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GEOSPATIAL MAPPING AND ANALYSIS OF WATER AVAILABILITY-DEMAND-USE WITHIN THE MARA RIVER BASIN

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To my family and friends, for their continued support and encouragement.

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ABSRTACT OF THE THESIS

GEOSPATIAL MAPPING AND ANALYSIS OF WATER AVAILABILITY-DEMAND-USE WITHIN THE MARA RIVER BASIN

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Florida International University, 2007

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The purpose of this research is to quantify water use within the Mara River Basin, an international river basin between the bordering countries of Kenya and Tanzania in Eastern Africa. This thesis looks at various water-use factors that exist within the basin and quantifies the amount of water they require, subsequently comparing this use to existing records of water availability.

Hydrologic records, site interviews, population census data, and spatial datasets were used in combination with a geographic information system to manually and spatially determine water demand. Six water use factors were analyzed within the basin, including large-scale irrigation farms, human populations, livestock populations, wildlife populations, large-scale mining operations, and lodges and tent camps.

Results show that the total current water demand within the basin does not appear to eclipse water supply during periods of mean flow. However, the current water demand does pose a threat to water resources within the MRB during periods of minimum flow.

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LIST OF ACRONYMS

CBS	Central Bureau of Statistics
DRSRS	Department of Resource Survey and Remote Sensing
ESRI	Environmental Systems Research Institute
FAO	Food and Agriculture Organization of the United Nations
FIU	Florida International University
GCS	Geographic Coordinate System
GDP	Gross Domestic Product
GIS	Geographic Information System
GPS	Global Positioning System
ILRI	International Livestock Research Institute
KWS	Kenyan Wildlife Serivce
LPD	Liters per day
MMNR	Masai Mara National Reserve
MRB	Mara River Basin
NBS	National Bureau of Statistics
NMM	North Mara Mine
PDOP	Position dilution of precision
RCMRD	Regional Center for Mapping of Resources for Development
SNP	Serengeti National Park
TANAPA	Tanzania National Parks
UNCSD	United Nations Commission on Sustainable Development
UNEP	United Nations Environment Program
UNESCO	United Nations Educational, Scientific, and Cultural Organization

UNPFA	United Nations Population Fund
URT	United Republic of Tanzania
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
WGS	World Geodetic System
WHO	World Health Organization
WRMA	Water Resource Management Authority
WSRB	Water Services Regulatory Board
WWF	World Wildlife Fund

1. INTRODUCTION

1.1 Background

It is no secret that fresh water shortages will plague the earth in the near future. Signs of over-exploited water resources are already vividly apparent in many areas of the world and will only worsen if current consumption and use patterns are not modified and adapted. The Mara River Basin (MRB), a part of the larger Nile River Basin, is one such area where water resources are an ongoing concern. The Mara River is an international river which flows between the bordering countries of Kenya and Tanzania. The Mara River Basin covers approximately 13,750 km , sixty-five percent of which is located within Kenyan territory and the remaining thirty-five percent within Tanzania. Growing water demands and unsustainable use of natural resources in the region is placing an increasing strain on the hydrology of the basin, threatening the livelihood of the many populations that rely on the Mara River as their sole source of water.

Water quantity is a major concern within the Mara River Basin, especially during the dry season when the threat of drought is high. Sustaining escalating water demands of the growing population within the basin, as well as meeting the requirements of the Mara-Serengeti ecosystem, is vital to the region. Flora and fauna that populate the Masai Mara National Reserve (MMNR) and the Serengeti National Park (SNP) rely on the Mara River for survival, for it is the only perennial river in the lower portion of the basin.

In addition to human and wildlife demands for water, livestock populations and pressures from large-scale irrigation farming are also placing mounting strain on the river. Water demands from numerous lodges within and around the MMNR and large-scale mining activities in the southern portion of the basin add to the long list of water needs. Moreover, uncontrolled and illegal abstractions are also of concern.

A dependable supply of fresh water is key in achieving sustainability. Water not only supports life, but serves as a foundation for economic development and policy implementation. Without enough water, health initiatives, poverty reduction strategies and environmental initiatives will be negligible. Kenya is already deemed to be in a 'water stressed' condition (1000-1700 m of water per person per year) and is predicted to reach 'water scare' status (less than 1000 m of water per person per year) in less than 25 years. Furthermore, the United Nations projects that Tanzania will become a 'water stressed' nation by 2025 (UNPFA, 2003 and UNEP, 2002).

1.2 Hydrology

The Mara River Basin is an important hydrologic system that not only serves the bordering countries of Kenya and Tanzania, but also exists as a valuable input to Lake Victoria, the world's second largest freshwater lake which forms the headwaters of the Nile River. The Mara River originates in the Mau Escarpment in Kenya's Nakuru District and flows approximately 400 km through the districts of Bomet, Narok and Transmara before crossing borders into Tanzania where the river flows through the administrative districts of Tarime, Serengeti and Musoma. On the Kenyan side of the basin, the Mara River flows through the MMNR and then enters Tanzania through the SNP before ending at Lake Victoria. The Mara River begins at an elevation of approximately 3,000 meters and drops to an elevation just over 1,110 meters (Krhoda, 2001).

