare of land because of this fragmentation. In some high potential areas land has already reached the stage where the plot size is uneconomical and too small to support a family and this is causing the migration of population from the high potential areas to the marginal arid and semi-arid areas in search of land to support them with adverse consequences for the migrants and the environment. The impacts and consequences of migration to the ASAL regions is discussed further in Chapter N9. This fragmentation has occurred in parallel to the formal sub-division of the large farms and estates into smaller family units.

2.3 Options for the Expansion of Agricultural Production in Kenya

Four basic options are available for expanding food availability in Kenya excluding food imports; these are:-

1. Intensification of production from existing agricultural land,
2. Incorporation of new land into the agricultural sector, and,
3. Reduction of post-harvest crop losses,
4. Expansion of fisheries and aquaculture.

These four options and the various consequences of implementing them are summarized in Figure N2.3.

2.3.1 Intensification of production from existing agricultural land

Intensification of production from existing cultivated land means increasing the yield per hectare; to achieve this various approaches can be adopted but these have various implications whether applied to rain-fed or irrigated agriculture. Some of the possible approaches have few if any adverse environmental implications, while others may, or almost invariably do have such impacts. Environmentally friendly approaches include the education of the farmers in better techniques through the activities of agricultural extension officers; such techniques might include rotational cropping and inter-cropping.

The increased use of agro-chemicals (fertilizers, pesticides and herbicides) also improves crop yields but has potentially adverse environmental impacts via pollution of the soil and water supplies if not properly controlled. Pesticide use can also become counter productive by killing off the natural predators and parasites of the pests which can lead to greater pest problems. Pests may also become resistant to specific types of pesticide which then requires either the application of higher concentrations of the same pesticide or a switch to a usually more expensive product. This situation is well known in relation to malarial mosquito resistance to some sprays and prophylactic drugs.

Improved yields also result from the planting of genetically improved seed stock. This approach although widely adopted does have two inherent drawbacks; first is the tendency for successful strains of, say, wheat or maize to be grown over extensive areas as a monoclonal culture (that is all the individual plants are genetically identical), this leaves this entire area susceptible to disease. By planting a range of different varieties of grain crops the spread of a strain specific disease is inhibited even if not entirely retarded. This approach is contrary to the concept of not putting all your eggs (or other vital resources) in one basket; it is the obverse of safety mechanism of risk spreading.

The second drawback is the threat of losing vital genetic resources or germplasm. The high yield varieties of many different crop species have been developed using genetic material gathered from wild or traditional varieties. If the high yield varieties are universally sown and harvested the traditional varieties may become either rare or at the extreme extinct. Once the traditional species or variety is lost the unique genetic material it once contained is also lost and cannot be replaced or recreated.

2.3.2 Incorporation of additional land into agricultural use

(1) Present agricultural land area and use

Data for 1988-89 indicates that the landuse distribution in Kenya is as follows:-

Land use category	Total area	(%)
Meadow and permanent pasture:	40,000 km^2	(7)
Arable and permanent cropland:	22,860 km^2	(4)
Forest and woodland:	22,860 km^2	(4)
Arid and semi-arid land:	474,275 km^2	(83)
Total land area of Kenya	571,416 km^2	

Taking more land into the agricultural sector of necessity requires that it is removed from another landuse sector be it forestry, rangeland, wilderness or National Park; whichever the case, the potential for landuse conflict exists. However, it should be noted that because land is a scarce and coveted resource in Kenya land has become the subject for speculation and it is estimated that 35% of the potential arable land is today lying fallow and held for speculation and profit (DANIDA 1989). As a result, recent increases in food production have been achieved mainly through intensifying rather than expanding cultivation. Never-the-less bringing this 'speculation' land under cultivation now would greatly improve the food supply situation in future and open up new scope for agricultural production and agro-industrial development. It would also reduce the increasing pressure on marginal or ASAL lands as discussed briefly below and in following sections.

(2) Forest encroachment and deforestation

In recent years the principal source of new agricultural land has been the indigenous forest areas of the country and this, in conjunction with clearing for other purposes eg. grazing, logging settlement and the creation of the Nyayo Tea Zones, is resulting in the reduction of forest cover by 19,000 hectares per annum. These abstractions have left only 3.9% of the Kenya land surface under forest of all types. This rate of deforestation is being countered by the planting of approximately 10,000 hectares of mainly exotic softwood species per year by official agencies in addition to an unknown amount of private and NGO afforestation project inputs.

Deforestation is one direct adverse consequence of the pressure on land resources created by the demand for food but further negative impacts on the environment derive from deforestation and affect other aspects of the human population resource base. Such impacts are both economic and ecological and include:-

1) Soil erosion
2) Loss of soil fertility
3) Reduction in soil moisture content
4) Loss of biological diversity
5) Impacts on water catchment conservation.

Discussion of these topics is not developed here but is included in following chapters of this report.

(3) Encroachment into marginal lands

The environmental impacts and consequences of taking land for agriculture from the National Parks and from marginal (Arid and Semi-Arid) ASAL areas are discussed fully in Chapter N9; here a brief summary only is included.

The main National Parks and reserves occur within the ASAL areas of the country which occupy over 83% of Kenya's land area and supports 20% of the total human population and 50% of the nations livestock.

Pressure from over-population in the more favoured areas of Kenya has resulted in migration into the more marginal ASAL lands which until recently were primarily used only for extensive range management or by nomadic pastoralists. These areas are only marginally suitable for fixed agriculture and their development represents a high risk venture with uncertain consequences and even at best only modest returns can be anticipated. The environment of these dry areas is fragile and has already succumbed to land degradation over considerable areas.

The principal environmental constraints in the ASAL areas are the very low and unreliable rainfall, easily eroded soils, the low ecological tolerance to sustained use and the low stock-carrying capacity of the land and its vegetation. The ecologically tried and proven pastoral-nomadic method of landuse in the ASAL areas has demonstrated its ability to cope with these problems over a long period of time but the dynamics of the social and ecological relationships between the nomads and their environment is beginning to break down under the influence of external pressures. Perhaps the most significant of these pressures are the changes in the land tenure system. Land that was previously used by the pastoralist during the harsh dry season as a refuge is currently being converted into permanent agriculture which reduces the land available for livestock and denies them access to dry season sources of water and forage. Similarly, such refuges have been incorporated into some National Parks (eg. Amboseli swamplands) with the same result.

The danger is that once these pastoral-nomadic systems have been replaced by cultivation and thereafter cease to exist as a viable means of survival in the ASAL areas it seems unlikely that they could be resuscitated should the newly developing fixed methods of agriculture fail to succeed. The development of the ASAL areas involves a great risk, thus needing a careful planning of the development.

2.3.3 Reduction of post-harvest losses

Whatever savings can be made to reduce loss of production after harvesting will effectively increase the food supply without incurring adverse environmental side-effects. Losses of cereals and legumes in storage are estimated to be about 15-30% per annum (NES 1987). Data are not available for other crops including the major export crops of coffee and tea. Clearly appreciable gains can be achieved by reducing these losses most of which are due to insect and fungal infestation and to rodents. Fungal infections and rotting are common when the crop has a high moisture content, or is wet when stored. Improved management can alleviate this problem. The fumigation of government silos is carried out periodically to control insect and fungal contamination, and the rodent problem can be reduced by mechanical rather than chemical means to minimize the possibility of environmental contamination.

2.3.4 Expansion of fisheries and aquaculture

Animal protein supply can be increased through expansion of capture and cultivation fisheries and does not require much additional land. Unfortunately capture fisheries in the countries lakes and rivers are declining due to development impacts and over-fishing. In Lake Turkana yields have declined in recent years as lake level has fallen due to impoundment of its inflowing rivers; the once productive fishery of the Winam Gulf is also in decline through over-fishing and extensive use of illegal nets sizes. As more dams without fish ladders are built on the nations major rivers migrant species cannot move freely along the rivers length and this must be assumed to reduce stocks.

Aquaculture or fish farming has a high potential from an environmental point of view in Kenya since the climate if favourable and species commonly used elsewhere in the world for culture are native to this country, the several species of tilapia are cases in point. Despite these advantages aquaculture development in this country has been extremely slow and today contributes a negligible amount to the annual fishery yield. The reasons for this poor perfomance require investigation and the answer lies more in social and management problems than with environmental constraints.

2.4 Urbanization and Industrialization

To some extent the pressure on land has been satisfied by an increasing proportion of the growing population moving to urban areas in search of better prospects and employment opportunities. This rural to urban migration, however, also has a cost and results in stress and strain on the urban infrastructure and environment.

The shift from a rural to a more urbanized society has been progressing for several decades as the data in Table N2.6 indicate. Since 1948 the urban population has grown from 276,000 to 4.8 millions in 1990 (estimated figure); over the same period the percentage of the population living in urban communities has increased from 5% to 24% (estimated figure). As far as can be seen the trend towards urbanization and associated industrialization will continue into the foreseeable future. This would indicate that Kenya is following the pattern seen in the developed countries of the world, and hopefully the twin developments of urbanization and industrialization will also reduce population growth rates as witnessed in the developed world after the industrial revolution.