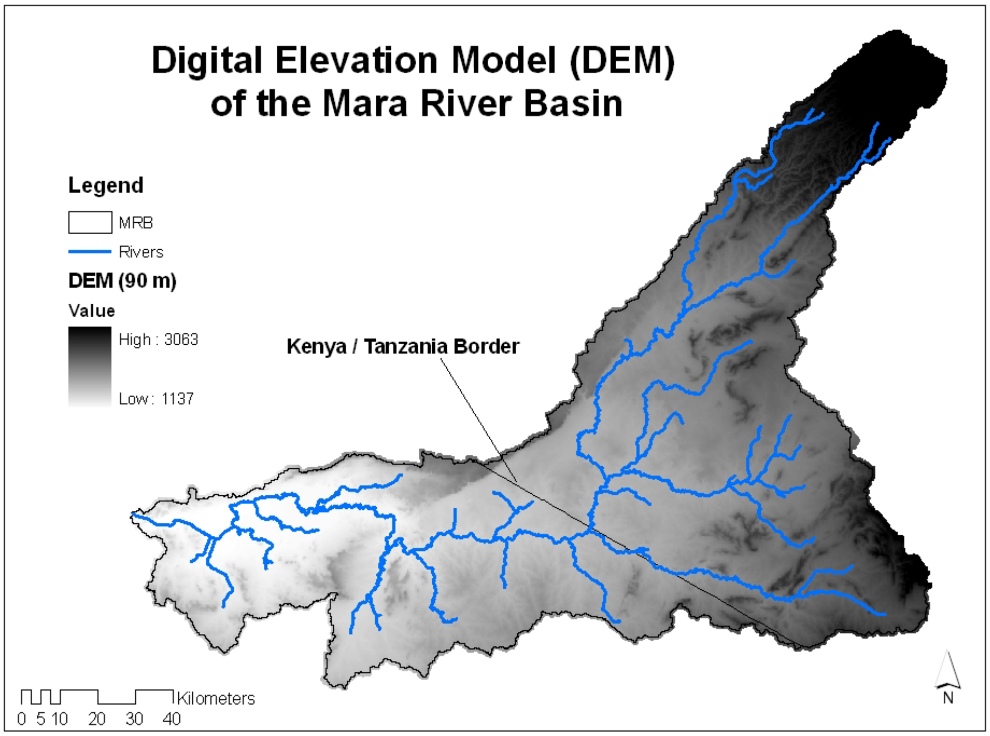

Figure 1: Digital elevation model of the Mara River Basin

The Mara River is feed by several dominant tributaries as shown in Figure 2. The two main perennial tributaries are the Amala and Nyangores Rivers which originate in the Mau Escarpment and flow southwest. Other main tributaries of the Mara River include the Engare Ngobit, Talek and Sand Rivers. Both the Talek and Sand Rivers originate from the Loita Hills and drain the Sannia and Loita Plains, a major dry season grazing and watering area for both livestock and wildlife.

In this lower portion of the basin, the Mara River is the only perennial river flowing during the dry season, making it vital in supporting riparian communities and wildlife, including those of both the Serengeti National Park and Masai Mara National Reserve. During the dry season, other water sources in the lower portion of the basin dry up and form shallow, stagnant pools of water, which in a drought year can disappear completely (Gereta, et al, 2002). While there is no universally accepted definition for a drought, it can generally be defined as, "a condition of moisture deficit sufficient to have an adverse effect on vegetation, animals, and man over a sizeable area." (Langbein and Iseri, 1995). Severe droughts within the MRB are estimated to occur once every seven years, but can occur at other times as well (Gereta, et al, 2002).

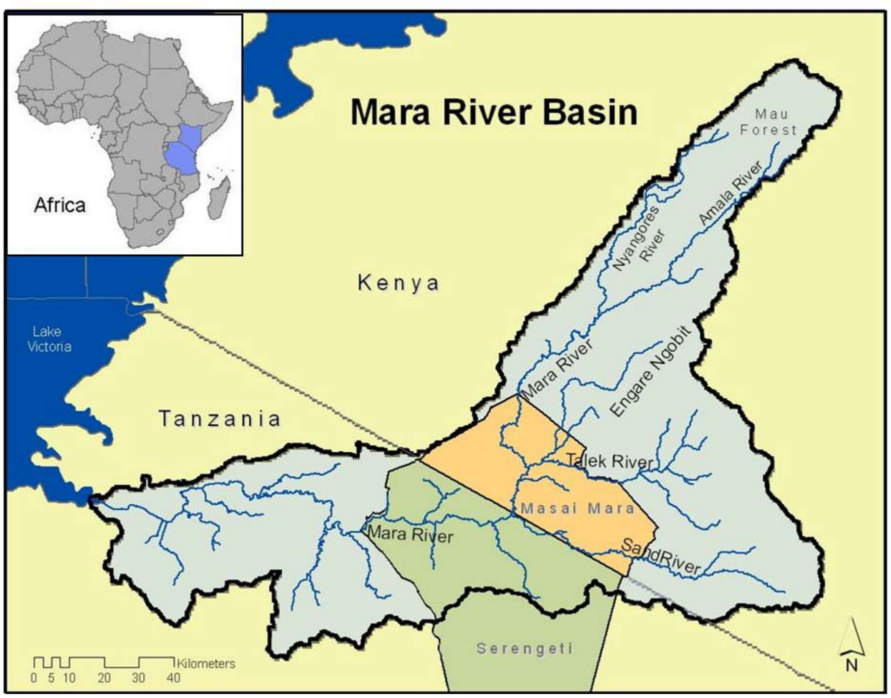

Figure 2: Mara River and its main tributaries: the Amala River, Nyangores River, Engare Ngobit River, Talek River, and Sand River.