In the expanding urban centres the increased demands for social services puts less strain on land resources than does the demand for food, but focuses demand on the economy as a whole. The provision of additional housing, education and medical services, water supply and electricity are all crucial, but perhaps none so much as the need for an expanded employment market. The creation of new job opportunities is vital to the economy and for the stability of the country in view of the large numbers of youth entering the labour force during the next twenty years (Table N2.2). Between 1989 and 2010 the number of 15 to 19 year olds entering the labour force for the first time is projected to increase from 2.5 to 5.1 million per year. This consequence and others relating to urbanization and industrialization are summarized in Figure N2.4; in terms of social services the problems and solutions to them are complex and beyond the scope of this report. The impacts on water resources are considered in Chapter N7.

N3. ENVIRONMENTAL CONSEQUENCES OF IRRIGATED AGRICULTURE

3.1 Introduction

The need for a major increase in agricultural production to feed Kenyas growing population can be met either by increasing yields from existing arable land, or by reducing post-harvest losses or by taking new land into the agricultural sector. Recent calculations indicate that approximately 510,000 hectares of land will have to be added to the current cultivated land within the next two decades(Ref. Interim report 1). The latter option may involve both the further clearing of the countries already greatly depleted forest lands where soils and climate are suitable for rain-fed cultivation and the utilization of agriculturally marginal lands by the use of irrigation. To date some 54,000 hectares of land are already under irrigation and a further 470,000 and 350,000 hectares of land have been identified in this study as having irrigation potential for upland crops and paddy irrigation respectively.

Although irrigated agriculture is an ancient art upon which many early civilizations flourished it is not without its environmental hazards and the world has inherited many of these early systems as archaeological relicts where the soils were rendered sterile by inadequacies in irrigation practices particularly with respect to drainage and salinization. Such problems still occur today and it is estimated that over 50% of the worlds irrigated area is suffering to some extent from adverse modifications to the soils caused by poor water management.

The development of irrigated agriculture produces many far reaching changes to the environment, many are beneficial and include:-

a) Higher yields per unit of land
b) Higher yields per unit of water; water conservation
c) Extended growing season, and possible multi-cropping
d) Greater crop safety through drought protection
e) Reliable and controlled water supply
f) Reduction of soil erosion
g) Improved agricultural management.

Modern irrigation thus seeks to maximize both direct and indirect benefits while minimizing economic, social and environmental costs. Direct benefits include higher yields and crop security; indirect benefits include improved income levels and standard of living and better nutrition of the population.

The benefits are generally well known and well understood but the deficits are often poorly understood and frequently overlooked: in the following pages we consider the adverse effects of irrigated agriculture and their consequences. These impacts not only involve the more obvious impacts of pollution and the loss of plant and animal habitats but also include modifications of the soil and water, and impacts on human settlements and economies. These adverse effects are detrimental not only to the general environment but frequently are equally detrimental to the irrigation system itself. Estimates made in 1980 (Biswas et al) indicate that due to soil deterioration massive tracts of irrigated cropland were going out of production at nearly the same rate as the amount of new lands were being added.

Many of the problems in the past resulted from an under-estimation of the complexity of irrigation and its interaction with the environment and social structures; irrigation development was seen as simply providing a system to deliver water to potential cropland at an acceptable monetary cost without considering whether the soil was suitable for long-term cropping; water was considered as a benign input and people were generally disregarded but assumed to be in favour of the development even though they were relocated and not consulted. Such schemes often failed but the failures are not widely reported because as one development officer noted "Development agencies do not have failures, just partial successes." In view of the present food-supply situation in Kenya "partial successes" which threaten long-term crop productivity or the general welfare of the people in the project area cannot be afforded.

One final point needs to be made before we discuss the adverse environmental impacts of irrigation and that is to stress that *before new lands are brought under irrigation priority should be given to the rehabilitation and upgrading of existing schemes.* These schemes are likely to be situated in more suitable locations with respect to land and water supply (which is why they were developed first) and their yields should be maximized before new ground is broken. If existing schemes are under-performing the reasons for this should be assessed, the problems resolved and the lessons learned applied to future schemes.

Several methods are currently available to supply crop water in a controlled manner and these have contrasting environmental impacts; these methods include:

a) Drip irrigation,
b) Sprinkler,
c) Furrow,
d) Basin or paddy irrigation.

As a broad generalization drip and sprinkler systems have the least and often negligible impact on the environment because they most closely simulate natural rainfall and do not produce accumulated surface water nor generate excessive surface return water. They are the most precisely controllable and therefore the most economical in terms of water consumption if correctly managed.

Furrow and paddy systems generally have more serious consequences because they produce large areas of standing water in which disease vectors can breed, and from which large volumes of water can evaporate. They also generate large volumes of chemically degraded water as return flows. Since the basin or paddy system has the greater area of water, problems are greatest under this form of irrigation system. However, all forms of agriculture which extensively utilize agricultural chemicals pose hazards to the environment and to public health and safety and as such these problems are not unique to irrigation.

In view of the comments in the previous paragraph the following discussion of environmental impacts focuses on furrow and paddy systems for this reason and because a majority of the proposed irrigation development schemes in Kenya are of the paddy type.

3.2 Environmental Impacts of Irrigation

The environmental impacts of irrigated agriculture are schematically represented and summarized in Figure N3.1; and discussed below under the following headings:-

3.2.1 soil modifications,
3.2.2 water quality changes in ground and surface water,
3.2.3 socio-economic impacts,
3.2.4 public health
2.5 effects on fauna and flora.

3.2.1 Soil modifications

The most frequently experienced soil problems associated with paddy irrigation are water logging, salinization and alkalization and it is probably true to say that almost all such schemes worldwide have to contend with water logging and salinization to some degree.

(1) Water logging

This may occur due to the over application of water or as a natural consequence of the topography, especially in low-lying areas such as swamps and floodplains where the water table is close to the land surface. Water logging adversely affects plant development by saturating the soil pore spaces in the root zone with water thereby denying the roots essential access to air (oxygen). Problems can, therefore, be anticipated where swamps are "reclaimed" for irrigated agriculture. The problem also arises where unlined delivery canals and channels lose considerable amounts of water into the surrounding land causing a significant rise in the local water table.

When the water table reaches to within 1 to 2 metres of the land surface the groundwater adds moisture to the root zone through capillary action and water moves upwards due to evaporation from the surface. Thus even in the absence of excessive surface water application the root zone can become saturated and oxygen exchange inhibited. This problem is in itself detrimental to crop production but is more so when the ground water is at all saline as is often the case in arid and semi-arid areas.

(2) Soil salinity

Soils may become saline due to the evaporation of irrigation water from the surface, or because the soils are formed from naturally salt bearing rocks, or from the combination of these two factors.

The quality of the water used for irrigation plays a major role in determining the extent of the salinity problem especially in dry areas where ample drainage water for flushing out salts is not usually available. Even good quality irrigation water with 200 mg/l of dissolved salts when applied at the rate of 10,000 m^3 per hectare per annum will deposit 0.2 metric tonnes of salt in the soil each year. Obviously the risk of salinization increases when poorer quality water is used. The problem arises because most of the water applied to the soil is either transpired by the crop or lost through evaporation leaving the salts behind in the soil. Since high salt concentrations in the soil inhibit the uptake of water by the plants the plants wither and eventually die. Yields from salinized soils are thus reduced unless more salt tolerate species or varieties are cultivated. When water is not in short supply the accumulation of salt can be arrested by flushing it out through specially designed drainage systems.

Soil salinity may also arise because of the chemistry of the parent rock from which the soil was derived. In areas of high rainfall these salts are leached out over time and reduced to levels which do not impair plant growth. In arid and semi-arid areas this desalting does not take place and the soils remain naturally saline. Although it is technically possible to correct this situation the process is rarely economically justifiable.

The problem of soil salinity is exacerbated when high salt concentrations derived from whatever source are coupled with water logging. Where this occurs the rising water table brings salts from below the root zone into this zone or to the soil surface where they are deposited. In serious cases this secondary soil salinization can render the land useless for crop production.

(3) Alkalization

This phenomenon is also called secondary soda salinization is an especially serious hazard of irrigated soils and results from the use of alkaline irrigation water or from alkaline groundwater which contain a high concentration of sodium. In the surface layers of the soil the deposition of sodium alters the normal ratio between sodium and calcium or magnesium which results in changes in the behaviour of clay particles. This results in the soil becoming sealed and nearly impermeable to water. At the same time the sodium may be sufficiently concentrated to be toxic to the plants.