The MRB has both a short and long rainy season, which can exist from September to December and from mid-March to June (with a peak in April), respectfully. Rains falter between June and October, as well as from December to January, making these months the dry seasons within the basin (Krhoda, 2001). The graphs in Figure 3 show maximum temperatures within the Kenyan portion of the MRB while Figures 5 through 10 show rainfall patterns within the MRB. Furthermore, Figure 4 depicts the locations of select weather stations in the MRB.

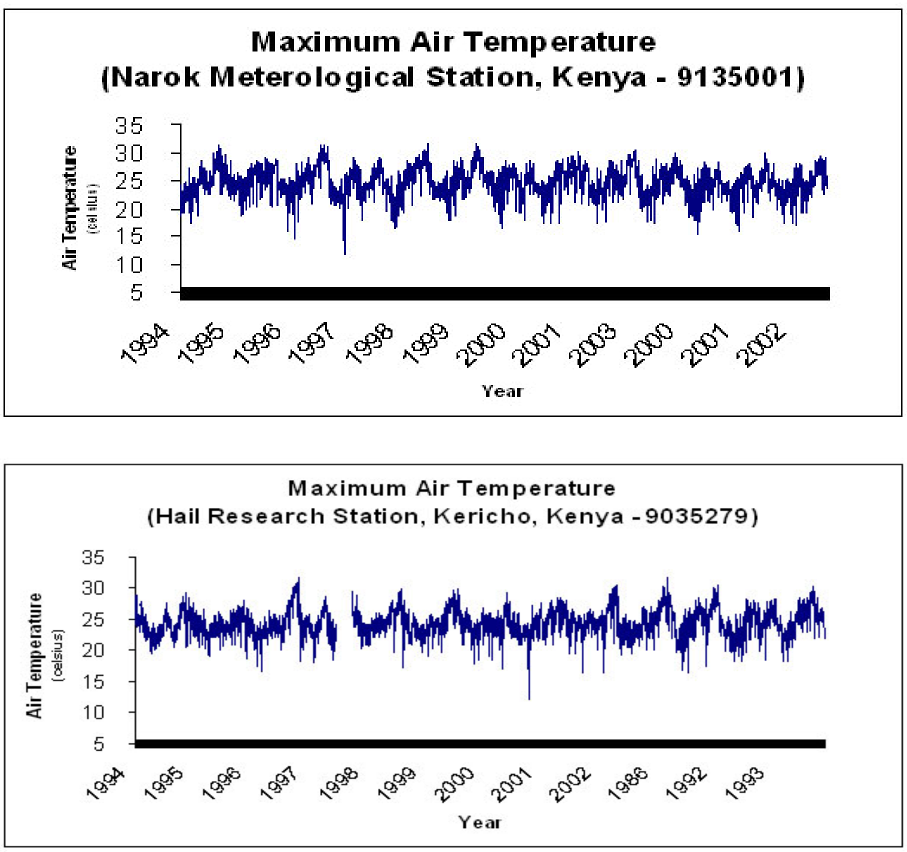

Figure 3: Maximum air temperatures at Narok Meteorological Station and Hail Research Station, Kenya

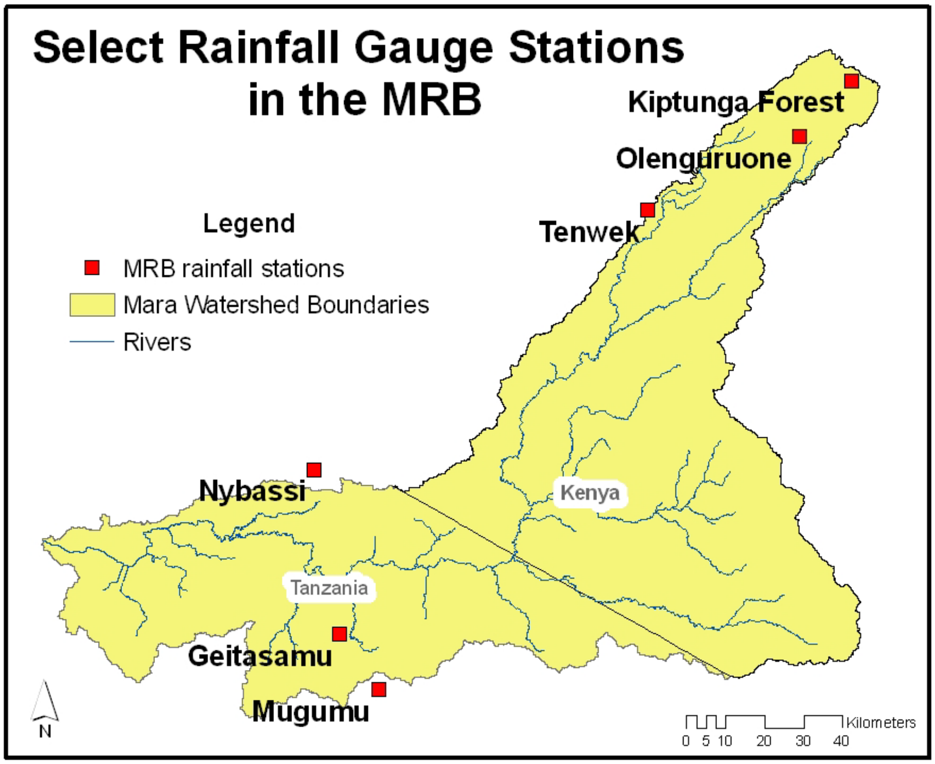

Figure 4: Locations of select weather stations in and around the Mara River Basin

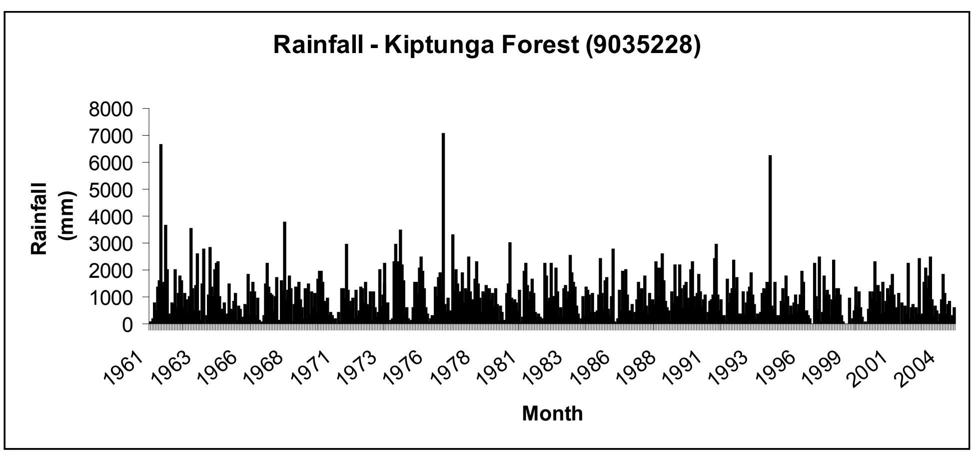

Figure 5: Monthly rainfall from 1961 to 2004 at Kiptunga Forest Station, Kenya.

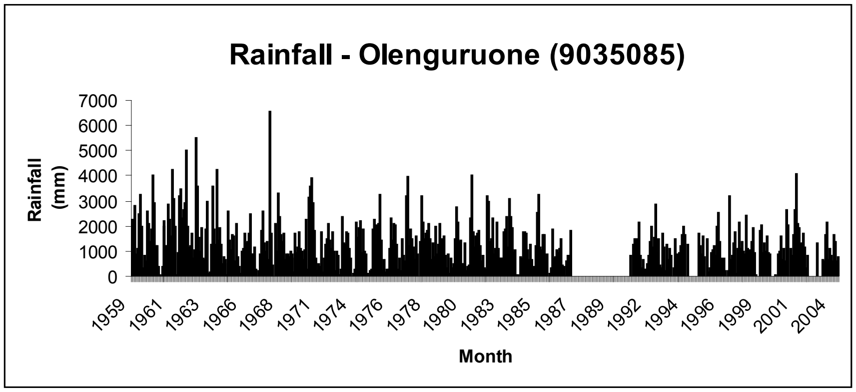

Figure 6: Monthly rainfall from 1959 to 2004 at Olenguruone Station, Kenya.

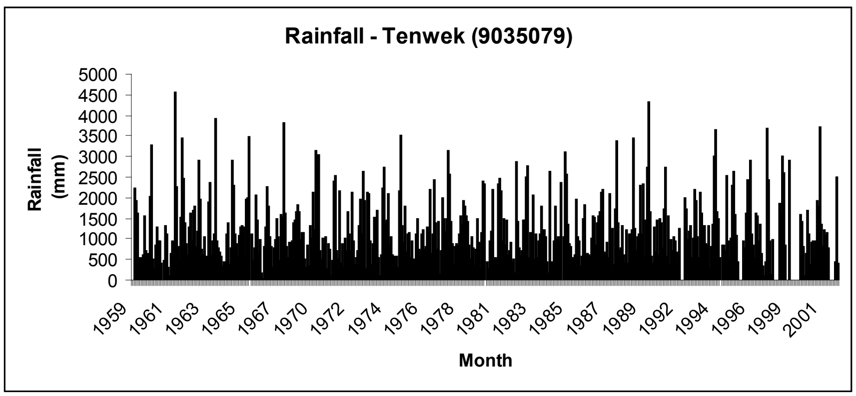

Figure 7: Monthly rainfall from 1959 to 2001 at Tenwek Station, Kenya.