The problem of alkalization may also develop via a different process when the water used for irrigation contains a high bicarbonate content. This occurs because the bicarbonate reacts with and precipitates calcium and magnesium which has the effect of raising the relative proportion of sodium; this then produces the same results as described above. Alkalinity in the soil is the most serious form of salinization in that it is far more detrimental to the soil and to crops and it more difficult to rectify.

3.2.2 Water quality changes in ground and surface water.

Water management in irrigation systems most usually emphasises the timing and quantity of water to be applied; far less attention is given to the quality of the water applied or to the equally important consideration of the quality or chemistry of the soils to be irrigated. Here we consider some aspects of water quality in relation to irrigation.

Two aspects of water quality need to be considered in relation to irrigation namely; the quality of the water entering the scheme and its effects on crop production, and secondly, the quality of the water leaving the scheme (usually called the return water) and its effects on the receiving water and downstream water users. Irrigation planning generally concentrates on the former with little regard for the latter.

(1) Inflow water quality

The quality of the water available for irrigation may be more significant in determining the success or failure of the scheme than soil characteristics of some lands; excellent soils may be unusable, for example if the water used for irrigation would quickly render them saline or toxic because of the concentration and composition of the salts it contains.

All naturally occurring water contains dissolved salts to varying degrees and the concentration of these salts varies seasonally in both surface and ground waters. In general surface waters are more stable over time in their major solute chemistry except in closed lake basins where seasonal changes in water levels may greatly influence the ionic concentration. Such a situation exists in Lake Naivasha for example. Similar changes occur in the other Rift Valley lakes but since these are highly saline they cannot be used for irrigation. Groundwaters also change in ionic strength seasonally and salt concentration may double during the dry season, especially in shallow wells and boreholes. It is therefore essential to have adequate data on groundwater quality for all seasons before proposing its use for irrigation especially in ASAL areas where excess water for flushing out salts is not available.

No specific salt concentration (expressed as electrical conductivity for example) can be proposed since the adverse effects of salts depend upon the composition and proportions of the salts actually present, and upon the type of soil under cultivation. Higher salt concentrations are tolerated on sandy, well-drained soils than on finer-grained soils. Areas normally well supplied with rain are less likely to develop salt problems because of the natural de-salting effects of the rain. The method of water application is also influential in determining the impact of saline irrigation water; drip systems for example with their greater control of the water volume applied generally permit the use of higher salinity water.

In general the response of crops to water having a given set of characteristics may vary widely depending upon other crop production parameters including:- soil type, crop tolerance, rainfall patterns, drainage conditions, irrigation method, availability of water and climatic factors. Each of these singly or in combination may affect the utility of a given water for irrigation of a particular crop.

Schemes of water quality evaluation and classification have been devised by several investigators and although none of these is universally applicable they can be used as general guidelines for assessment. The problems created by irrigation water quality are farm management problems and must be solved at that level; therefore water quality assessment and evaluation must be in terms of its specific use on a specific scheme in relation to the localized conditions of the scheme (FAO 1979). The problems created are basically grouped under four headings:-

1. *Salinity*: affects crop water availability and usually arises in water with an ECw of > 0.7 mmhos/cm and becomes severe at ECw >3.0 mmhos/cm.

2. *Soil permeability*: affects the rate of infiltration into and through the soil and is reduced by certain salts or lack of salts in the water. If total salt content is low (<0.5 mmhos/cm) the water is corrosive and depletes soils of soluble minerals and nutrients, at lower dilutions permeability is badly affected. Above 0.5 mmhos/cm permeability is not affected so long as the ratio of calcium and magnesium to sodium is good (as assessed by the SAR index).

3. *Toxicity*: affects sensitive crops which concentrate certain ions in their roots or leaves which results in loss of production. Sodium, chloride and boron are the ions most commonly associated with toxicity. This problem may become acute when using sprinkler irrigation.

4. *Miscellaneous*: affects susceptible crops and include problems associated with excess nitrogen compounds, bicarbonate deposition, pH levels beyond the normal range of 6.5-8.4 and the presence of certain rare metals including lithium.

The parameters of importance to irrigation water quality are listed below; and the FAO guidelines for evaluating irrigation water quality are given in Table N3.1 but are not discussed in detail here.

Parameter	*Unit*	*Symbol*
Electrical conductivity	uS/cm	ECw
Calcium	meq/l	Ca
Magnesium	"	Mg
Sodium	"	Na
Bicarbonate	"	HCO3
Carbonate	"	CO3
Boron	mg/l	B
Nitrate-nitrogen	"	NO3-N
pH	---	
Adjusted sodium absorption ratio (1)	---	SAR
Potassium (2)	meq/l	K
Lithium (2)	mg/l	Li
Iron (2)	"	Fe
Ammonium-nitrogen (2)	"	NH4-N
Phosphate-phosphorous (2)	"	PO4-P

(1) Calculation procedure can be found in standard texts.
(2) Testing required under special conditions only.
Source: FAO Irrigation and Drainage Paper No;29 (1976).

One often unpredictable source of adverse impact on irrigation schemes resulting from the quality of the irrigation water is the unexpected development of water pollution upstream because of changes in land use or domestic or industrial activity. To avoid such problems a catchment or river basin approach to water resource development should be employed.

It should, perhaps be noted here, that the return water from an upstream irrigation scheme is often a principal culprit in water quality degradation. Return water from irrigation schemes is usually far more saline than the water entering the scheme because salts have been added within the scheme in the form of fertilizers and other agro-chemicals, and then concentrated through evaporation as illustrated in (2) following.

Salt concentration is not the only problem encountered in irrigation water; pesticide and herbicide residues may also remain active and adversely affect subsequent users. In addition the water leaving an irrigated paddy is often total deoxygenated with a high oxygen demand (BOD) and is consequently of no further use for irrigation unless reoxygenated. In addition the fear of crop diseases being transferred from one paddy or scheme to another limits the use of return water for further irrigation downstream.

Further problems are associated with water related human and animal pathogenic organisms which may cause a wide variety of diseases including cholera, typhoid, bilharzia and malaria. As yet water quality criteria for irrigation are not well developed and standards are set in relatively few countries.

In summary, the effects of inflow water quality on irrigated agriculture can be serious and demand attention in the early stages of project development but after crop type, method of irrigation and soil analyses are completed. Overall these impacts are not considered to be as environmentally significant as the effects of irrigation on water quality which are discussed in the following section.

(2) Impacts on water resources and water quality

The effects of irrigation on the quality of the receiving water may be categorized as follows:-

a) Impoundment effects
b) Diversion
c) Groundwater abstraction
d) Return flow impacts.

Impoundment effects:

The environmental and ecological effects of impounding river water are well documented and include;

* eutrophication
* aquatic weed problems
* water associated diseases
* creation of barriers to fish and shipping
* social impacts of relocation and resettlement
* impacts on downstream water users.

These, and other impacts are discussed in detail in Chapter N4.

Diversions:

When water is diverted from a river into an irrigation scheme a majority of this water is not returned to the river due to percolation, evaporation and transpiration losses; river flows below the off-take are therefore reduced and the impact on the downstream human and ecological communities is generally proportional to the percentage of the flow diverted. Such impacts are obviously seasonally variable and affect the least tolerant species to the greatest extent. It is, therefore, essential to ensure that adequate compensation flow is provided to maintain the downstream communities and water users especially in the more critical dry season low-flow periods.

As rivers become increasingly used as receiving waters for effluents of various kinds and originating from various sources the need to maintain adequate volume in the river for dilution purposes becomes greater and more critical. Thus the demand for irrigation water must not be given an over-riding priority over compensation flows if the river is to continue to cleanse itself adequately and be fit for use by downstream consumers.

Diversions which drastically reduce the dry season flows in rivers also pose health hazards if stretches of stagnant water are created where disease vectors can breed and multiply. Similarly stagnant pools become foci for multiple social activities including water collection, washing and also the receptacle for untreated sewage and domestic wastes. These impacts particularly affect the urban and rural poor who have no access to safe water supplies or proper sanitation.

Groundwater abstraction:

Abstraction of groundwater at a rate exceeding the natural recharge rate will lower the water table and result in increased costs as wells have to be deepened and pumping costs rise. Continued over-pumping may also lead to land subsidence which may adversely affect the levelling and water distribution systems of an irrigation scheme.

In some locations abstraction may cause the intrusion of more saline water into the aquifer. This occurrence is all to common in coastal regions but may also occur in areas with evaporite strata causing high salt concentrations in some aquifers.

The exploitation of "fossil water" supplies should not be considered for extended irrigation purposes since this is a non-renewable supply; this source of water should be used for domestic drinking water as an emergency supply only.

Return flow impacts:

The degraded quality of the water leaving an irrigation scheme and being returned to a river or lake is now recognized as a serious ecological and management problem and one which has to be addresses at the earliest possible stage in irrigation project planning. Control of return water quality has become more important as the demand for fresh water from competing water users has increased due to population growth and the growth of industry.