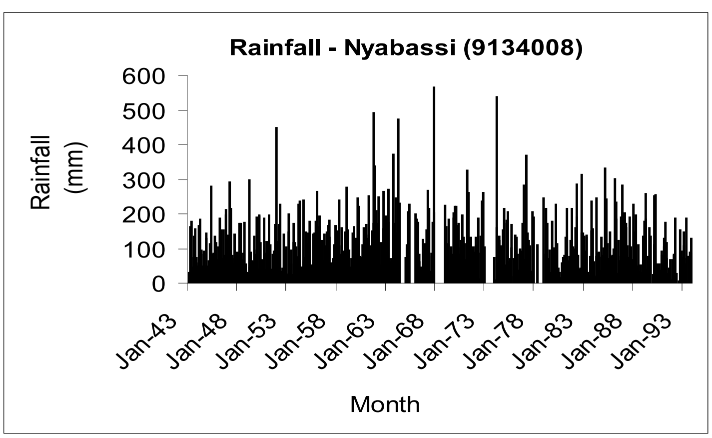

Figure 8: Monthly rainfall from 1943 to 1993 at Nyabassi Station, Tanzania.

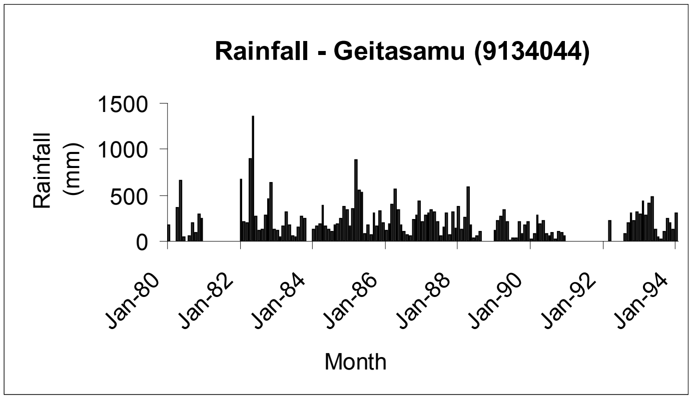

Figure 9: Monthly rainfall from 1980 to 1994 at Geitasamu Station, Tanzania.

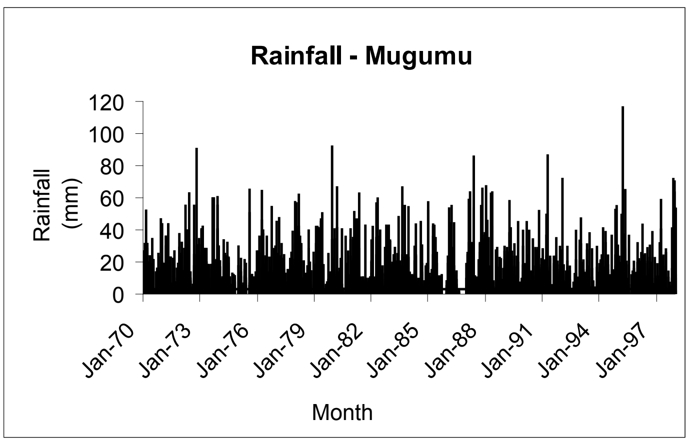

Figure 10: Monthly rainfall from 1970 to 1997 at Mugumu Station, Tanzania.

In Kenya, the mean annual rainfall in the upper portion of the basin (the Mau Escarpment) averages between 1,000 and 1,750 mm, while mean rainfall in the southern portion is between 300 and 800 mm per year. The rainfall in the northern and western portions receives the most rain, which ranges from 1,200 to 1,800 mm per year (Krhoda, 2001). In Tanzania, the district of Tarime and a portion of the Serengeti district receive a proportionately larger amount of rain than their surrounding areas due to higher elevations, receiving between 1,250 mm and 2,000 mm annually. Much of the Musoma district and the eastern parts of Serengeti receive annual rainfall ranging from 900 mm to 1,300 mm per year (Yanda and Majule, 2004).

The Mara River contributes approximately five percent of the total amount of water that flows into Lake Victoria; however, it is probably one of the most important rivers in regards to conservation for it supports both the MMNR and SNP (Nile Basin Initiative, 2004).

1.3 Land Use and Land Cover

The Mara River Basin is made up of a diverse landscape. The Mau Forest exists in the northernmost portion of the basin, where the Amala and Nyangores catchments are located. Small-scale farming is prevalent within this region and encroachment on protected land is common. Gereta et al (2002) used satellite images to conclude that forest cover in this region decreased from 752 km in 1973 to 650 km in 1985 and then to 493 km in 2000.

Large-scale tea plantations are found just south of the forested area in combination with small-scale farms and human settlements. Urban settlements within this region include the town of Bomet, the Tenwek Missionary Hospital Community, and the Mulot Trading Center. Continuing south, large-scale mechanized agriculture, and a small number of private irrigation farms, are found in the region where the Nyangores and Amala Rivers merge to form the Mara River. Land within this region is increasingly being converted for agricultural use and human settlement (Ottichilo et al, 2000). Group ranches surround the outskirts of the MMNR which borders the Serengeti National Park in Tanzania. Land cover within the parks range from savannah grasslands to taller stands of grass (in areas with more moisture) to areas covered by *Acacia* woodland (Krhoda, 2001). As the basin nears Lake Victoria, the landscape changes to swampland, which is referred to as the Mara Swamp. Urban settlements located within the Tanzanian portion of the basin include Buhemba, Ngoreme and a portion of Mugomo.

Research on land use activity within the Mara River Basin shows that extensive change has occurred. For example, Serneels et al (2001) utilized Landsat images to show that between 1975 and 1985, an additional 11,000 ha land was converted to large-scale wheat farming in the Loita plains, north of the MMNR. Furthermore, the Landsat images also showed that as of 1995 an additional 33,000 ha had been converted for large-scale farming. Even after this conversion, Onjala (2004) estimated that only twenty-eight percent of available arable land was under agricultural production in the MRB.

1.4 Resource Degradation

Currently, a number of factors contribute to the degradation of the Mara River Basin. Deforestation, changing land-use patterns, increased human population and poor management of water abstractions and wastewater in both Kenya and Tanzania are threatening sustainability. Deforestation in the Mau Escarpment is being caused by human population increase, small-scale agricultural expansion and timber collection for fuel and construction materials. These factors, in combination with poor soil conservation efforts and overgrazing of livestock, result in increased erosion throughout the region.

The types and distribution of soils in the MRB is varied depending on the topography. In areas of higher elevations, the soil types range from mountains rich with shallow layers of volcanic soils to shallow but well-drained dark reddish-brown soils on the hills and minor escarpments (Krhoda, 2001). The later soil type is prone to sheet erosion, which is an escalating concern as population increases push farmers to develop this fragile soil. Furthermore, the basin also includes areas of reddish-brown sandy soils and the darker clayey soils which are poorly drained yet heavily leached (Krhoda, 2001).

Soil erosion and run-off have been associated with sediment build-up at the mouth of the river, increased turbidity which harms aquatic life, decreased soil fertility, and contamination of the river due to releases of pesticides and pollutants into the water system (Mati, et al, 2005). Moreover, increased inputs of fertilizers, such as nitrogen and phosphorus, augment the threat of eutrophication (Muir, 2007). Furthermore, unsustainable mining practices in the southern portion of the basin threaten water quality, mainly from small-scale miners who use mercury in the mining process.

In addition to water quality, water quantity is also an ongoing battle. Water users within the basin abstract water directly from the river or from boreholes. Unfortunately, the water abstraction system within the basin is poorly planned, causing abstractions to occur in an uncontrolled manner and often times without permits.

It is during the dry season when the most strain is placed on the water resources of the basin, for water is needed for irrigation, for watering livestock, and to support mining operations and hotel facilities. Moreover, it is during this time when over 1 million wildebeest, 300,000 zebras, and 300,000 Thomson gazelles migrate to the northern region of the Serengeti National Park and to the Masai Mara Reserve where the Mara River serves as their dry season refuge (Wolanski et al, 1999). This phenomenon, also known as the annual migration, is dependant on reliable and sufficient dry season flow from the Mara River, which not only serves as a vital source of water but also sustains vegetation needed for grazing (Serneels and Lambin, 2001).

With continuing and inevitable increases in human population growth, irrigation farming, mining and tourism, the need for water within the Mara River Basin can only rise. The degrees to which these increases will affect the hydrology of the Mara River Basin need to be determined.

1.5 National Water Policy

Historically, both Kenya and Tanzania have addressed water management issues in a highly centralized fashion, from central government ministries, which have had little concern with water policies of neighboring countries (Nile Basin Initiative Project, 2004). However, in recent years, both Kenya and Tanzania have introduced new National Water Policies which move in the direction of decentralizing water resources management. This decentralization has come in the form of increased focus on management at more localized levels, the introduction of transboundary cooperation in water management initiatives, and increased participation from water users in management decisions. Furthermore, management at both the catchment and basin levels has been incorporated into both Kenyan and Tanzanian National Water Policies as well as the concept that water is an economic good.

1.5.1 National Water Policy - Kenya

In Kenya, the Water Act of 2002 is one of the major policy frameworks put into place by the Ministry of Water and Irrigation to aid in water reforms taking place within the country. The Water Act of 2002 outlines the fundamental objectives for managing Kenya's water resources and identifies the National Water Resource Management Strategy as one of the main instruments in defining the country's approach. As an institution, the Water Resource Management Authority (WRMA) has developed the 'Rules to Govern Water Resource Management in Kenya' in order to meet its roles and responsibilities. While the Ministry of Water and Irrigation is responsible for the development of legislation and policy formation, the WRMA is tasked with planning, management, protection and conservation. Additionally, the WRMA is also responsible for the issuance of water permits and the enforcement of their conditions, regulation of abstraction structures, and regulation of water use (NWRMA, 2006). Institutional bodies set up under the WRMA include Catchment Area Advisory Committees and Water Resource Users Associations which advise on water resources at the catchment level and serve to localize participation in water management issues, respectively.