Of the water abstracted for irrigation use, 40-80% is consumed via evapotranspiration and incorporation into the crop. A further quantity infiltrates into groundwater reservoirs and the balance makes its way into the drainage systems and ultimately returns to a receiving surface water which may or may not be the one from which it was originally abstracted. During this process the quality and the quantity of water returned to the receiving water has been seriously reduced.

Since evapotranspiration does not remove dissolved salts these remain in the soil and water within the irrigation scheme. The mineral concentration of the soil and drainage water in irrigated areas ranges from 2 to 10 times greater than the incoming irrigation water according to Hotes and Pearson (1977). No data are available for irrigation return flow water quality data for Kenya but the scale of the problem can be assessed from the table below:

Total hardness of return water from irrigation schemes in the United States of America (mg/l $CaCO_3$)

Location	*Upstream of Irrigation*	*Downstream of Irrigation*
Rio Grande, Texas	111	631
Yakima, Washington	33	134
Sunnyside, California	40	299
Arkansas River	212	890
Sutter Basin, California	72	480

Source: Hotes and Pearson 1977.

If increased salinity due to evaporation is coupled with flow reduction in the receiving water due to diversion then the combined increases on salinity can significantly endanger downstream users, including other irrigators.

Residual agricultural biocides in the return water may include insecticides, herbicides, fungicides and molluscicides which may impair the utility of the water for potential downstream users. These toxic chemicals are normally used intensively on irrigation schemes since ideal conditions are provided for the growth and development of weeds, fungi, insects, vermin and other pests. As pests develop genetic resistance to these chemicals farmers resort to heavier and more frequent application or turn to more toxic compounds to protect their crops. Inevitably some of the more persistent chemicals remain active and in solution in the irrigation water and pass out of the irrigation scheme and into the receiving water where their presence may limit the uses to which the water can then be put.

To increase and sustain high crop yields substantial quantities of fertilizers are also applied in irrigated areas especially where high yield varieties are being cultivated. These nutrients (nitrate and phosphate) are also carried in the drainage water to the receiving water where they enrich the water and fertilize the development of aquatic weeds and algae; a process called eutrophication. The development of such weeds and algae can greatly reduce the water quality of natural waters and reservoirs to a point where they become unusable. Some algal species produce very high population densities under these conditions and form "algal blooms" in the water; they can also excrete toxic wastes which may result in illness and deaths among people and especially livestock which drink the affected water.

The over-supply of nitrogenous compounds in fertilizers and some herbicides can be especially serious if this results in excessively high concentrations of nitrate in the drinking water supplied to infants. Excess nitrate can cause respiratory failure in infants which may prove fatal.

In some specific areas the adverse impacts of polluted return water on the receiving water course can be minimized or eliminated entirely if local wetland swamps are incorporated into the planning and design of the irrigation scheme. These swamps are capable of providing an effective method of removing substantial quantities of plant nutrients from the return water and also of reducing the BOD levels. The proposed large scale development of irrigation on the Kano and Nyando Plains is a case in point. Return water from these developments could well severely impair the water quality of Nyakach Bay (see Chapter N8) and perhaps larger areas of the Winam Gulf if they are returned untreated. The extensive swamps in the Nyando river mouth could be designed into the project to improve the quality of the return water and protect the Gulf from eutrophication and deoxygenation. The only possible hindrance to this approach to environmental management (apart from hydrological problems, if any) is the effect of residual herbicides from the irrigation scheme on the swamp vegetation. Selection of non-persistent herbicides that have the minimum impact on the swamp vegetation should be preferred.

3.2.3 Human impacts

The ecological impacts of irrigated agriculture have been well known for some time but more recently social and economic impacts have become apparent which some authorities consider to be of even greater consequence than those inflicted upon the physical environment. These effects, apart from health aspects which are discussed in the next section, can be categorized under four main headings:

* Human settlement patterns
* Socio-economic aspects
* Social organizations
* Community participation and support.

(1) Human settlement patterns

Relocation and resettlement:

Rarely if ever do the patterns of land ownership and the requirements for irrigated agriculture coincide; consequently the development of irrigation is normally accompanied by enforced changes in human settlements and land ownership necessitating the relocation, resettlement and compensation of those dispossessed by the project. The development of irrigated agriculture in populated areas is, therefore, almost inevitably socially disruptive and this disruption must be listed on the debit side of the cost-benefit analysis and appropriate mitigation planned and implemented.

Problems of social disruption are particularly apparent when the plot size is small (many families are affected, and many lose their entire holding) and where plot boundaries are not formally surveyed and accompanied by legally registered title deeds. Land used traditionally without any claim to ownership (common land) is held by the clan, tribe, village or extended family and its use is regulated by local officials without reference to the national government. Much of the land used by the nomadic pastoralists falls into this category and the problems resulting from pressure on this resource are considered in detail in Chapter N9.

The resettlement of dislocated populations is the most extensively studied social impact of irrigation development. These studies have frequently emphasised the impacts of the larger schemes while smaller schemes have not received equal attention. The impacts of increased disease, malnutrition, social unrest and poor planning during the relocation phase have been well documented and overall planning has been greatly improved in the light of these earlier experiences.

Compensation:

Families and individuals forced to move from their homes by development projects are entitled under Kenyan law to compensation for their losses. Losses will include their land, homes, crops and the cost of relocation and resettlement. In principle those adversely affected by development should be compensated such that they are not socially or economically prejudiced by the development. Further aspects of compensation, relocation and resettlement are considered in Chapter N4 in connection with the developmental impacts of large scale dams and reservoirs.

Malnutrition:

Because of the high costs of irrigation scheme development all the land within the project command area (ie. that land suitable for irrigation) must come under irrigation and farmers must increase yields per hectare to cover the increased costs of agricultural inputs associated with irrigation. The command area, therefore, tends to become dominated by the nominated irrigated crop, a monoculture, and the farmer is forced to forsake the cultivation of more traditional crops and livestock. Land uses such as vegetable cultivation, grazing, fallow or woodlot, which may be socially or culturally preferred, are no longer feasible or permitted options within the scheme and the farmer becomes more closely bound to land use decisions imposed by the project and over which he has less or no influence. An all too frequent consequence of irrigated monocultures is the development of malnutrition among the project workers, and especially their children, because of the lack of alternative foodstuffs and an unbalanced diet.

(2) Socio-economic functions

Farmer resistance: resistance to the introduction of irrigation by farmers who lack previous experience in irrigation technology occurs fairly often since new techniques and skills have to be learned and quickly put into practice. In this context agricultural extension services and demonstration farms can play a significant role in redressing this problem and can greatly reduce the difficulties experienced in the conversion from rain-fed to irrigated agriculture.

Water use conflicts: irrigation schemes affect the existing water use patterns and alter user priorities. Waterways in the scheme become sources of water for purposes other than crop watering including stock and domestic use which may lead to health hazards since this water is generally unfit for human consumption without adequate treatment. The presence of livestock within an irrigation scheme can result in conflicts when crops and bunds are damaged and rights of access or denied or abused. A further major water and land use conflict is occurring in ASAL areas were land is being converted to irrigation which was vital for the maintenance of pastoral livestock. This important topic is fully discussed in Chapter N9

Labour and market constraints: lack of labour and access to suitable markets can create social problems. Loss of yield will occur when sufficient labour is not available during labour intensive periods of the cultivation cycle, eg. planting, weeding and harvest times. The scheme may also divert labour from other socially necessary activities such as fishing, wood gathering or cutting and food production for family consumption to the detriment of the community as a whole. It is also necessary for the local or distant markets, and transport routes to be developed in parallel with the scheme.

Financial constraints: through involvement in an irrigation scheme the farmers has an increased potential for improving his monetary income and standard of living. But, to actually achieve this increase he needs access to pre-financing or credit facilities to fund his initial expenses. Without investment in good seed stock and agrochemicals through lack of funds the farmer is unlikely to realise the potential offered by the scheme and the scheme will fail.

Farmers also often become trapped in a situation where their costs in terms of seed and chemical inputs are uncontrolled and rising while the value of their crop is controlled by government regulation to protect the consumers. Yields naturally fall under such conditions and project targets are not achieved and eventually farmers are deprived of an adequate living.

(3) Social Organization

Irrigation schemes must be integrated into national planning to ensure reliable supplies of water, chemicals, machinery and many other inputs and there must also be decentralized control over the distribution and maintenance of these inputs within the scheme. Thus a central irrigation authority (possibly the Ministry of Agriculture, see Subsection 4.6.2 of Sectoral Report P) is needed to manage the major structures including dams, pumps and supply channels to insure the supply of water when needed. The management should cover major private irrigation schemes. In addition farmer cooperatives or water-user groups are needed to determine schedules, set application rates and maintain system-to-field structures (ditches, drains and water control devices etc.) and manage the day-to-day running of the irrigation scheme.

The selection of a specific project and its location should be based on technological and agricultural criteria and not on the scale of the political benefits to be reaped. Very large schemes which have considerable political prestige value are too often given preference over more technically justifiable small-scale projects to the detriment of the economy and the people.