One of the new arrangements under the Water Act of 2002 is the separation in management of water resources and water and sewerage services. As a result, the Water Services Regulatory Board (WSRB) was created. Unlike the WRMA, which has control over water resources, the WSRB is responsible for water and sewerage services. Efforts under this sector include a movement towards the commercialization of water supply services, especially in urban areas (NWRMA, 2006).

1.5.2 National Water Policy - Tanzania

As in Kenya, the water sector in Tanzania is in a transitional period. Traditional management strategy that was originally based on administrative borders is now moving towards management initiatives based on water catchment areas, as guided by the National Water Policy of 2002. This policy was developed by the United Republic of Tanzania under the Ministry and Water and Livestock Development. However, water resources within the country will continue to be managed at the national level under the Ministry of Water and Livestock Development.

Under the new organization, nine river basins have been identified for management initiatives at the basin level. The Mara River is to be managed by the Lake Victoria Basin Water Office located in Mwanza, which will also consist of a Basin Water Board. This Board will be made up of ten members appointed by the Minister of Water and Livestock Development and will be representative of various stakeholders. It is at this level where applications for water abstraction permits will be reviewed and decided (Tanzania Ministry of Water and Livestock Development, 2002)

A sub-basin level has also been created, further decentralizing management. The Mara River is subject to the Mara Sub-Catchment Water Office located in Musoma, which is also where the Mara Catchment Water Committee resides. The Mara Sub-Catchment Water Office is then further divided by districts, which still incorporate the Districts of Musoma Rural, Tarmine, and Serengeti. At each of the district levels, the goal of the National Water Policy of 2002 is to establish water user's associations where stakeholders can play a role in the management of water resources (Tanzania Ministry of Water and Livestock Development, 2002).

1.6 Research Questions

The Mara River Basin draws much attention from researchers due to the vast biodiversity and ecological significance associated with both the MMNR and the SNP. However, much of the research that has been conducted in relation to water deals with issues of water quality rather than issues of water quantity. Limited studies have been conducted on water quantity but are either dated, very general in scope, or consist of different study areas. Furthermore, there have been no studies to date that have attempted to quantify the total cumulative water-demand placed on the MRB from the various users that exist within the system.

While such an analysis has yet to be conducted, this does not serve as an indication that it is not needed. In taking a closer look at the current situation of the Mara River Basin, it seems quite clear that water quantity use and demand require further study.

The aim of this research is to calculate the cumulative demand of water need in the Mara River Basin based on current water uses and to then compare the cumulative demand of water need in the MRB to records of water availability. In order to accomplish these goals, the following research questions were asked:

1. What is the current hydrologic situation in the MRB? What factors are contributing to the growing water demand in the basin (i.e. agriculture, industry, increasing populations, etc.)?
2. What are the water-use factors that exist within the MRB? How do these factors play a role in the hydrology of the MRB?
3. What is the cumulative demand of water need in the MRB, based on current uses?
4. How does the cumulative demand of water need in the MRB compare to records of water-availability within the basin?

1.7 Goals and Objectives

This project aims to produce a better overall understanding of the water availability that exists within the Mara River Basin as well as the demand that is currently being placed on its rivers. Through the use of a Geographic Information System (GIS) and hydrologic data, water demand and supply can be analyzed and compared to allow for a better understanding of the overall hydrology of the Mara River Basin. The use of GIS will assist in providing an overall picture of what the water demand-use is in the area, while the hydrologic data will provide insight into the water supply of the MRB. Water availability data will allow for a better answer to the question of whether or not there is "enough" water in the basin to meet all of its current and expanding demands.

In order to achieve the above goals, the following objectives were designed.

1. Investigate the current situation within the MRB by looking at how degradation is affecting the water resources of the basin.
2. Map relevant water-demand factors within the MRB.
3. Estimate the cumulative demand of water need in the MRB based on both current and future use.
4. Determine how the cumulative demand of water need in the MRB (current and future) compare to water availability within the basin.

2. LITERATURE REVIEW

2.1 Hydrologic Cycle

The hydrologic cycle is a continuous cycle that describes the movement of water in the environment as it transforms between various states of liquid, vapor and ice. Water is in constant motion with no specific beginning or ending point but rather a revolving circulation. The sun heats water stored in oceans, lakes, streams and soil causing it to evaporate as vapor into the air. Studies show that the oceans, seas, and other bodies of water (lakes, rivers, streams) provide nearly ninety percent of the moisture in the atmosphere while the remaining ten percent of the moisture found in the atmosphere is released by plants through transpiration (Graham, et al, 2006). Furthermore, sublimation takes place which is the process of ice and snow transforming directly into water vapor without first melting into water. As vapor from these processes rise into the atmosphere, cooler temperatures cause the vapor to condense into clouds which are moved around the globe by air currents. Precipitation in turn, brings water back to the earth's surface in the form of snow or rain. Gravitational flow of water causes water to move over the landscape. Some of this water is discharged back into rivers where it will eventually make its way back to the ocean and some of the water will enter into lakes. Additionally, a portion of the water will penetrate into the ground as infiltration, either staying close to the surface or penetrating deep beneath to surface to recharge aquifers. Infiltration that remains nearer the surface can make its way back to surface water bodies in the form of ground-water discharge or can emerge as a springs.