(4) Community participation

All development projects are more likely to succeed if planned **with** the people rather than **for** the people. Planning at the earliest stages must include consultation with the communities to be affected or involved with the project. Early community participation may then mitigate many of the problems so often encountered by projects implemented "from above" without prior consultation with the local population; it is all too often assumed by the developers that there will be unqualified acceptance of the project by those perceived as beneficiaries. It is noted that Harambee spirit is a very effective momentum of raising the community participation initiative.

3.2.4 Public health impacts

Three important aspects of the impacts of irrigated agriculture on public health are discussed:

i) Disease
ii) Malnutrition
iii) Hazards from agricultural biocides.

(1) Disease

Introduction:

It is an unfortunate fact that water resource development projects frequently bring in their wake an increase in water associated diseases and this is particularly true of irrigation projects in the Third World. This spread continues despite detailed knowledge of disease transmission routes, advanced diagnosis, treatment and prophylaxis, and greater numbers of trained medical personnel in the field. Thus the prevention of unintended increase in the incidence of disease in irrigation schemes must figure high in project planning priorities to ensure an improvement in the quality of life for those living in or near the project area.

Water provides a favourable habitat for the reproduction, development and growth of many disease organisms and their vectors. Rough estimates indicate that between 20 and 30 infective diseases may be affected by changes in the abundance and distribution of water. Disease pathogens may be transmitted directly from person to person, or via a vector, and warm, moist or wet habitats are particularly favourable to both pathogens and vectors. As a result people living near irrigation schemes in the humid tropics are potentially exposed to a wide range of infectious diseases. These diseases can most usefully be categorized by their mode of transmission or spread; four main categories are recognized (Feachem et al. 1977) and shown in the Table N3.2.

Although the incidence of many of the diseases listed below may be increased by the construction of paddy irrigation schemes, especially those with perennial multi-cropping cultivation, some merit special consideration because of their more frequent association with this type of irrigated agriculture; these diseases include schistosomiasis, malaria and various faecal-oral diseases. Several other insect-borne diseases are mentioned briefly.

Classification of water related diseases:

Water related diseases are classified under five main headings though it should be realized that distinctions between categories are not always clear and that some pathogens may be transmitted by one or more different routes and thus fall into several categories; similarly some infections may be caused by more than one agent.

(a) **Faecal-oral diseases:** these are diseases caused by pathogens originating in the gut and faeces of the host; they may be transmitted to another host via water if excretion to a water source occurs, or by direct contamination in unhygienic toilets or through food preparation in which case water is not involved. Several diseases in this category are also classified as water-washed or water-borne (see below).

(b) **Water-washed diseases:** these are infections which are normally reduced in incidence with an increase in the volume of water used for cleaning and personal hygiene. Thus piped water supplies reduce such diseases but it is the quantity and not the quality of water supplied which is of paramount importance.

(c) **Water-borne diseases:** water-borne transmission occurs when the pathogen is consumed by a person or animal in drinking water resulting in infection. Classic diseases such as cholera and typhoid fall into this category.

(d) **Water-based diseases:** are caused by pathogens which spend part of their life-cycle in an intermediate host which is aquatic. All these pathogens are worms of various sorts and schistosomiasis is the prime example.

(e) **Water-related insect-vector diseases:** here the pathogen spends part of its life-cycle in an insect intermediate host and this insect either breeds in or bites near water; mosquitoes and tsetse flies are respective examples transmitting malaria and sleeping sickness respectively.

In Table N3.2 the classification of water related diseases is summarized with selected examples of the more prevalent diseases, their associated pathogens and vectors (where relevant). Table below indicates the principal preventive strategies available to combat these diseases.

Mechanisms of disease transmission.

Transmission Mechanism	Preventive Strategy
1. *Faecal-oral diseases*	Improve water quality; prevent casual use of fouled water sources
2. *Water-washed*	Improve water quality Improve personal hygiene Improve access to water
3. *Water-based*	Reduce contact with water Control aquatic snails Improve water quality
4. *Water-related insect vectors*	Improve water management Eliminate breeding sites; and reduce contact between insect and people

Source: Feacham et al. 1977.

MALARIA: its ecology and control

The malaria pathogen (*Plasmodium sp.*) is transmitted by the female mosquito of the genus *Anopheles spp.* In Kenya *A. gambiae* is the main vector species. It is a widespread, robust and long-lived species easily infected by *Plasmodium*. It often rests in houses and feeds primarily on man. The mosquito lays its eggs in temporary pools or slowly moving water where the larval and pupal stages also develop. Malaria is thus an insect vector-borne water-related disease. In areas of high endemicity, mortality from malaria is high, especially among children, but those who survive develop natural immunity.

In general it may be stated that where malaria transmission is naturally least, the dangers from irrigation development may be greatest. In areas of the country where year round rainfall provides permanent breeding sites the disease can be transmitted throughout the year; elsewhere where seasonal rains occur the disease is also seasonal. Irrigation schemes that provide permanent water also provide year round breeding sites and, therefore, will promote the transmission of malaria. The breeding of the mosquito is also affected by temperature such that above 1300 metres the temperature is too low for year round breeding and mosquito population become very unstable.

No single method of control will be effective by itself. Strategies employing a combination of approaches must be adopted with the specific types determined by the prevailing conditions in the project area. The available methods include:-

i. **Killing of the adult mosquitoes:** by the use of persistent insecticides, especially on the walls of dwellings where the adults often rest. This method has proven effective in the past but the build-up of genetic resistance in many species of mosquitoes has reduced its efficiency in recent years and also raised the costs as more expensive chemicals have replaced DDT. It should also be noted that the African mosquito responsible for transmitting malaria *Anopheles gambiae* is a long-lived and robust species which bites frequently and to achieve useful reductions in the incidence of malaria its populations have to be reduced to very low levels.

ii. **Killing of larvae and pupae:** larvicidal compounds can be applied to water bodies used as breeding sites by mosquitoes during the breeding season; this approach has the drawback of potentially contaminating drinking water supplies and this restricts the application of this approach. Alternative methods foe eliminating larvae aim to cover the water surface with a fine film of oil which prevents the larvae and pupae from gaining access to air and causes suffocation. This approach is expensive and requires repeated application of oil especially in flowing waters to have any chance of success. The survival of other air breathing organisms in the water is also threatened.

iii. **Habitat management:** mosquitoes need water in which to breed and different species have very precise requirements relating to shade, vegetation cover and various water quality parameters including organic content. By altering the habitat mosquitoes can be discouraged from laying their eggs. Draining or in-filling of all unnecessary water bodies, even small man-made pools eg. water butts and gutters, and the clearing of blocked drainage ditches will also reduce the numbers of mosquitoes significantly. For example the Yellow fever mosquito *Aedes aegypti* breeds in small clean water containers such as discarded tin cans and car tyres; by denying access to these sites to the mosquitoes the incidence of malaria and other mosquito-borne diseases can be drastically reduced.

iv. **Chemotherapy of the afflicted population:** permanent residents of areas with endemic malaria will have developed a degree of natural immunity to the malaria parasite and do not suffer the adverse effects of the infection to the same extent a newcomers to the area. Young children are also badly affected until they too either succumb to the disease or develop immunity. The provision of access to chemotherapy to reduce the impacts of malaria and/or the supply of mosquito nets to prevent infection will also play a part in controlling malaria since the Anopheles mosquito generally feeds at night.

SCHISTOSOMIASIS: its ecology and control

This parasitic infection , also known as bilharzia, is a debilitating disease which is rarely fatal. It especially afflicts people between the ages of 10 to 20 due to their greater contact with infected water bodies. Diesfeld and Hecklan (1978) estimated that one million people in Kenya are infected with schistosomiasis and Highton and Chaudhry (1974) and Chaudhry (1975) report that all the major irrigation schemes in Kenya have been colonised by potential intermediate snail hosts.

Two genera of snails are involved each having slightly different habitat requirements and transmitting two different forms of the disease:-

a) *Bulinus* (mainly *B. africanus*) prefers still or slowly moving perennial streams and is found also in small pools, water holes and permanent dams below 1800 metres altitude; it is responsible for transmitting urinary bilharzia (*Schistosoma haematobium*) and eggs are passed out with the urine. Bulinus is able to aestivate for long periods in the muddy bottoms of dried water bodies. The snail is widely distributed throughout Kenya though the parasite is confined to the coastal plain, the central part of the country and around Lake Victoria.

b) *Biomphalaria* (mainly *B. pfeifferi*) is the second genus and can live in faster moving water and is common in irrigation channels and dams where it is able to avoid desiccation by aestivating for several months while buried in bottom sediments of pools or dams. This genus transmits *Schistosoma mansoni* which infects the intestine and eggs are excreted with the faeces. Both snail and parasite are widely distributed throughout Kenya except along the coast where water temperatures are too high for the snail or above 1800 metres where temperatures are too low. It is uncommon to find both species of snail cohabiting the same area of water.

The basic life-cycle of the schistosome worm is summarized in Figure N3.2. This figure indicates that the cycle of infection can be broken at one or more of four susceptible stages in the cycle and these represent potential control points, namely:-

i) Reducing the output of eggs by patients using chemotherapy,
ii) Reducing contact between people and infected water bodies,
iii) Reducing the number of eggs entering water bodies (via a combination of points i and ii) and improved sanitation,
iv) Control or elimination of snail intermediate hosts

These four main approaches to control schistosomiasis are considered further in the following paragraphs; the principal methods for control are summarized in table below.

Summary of methods for the control of schistosomiasis

CONTROL OF BILHARZIA	Social Management (Interrupt 1,3,4) (see Figure N3.a)	a) chemotherapy b) reduction in contact with infected waters c) prevention of excretion in public water sources
	Management of snail habitats (Interrupt 2) (see Figure N3.a)	d) molluscicide application e) drainage & filling of all non-vital water bodies f) water level fluctuation in irrigation schemes and reservoirs g) design channels to create inhospitable habitat for bilharzia snails h) biological control

A. Social management

i. **Chemotherapy**: Praziquantel (Biltricide) is the drug of choice against all forms of schistosome and has negligible side effects. Two others Oxamniquine (Vansil) and Metriphonate are effective only against *S. mansoni* and *S. haematobium* respectively and also have some adverse side effects in some patients. Although the use of these drugs reduces the numbers of excreted eggs available to infect local water supplies this approach is not a practical long-term solution especially for those who because of their circumstances will be continually reinfected such as paddy workers, fishermen and children.

ii. **Reduced contact:** reducing the amount of time spent in infected waters can greatly reduce the worm load carried by man. Contact occurs through domestic and recreational uses of water and also during defecation which promotes the disease. To facilitate a reduction in contact alternative sources of water and proper latrine sanitation are needed; these would simultaneously reduce contact and also the numbers of eggs entering water supplies.

iii. **Sanitation:** theoretically the most effective means of eliminating bilharzia is to prevent the eggs in human waste from entering water supplies. This requires major changes in the social behaviour of the waterside dwellers and the provision of alternative sites for waste disposal. In practice this has not proven effective. To encourage better sanitary habits proper excreta disposal facilities need to be provided which are more convenient to use than the natural environment. Even so, provision of such facilities does not ensure utilization.

The effectiveness of eradicating schistosomiasis by decreasing the numbers of eggs contaminating water supplies is lessened because of the enormous multiplication of the parasite infective stage within the snail; thus a single egg can ultimately give rise to a huge number of miracidia and many people can thereby become infected as the result of this single egg entering the water supply.

B. **Management of snail habitats**

iv. **Application of molluscicides:** there are several types of molluscicide available which work effectively but are costly and often have adverse side effects on non-target organisms including fish, water birds and man.

v. **Drainage and in-filling of snail habitats:** the removal of unnecessary pools of water in ponds and ditches containing emergent and submerged aquatic weeds will discourage the build-up of large snail populations; unintended adverse impacts on the environment are, however, unavoidable.

vi. **Water level fluctuations:** the stranding of snails in the drawdown zone of reservoirs can reduce population density to some extent but the ability of many snails to burrow into the muddy sediments helps them to avoid desiccation and death often for many months.

vii. **Water management:** intermittent application of water rather than ponded paddy systems greatly reduce the abundance of vector snails. In the Philippines where rice was formerly grown in paddies, the number of snails reduced from over 200 to less than 1 per square metre as a result of conversion to intermittent irrigation. Rice yields were reported to have increased by over 50% at the same time. This technique would also reduce other water associated diseases including malaria.

viii. **Channel design:** where water is conveyed in smooth lined channels snails can be discouraged and dislodged by water velocities exceeding 0.8 m/s in the absence of rooted vegetation.

ix. **Biological control:** the introduction of snail predators (other snail species and some fish) into irrigation schemes in various parts of the world has been tried but with limited success.

In conclusion, it must be stressed that a combination of chemotherapy of egg excretors, molluscicIding and engineering measures coupled with changes in social habits are required to effectively reduce the incidence of bilharzia and that some of these measures must be maintained for long periods if the disease is to be kept at a reduced level.

Evaluation of disease risk:

To assess the risk posed to the health and welfare of the public by the implementation of an irrigation scheme it is necessary to compare the existing pre-project risk (the without-project scenario) with that expected to exist with-project. This is not an easy assessment to make and the results of such analyses are only semi-quantitative. One attempt at this kind of evaluation has been carried out in Kenya and the results are presented in table below.

Net increase in health risks resulting from irrigation/drainage.

Basin	*Malaria*	*Schistosomiasis*	
		haematobium	*mansoni*
Yala	0	2	1
Kano Plains	0	2	1
Baringo	1	0	1
Kerio Valley	1	1	1
Upper Tana & upper Athi	1	1	2
Lower Tana & upper delta	0	1	0
Lower Athi	0	2	1
Taita Taveta	0	0	0

Legend: none = 0 low = 1
medium = 2 high = 3

Source: Study on Options and Investment Priorities in Irrigation Development: Kenya. 1987.

These data must be interpreted carefully; the emphasis is on risk increase and not risk per se. Thus in the Kano Plain or Yala area the risk of malaria is naturally very high, in which case the implementation of an irrigation project is unlikely to increase the actual risk involved. In contrast, in these same areas the project would increase the risk of infection by *Schistosoma haematobium* moderately and slightly for *S. mansoni*.

It must also be realized that although the risk of disease may not be increased by project development this does not necessarily mean that a larger number of people will not be affected since, if the project attracts people into the area (and especially if they are not immune to the local diseases) then more will be put at risk become infected. At the Hola irrigation scheme, for example, the population density in the area increase 100 fold, yet the incidence of malaria remained the same ie. holoendemic.

The term risk used here implies a combination of both chances and severity of infection. For a non-immune person one bite from a malaria falciparum carrying mosquito may prove lethal; while infection by a single schistosome causes only mild discomfort and only repeated infections (as experienced by paddy workers) can lead to chronic debilitating illness and permanent disability. Thus in the case of malaria chance of infection is most important, while for bilharzia both chance of infection and severity are important.

In addition to the comments on risk made above it should be noted that the degree of risk inherent in irrigation development depends on several factors related to project design and management, briefly the method of water application very much determines the risk hazard as follows:-

Greatest risk hazard ..... paddy and permanently flooded furrows,
Intermediate hazard ...... temporary flooded systems,
Least hazard .... sprinkler and drip irrigation systems.

Cropping intensity also plays a significant role in irrigation risk development; the malaria risk at Mwea for example, where one rice crop per year is grown, is considerably lower than in the Kano Plains, where two crops are grown.

It is specifically noted that, other than the lack of sanitation cited above, some of major factors causing water-related diseases in irrigation area are inadequate supply of drinking water and poor environmental awareness of the communities. The planning and implementation of irrigation projects should consider these factors carefully.

It is also emphasized that environmental impact assessment, particularly on health, is quite important on irrigation schemes. It is worthy of carrying out post assessment survey for the existing schemes to disclose the situations actually prevailing in the irrigation area.

(2) Malnutrition

As noted previously in Section 3.2.3.(1) irrigation schemes are generally dedicated to the production of a single crop species and the entire command area of the scheme usually is given over to the production of that crop to meet target production levels. Often little or no land is available for the project farmers, who are usually tenants, to cultivate food crops on plots of their own within the scheme. In addition, the farmers are rarely sufficiently well paid for them to be able to purchase food staples from the local markets and malnutrition is often the result, especially among children.

(3) Hazards from agricultural biocides

Introduction:

Irrigated agriculture has been practiced worldwide for several millennia without the use of agricultural biocides (insecticides, herbicides and fungicides etc.) but since their development and widespread availability after World War II these chemicals have become an integral part of modern agriculture. Although immediate yields have benefited, this has been accompanied by pest resurgence, development of insect resistance, destruction of economically and agriculturally useful insect predators, harm to aquatic fauna in paddies and natural waters, pollution, health hazards, and increased difficulty in controlling insect vectors of diseases such as malaria, dengue fever and encephalitis.

Biocide increase and the use of synthetic fertilizers is directly related to the development of high yielding cultivars of several major crops including rice, maize and wheat, which presently lack resistance to many insect pests and diseases. Moreover, the agronomic practices necessary for growing these high yielding varieties often induce pest infestation. Heavily fertilized paddies, for example, promote pest multiplication, while the typically short stemmed plants growing a dense canopy create ideal microclimates for many pests and diseases. Multiple cropping of rice has also significantly increased pest populations.

Biocides as such cannot be described as being either good nor bad. They are, however, only one of several methods available for controlling pests, diseases and weeds, and it is their wholesale adoption with little attention to alternatives which has led to many major problems in the past. The adoption of integrated pest management programmes incorporating crop management control techniques, biological control and the restricted use of biocides should be pursued in future irrigation development projects in order to lessen the adverse effects of biocide application.

Direct poisoning of humans and livestock:

Many of the biocides commonly used in agriculture are extremely toxic to humans, livestock, other mammals, birds and fish. The World Health Organization has reported that 500,000 people are poisoned by biocides each year; Weir and Schapiro (1981) also report that the poisoning rate is 13 times higher in developing countries than in the United States mainly due to ignorance and illiteracy. Sub-clinical intoxication is also very widespread and the concentration of many biocides which accumulate in food products exceed WHO recommended levels in developing countries. It may be noted that this not only has adverse health implications but also direct economic effects when exports of such contaminated products to the developed countries are rejected as unfit for human consumption.

Contributing factors to biocide poisonings include:

a) eating of dressed seeds,
b) direct contamination during preparation or application of the biocide due to lack of protective clothing or training,
c) re-use of biocide containers for water and food storage,
d) eating of poison bait laid for rodent control,
e) storage of biocides together with food supplies,
f) illiteracy preventing proper reading of instructions and warnings on biocide containers,
g) contamination of water supplies.

Pest resurgence:

Pest resurgence of pest species, and especially insects and mites, after application of pesticides is well recorded and arises from a combination of factors. First, the natural predators and parasites which normally keep the pest population under control are usually more susceptible and suffer greater losses due to biomagnification of the concentration of the biocide through the food chain. Second, pests often have higher fecundity levels than their predators and are therefore able to rebuild their reduced populations at a faster rate. Third, habitat or refuges for the predators and parasites may be lacking in the project area from which they can recolonize the area. As an example, resurgence of anopheline mosquitoes occurred after the Ahero irrigation scheme was sprayed and their natural predators were selectively eliminated.

Where the use of biocides increases the abundance of disease vector species populations this inevitably raises the chances for an increase in the incidence of the relevant disease.

Pest resistance:

Forty years after the discovery of the first organochlorine compound (DDT), and thirty-five years after the discovery of the first organophosphorous compounds (TEPP and parathion) in 1945, about 400 arthropod pest species have become resistant to the major biocides, in 1965 the figure was 182. According to recent reports the increase in resistance has been almost exponential in the past one or two decades.

Resistance develops when part of the target population receives a dose of biocide insufficient in strength to kill off the naturally more resistant individuals within the population leaving them to breed and produce a second generation with a resistance level which is, on average, higher than the parental generation. This process is then repeated with subsequent sprayings and generations. Inevitably resistance develops fastest in those species most frequently targetted ie. the crop pests. To some extent it can justifiably be claimed that modern agriculture with its dependence on biocides is the major force creating crop pests.

In rice paddies in Japan the resistance of the green rice leaf hopper (*Nephotettix spp.*) to malathion has increased ten fold and resistance is reported in other major rice borers and leaf miners.

Pesticide resistance is not confined to crop pests but is now widespread among insect and snail vectors of medical importance and in rodent vermin. Thus some large scale programmes to eliminate malaria have rebounded as the vector mosquitoes and the pathogen have both become resistant to the primary biocides and prophylactic drugs; and the bilharzia snail *Bulinus truncatus* is resistant to the molluscicide trifenomorph in the Gazira scheme in the Sudan.

The development of resistance results in an ever escalating use of more concentrated and toxic compounds to contain the outbreaks of crop and medical pests. While at the same time the frequency of application of the original pesticides is continually increasing in many areas. In the Gezira Irrigation Scheme (Sudan) for example, spray frequency increased from once per year in the late 1950's to 5 per year by 1966 and to 11 sprays per year by 1980. More recent data are not available.

3.2.5 Miscellaneous impacts

Fuel wood demand and deforestation

In the planning stages of several major irrigation developments worldwide, including the Bura scheme in Kenya and the Rahad and Gezira the lack of foresight in providing fuelwood plantations for scheme residents has caused significant environmental and social problems. Uncontrolled cutting of the natural vegetation may lead to deforestation and increased soil erosion which may prove detrimental to the scheme itself is waterways become silted. These topics are discussed in greater detail in Chapters N5 and N6 respectively.

N4. THE ENVIRONMENTAL IMPACTS OF DAMS AND RESERVOIRS

4.1 Introduction

The number of dams and reservoirs constructed each year continues to increase at an accelerating pace in the developing world as populations and economies expand and create an increased demand for power and water supplies for agriculture, industry and domestic use. In the early 1970's only 10% of the worlds rivers were regulated, this percentage is now expected to increase to over 65% by the year 2000 and many of the remaining developments will occur in tropical developing countries.

The most cost effective dam developments are those designed to be multi-purpose and intended to perform a number of functions or provide a variety of benefits, namely;

i. Primary functions or benefits

* power generation
* water storage for irrigation
* water storage for water supplies
* flood control

ii. Secondary functions or benefits

* navigation
* fisheries
* recreation
* wildlife conservation

Against these benefits must be weighed certain ecological and human problems some of which are unique to tropical man-made dams and reservoirs. Experience to date has indicated considerable deficiencies in the planning, design and construction of dams which have resulted in many and often severe adverse environmental impacts. Many of these impacts could have been successfully mitigated or off-set to a considerable degree if appropriate study and planning had been incorporated during early stages of the development process.

The environmental aspects of dam construction discussed below are summarized in Table N4.1 and presented schematically in Figure N4.1; and are based on published guide-lines for environmental assessments of dams and reservoirs (Freeman 1974, ADB 1988).

4.2 Environmental impacts of dams and reservoirs

4.2.1 Environmental effects due to project location

(1) Resettlement and compensation

The resettlement and compensation of people displaced from the dam site, inundation zone and other areas is now recognized as one of the major social impacts of dam development projects and has caused serious social unrest in past projects worldwide because of failure to include adequate planning or sufficient funds in the project core budget to cover appropriate resettlement costs including transport, loss of earnings and rehabilitation costs.

People materially disaffected by the construction of dams and reservoirs and particularly dams designed for power generation are liable to compensation for three basic categories of loss, namely:-

a) Permanent loss of possessions eg. land required by the dam-site, reservoir, canals, power house compounds, and for crops, buildings and trees lost or damaged during construction or maintenance,

b) Temporary loss of possessions eg. land required and leased for construction camps and some access roads,

c) Partial loss of legal rights eg. wayleave agreements along the power transmission line 'trace' when power generation is a feature of the development.

In addition, some families whose land holding would become uneconomic, or who would lose their livelihood might be forced to resettle due to inundation or construction although they may actually reside outside the area of immediate impact eg. the reservoir site.

Valuation:

The Kenya Power Company which has been involved as the client in a majority of the larger dam schemes in Kenya, has a method for arriving at an agreed value for compensation which is standard Company procedure and includes the Commissioner for Lands in association with professional land valuers. The price paid by the KPC is this agreed amount plus 15% which covers inconvenience, the impact of land purchases on land values and incidental expenses.

Care has to be taken to avoid land value rigging once it is publicly known where the project will be buying land. Rigging can take several forms but includes the planting of crops and trees and the building of additional structures for which compensation is then sought.

Method of payment:

The Kenya Power Company has a policy of cash-for-land payment for compensation settlements. Past experience has shown, however, that this system has led to difficulties when the payment money for land was used for purposes other than to replace the land which had been sold. This has resulted in some families becoming landless which in turn led to lawlessness in the affected Districts. In addition, a recent survey of people threatened with displacement at the Magwagwa reservoir site provided the following data indicating their preference as to the most suitable mode for payment of compensation:-

Mode of payment	Number in favour	Percent in favour
Land-for-land	763	82.3
Land-and-cash	155	16.7
Cash only	4	0.4
Do not know	5	0.5
Total	927	100.0

The people are obviously much more in favour of compensation in kind eg. land-for-land (82%) than the alternatives and a negligible number preferred the existing KPC approach. The principal reason given for this preference was because of the increasing difficulty in finding and purchasing suitable alternative land in Kenya as population pressure on the land make land an increasingly scarce commodity. Perhaps, in the circumstances, the Kenya Power Company could reconsider and modify its policy on payment to take account of this potential problem.

The quality of the land received in exchange must also be taken into account for the land given up was, most probably, a functional and productive farming and family unit; this cannot be replaced simply by an equal area of land; the entire system must be fully compensated. In addition, land of a similar agro-ecological zone should be provided to reduce the necessity for retraining of farmers and their adjustment to the different crops and agricultural practices required in other zones.

The form of resettlement with the land-for-land approach has to be justified also from the point of view of Kenya law as outlined in the Land Acquisition Act and the Constitution of Kenya. Resettlement is considered allowable in situations of compulsory land acquisition for the purposes of large development projects of national importance and the compensation strategies are specified under the Land Acquisition Act where the land is formally registered as in the reservoir site.

With regard to compulsory acquisition and involuntary resettlement, two important principles should be adopted in project implementation:-

a) the standard of living of the displaced people should at least be maintained, but preferably improved, and,

b) Social-cultural and mental stress resulting from resettlement should be minimized; this especially involves consideration of re-employment for those who are unable to continue in their current work because of relocation. Also important is the break-down of cohesive communities and the possibility of relocation to a different ethnic locality with its consequent problems and stress.

It should also be noted that within the principles and legal framework of involuntary resettlement in large national development projects the Government of Kenya has the legal responsibility for the provisions and assistances to the displaced people during the period of preparation for resettlement, translocation and actual resettlement.

Timing of payment:

The Constitution of Kenya and the Land Acquisition Act require "prompt payment of compensation" whether this be cash or land-for-land. In addition if people are to lose their dwelling place as a result of the project they should have the opportunity to rebuild their home elsewhere prior to being evicted from their original home. Similarly, the social infra-structure eg. schools, churches and health facilities, should be constructed in the relocation areas prior to inundation to assist those displaced to achieve a smooth transition to the resettlement sites and a continuity in their education and worship.

Relocation expenses:

In the event that a family has to be relocated to another location the cost of transport and other incidental expenses should be borne by the project.

(2) Encroachment into river catchments.

Temporary construction roads and permanent access roads built for the project often have the adverse impact of opening up the river valley to "development" or other forms of exploitation by loggers, farmers and others previously denied access due to the lack of roads. This can lead to increase soil erosion in the catchment which may shorten the working life of the reservoirs downstream through increased rates of siltation. The hydrological regime of the upper river may be affected by changes in vegetation cover and impair the base flows of the river with adverse impacts on water supplies. Wildlife and important conservation areas may also be opened up in this way and suffer degradation as a consequence.

(3) Encroachment into National Parks and Forest Reserves.

The creation of reservoirs inside National Forests or Forest Reserves, especially those dominated by indigenous trees rather than exotic plantations should be avoided. A case in point is the present proposal for a large dam within the South Nandi Forest which would inundate over 8 km^2 (or 4% of the forest area) of mature and unspoiled indigenous forest.

On the other hand the presence of a dam within many of Kenyas National Parks, if sympathetically designed and landscaped, could be a benefit to the Park and the Park environment so long as the reservoir covers only a small fraction of the total park area and does not inundate sites of ecological importance such as areas of riverine gallery forest, unique breeding sites or habitat of endangered species. The proposals to build such dams for power generation in the Meru National Park (Adamsons Falls) and the Kora National Reserve (Kora Rock) may well benefit these parks in several ways, for example:-

* the lake will create new habitat for wildlife especially crocodile, hippopotamus, and aquatic birds which will be more accessible and visible for tourists,

* the dam could be designed to carry a road across the Tana River which would greatly benefit tourism and park management by joining Meru and Kora and permitting game drive circuits to be developed,

* waterside locations are generally regarded as favourable sites for the development of tourist lodges with obvious national benefits.

The principal drawback of power dam development in National Parks is the adverse aesthetic impacts of the power transmission lines and the added traffic and disturbance due to operation and maintenance of the power station and the associated residential areas. Again, careful and sympathetic planning could go a long way to reducing these impacts to acceptable levels if given early and sufficient priority during project planning and budget allocation.

(4) Impairment of historic and cultural artifacts and sites.

The project site should be thoroughly surveyed to establish the existence or otherwise of sites of historic, cultural or scientific importance. In the event that such sites or monuments do exist in the project area, the Kenya Antiquities and Monuments Act 1983 provides information concerning the action required on the part of developers to report and protect such finds from damage or destruction.

(5) Catchment erosion and siltation.

As mentioned in 2.1.2 above, encroachment into the catchment areas of reservoirs which leads to increased soil erosion will shorten the working life of the reservoir and imposed severe economic costs on the project and the national economy. Protection of catchment from soil erosion through the implementation of soil conservation measures and forestry projects should receive high priority in the planning of all dams and reservoirs the costs of which have to be included in the project's core budget. Soil conservation is needed especially in some critical sub-basins of the Tana and Athi river basins where the head-water valleys are heavily populated and intensively cultivated and soil erosion is already a persistent problem.

(6) Impairment of navigation.

Dams on major rivers which by virtue of their size are used for navigation can total prohibit this use of the river with potentially dire consequence for upstream communities who may rely on the river for the exportation of their produce. This is unlikely to be of significance in future river developments in Kenya.

(7) Effects on surface and groundwater hydrology.

The total annual discharge from regulated rivers can be significantly reduced by evaporation and seepage losses from man-made lakes. The annual loss of water from the Nasser-Nubia Dam on the River Nile at Aswan in Upper Egypt is only a little less than the entire discharge from all Kenya rivers each year. The proposal to build two large dams on the South Ewaso Ngiro at Leshota and Oldorko may result in daily evaporation rates which exceed the minimum mean daily flow in the river for much of the year. Water lost in this way is no longer available to downstream users and the social and economic cost of this loss must be set against the value of the proposed projects.

Reservoirs also create the possibility of water logging in the immediate reservoir area and other adverse impacts on groundwater supplies. The extent and nature of these impacts requires evaluation during the early stages of project planning.

(8) Effects on migrating fish.

Many species of fish make annual migrations along rivers during the breeding season and the construction of dams inevitably impedes their progress. To date no dams in Kenya have been provided with fish ladders or bypasses and fish, especially in the Tana river are no longer able to move freely through the upper-middle reaches of the Tana. In future developments this aspect of construction should be properly addressed though thorough study is restricted by the lack of any recent data on river fisheries.

(9) Inundation of mineral resources.

The possibility that important and valuable mineral resources will become inaccessible due to inundation should be investigated and mitigation methods assessed.

(10) Other adverse inundation effects.

Impacts here include the loss of agricultural lands, forests, the endangering of wildlife in the area and the possibility of inducing earthquakes.

(11) Improved access across the river via the dam wall.

In many areas rivers present significant barriers to travellers where no bridges exist. The inclusion of an access road across the dam crest represents a significant social benefit to the local community. Such benefits could be gained at the Sondu-Miriu weir site and at the proposed Usueni, Adamsons Falls and Kora Rock sites on the Tana River.

(12) Impaired passage across the reservoir away from the dam site.

In contrast to the benefits obtained by a road across the dam the reservoir represents another potential hindrance to travellers. The provision of a ferry service as part of project planning would mitigate this problem if local conditions permit.

4.2.2 Problems from oversights in planning and design

(1) Road erosion.

A common environmental problem is the continuing erosion from exposed areas resulting from the construction of access roads without available provisions for resurfacing or regreening the exposed areas. In some areas of Machakos District, soil eroded from roads contributed the major portion of all sediment entering tributaries of the Athi River.

(2) Pre-impoundment reservoir site preparation.

Preparation normally consists of the removal of trees, bush and scrub which may interfere with the operation of the reservoir.

Clearance is usually carried out for three reasons:-

a. to harvest valuable standing timber for resale, and to salvage other wood for use as firewood or charcoal,

b. to remove vegetation which would decay under water which may lead to reduced levels of dissolved oxygen, and the release of plant nutrients which may cause eutrophication. To avoid these problems the vegetation must be cleared from the area not simply cut down. Burning of felled vegetation will greatly reduce the threat of deoxygenation and also that from eutrophication but to a lesser extent. However, the presence of nutrients in the water may also provide some benefits to the reservoir fishery since plant production will be stimulated the growth of some fish populations including 'tilapia'. On the other hand these same nutrients will also stimulate the growth of nuisance aquatic weeds which have caused serious environmental and management problems in several large man-made lakes in Africa in the past,

c. submerged trees which remain standing in the reservoir can interfere with fishing by snagging nets and entangling other fishing gears to the overall detriment of the fishery; in contrast these trees also provide refuges for fish and fertilize the water as they decay as described above.

In the long term if trees are not removed they will eventually decay and subsequently may be uprooted posing a potential danger to power station intake structures.

(3) Water use conflicts.

This involves a balancing of conflicting needs for the use of the water stored in the reservoir for hydropower generation, irrigation, flood control, water supply and compensation flows. In many instances the right of the downstream communities is given lower priority than that of the project while they rarely receive any direct benefit from the project. Conservation of the minimum flow in river courses is an important aspect carefully planned in any water development and river management works.

4.2.3 Problems during the construction stage

(1) Soil erosion and silt runoff.

Extensive erosion can and does occur around borrow pits, quarries, cut-and-fill areas due to a lack of adequate planning during construction, and a lack of resurfacing of regreening after construction is completed.

(2) Other construction phase hazards.

Many other hazards exist during the construction phase which affect the general environment, the construction work force and the local community. Some of these hazards are listed below;

* workers safety
* sanitation of construction camps
* water-related and faecal-oral diseases
* dust, noise, fumes etc.
* social pressures on local communities.