In dealing with issues of water quantity associated with watersheds, it is essential to have a solid understanding of the hydrologic cycle. The natural water circulation system must be considered in relation to, and in addition to, the anthropogenic actions that also impact the hydrologic cycle. With specific attention being placed on the Mara River Basin, such anthropogenic factors include changes in the landscape through agricultural expansion and deforestation, as well as from water abstractions from the rivers and underground aquifers. Changes in the landscape from agricultural expansion and overgrazing of livestock can facilitate increased surface runoff, less water infiltration, and increased evapotranspiration. Furthermore, water abstractions and boreholes remove water from the natural system, potentially affecting recharge rates and overall flow patterns. Since the hydrologic cycle is a revolving cycle, each individual action has the potential to impact the entire system to some degree, whether it is small or substantial. All of these scenarios further the possibility of decreased river flows, which could be devastating to the system, especially during the dry season.

2.2 Water Supply in the Mara River Basin

Rainfall is the main driving force that supports life within the MRB. However, rainfall within the basin is erratic, varying across seasons as well as annually. During dry periods, insufficient rainfall places strain on the hydrology of the basin. It is estimated that droughts occur every seven years within the MRB, although variations to this are quite possible (Gereta et al, 2002). Droughts are a contributing factor to the loss of livestock as well as to decreases in the vast array of wildlife that migrates through the Mara-Serengeti ecosystem. Ecohydrological modeling predicts that in a period of severe drought, wildebeest populations could drop eighty percent and potentially not recover (Gereta et al, 2002). Needless to say, this would have devastating effects on the conservation areas that exist within the basin and the income they provide to the area through tourism. For example, a severe drought in 1993 was responsible for the death of over 400,000 wildebeest (Gereta, et al, 2003). Furthermore, the 1999/2000 drought resulted in large mortality rates of both livestock and wildlife in the Narok district of Kenya (UNEP, 2002).

2.2.1 Water Resources within the Mara River Basin

There are several sources of water in the MRB, the dominant of which lies in the Mara River and its tributaries. According to household surveys conducted within the MRB, sixty-two percent of households use water from the Mara River for both their domestic and livestock use (Aboud, 2002). Other water sources include springs, rainwater, wells, and boreholes. In the case of microcatchments, the extent to which they are utilized within the MRB is not well known. However, water harvested into micro catchments is commonly used for small-scale irrigation, livestock drinking and domestic use (Yanda and Majule, 2004).

Large-scale operations that exist within the MRB, such as irrigation, mining, and high-end tourist facilities, have the technology and financial capabilities to extract water from the river via mechanized pumps. However, the majority of the population relies on watering cans, small furrow canals and small powered water pumps to draw water from the river. If the water level in the river drops low enough, water cannot be obtained through any of these techniques and the dependants must collect their water manually.

2.2.2 Water Quantity within the Mara River Basin

While a large amount of research is conducted within the Masai Mara – Serengeti ecosystem, studies involving water quantity issues within and/or around the MRB are limited in number and are concentrated within fields with little overlap between the different water-use sectors. Gereta et al. (2002), for example, uses an ecohydrological model to look at the impact of deforestation, irrigation and the previously proposed Amala Weir Water Diversion Project in Kenya on the Serengeti ecosystem, focusing on subsequent wildlife loss. The nature of this study looks at select water use factors only within Kenya and is not inclusive of the entire basin. Another study by Onjala (2004) looks at irrigation potential, current irrigation schemes and livestock water demand in the context of developing a gross marginal analysis of crop cultivation in the MRB. This study highlights irrigation and livestock demand within the Mara River Basin but due to the scope of the paper does not consider other water-use factors. An additional study conducted by Mati, et al (2005), provides a comprehensive assessment of water availability in the drought-prone Isiolo District, Kenya, with attention on human and livestock water demand. However, the Isiolo District exists beyond the borders of the MRB. Furthermore, the 1992 Study on the National Water Plan (MoWD and JICA 1992b) looks at the annual water demand of Kenyan households, agriculture, and industry compared to the country's potential annual water supply (WRI, 2007). While this study provides an in-depth overview for Kenya, the study is not sufficient in analyzing the current water demand within the MRB because it only looks at the Kenyan portion of the MRB, does not incorporate the full array of water demand factors existing within the MRB, and was published several years ago (1992). Consequently, the conclusion can be drawn that an inclusive quantitative analysis of water demand-use and availability within the Mara River Basin has yet to be developed.

2.2.3 Water Demand Factors within the Mara River Basin

2.2.3.1 Human Population

The human population is multiplying in all areas of the MRB. In Kenya, the total population for the districts containing the MRB (Nakuru, Bomet, Transmara, and Narok) is 2,106,174 as of the 1999 census with predictions of a population increase to 2,739,233 for the year 2010 (Kenya NBS, 2006) as illustrated in Figure 11. The projected combined annual population growth rate for Nakuru, Bomet, Narok and Trans Mara is 2.4 percent for the period from 1999-2010 (Kenya NBS, 2006).

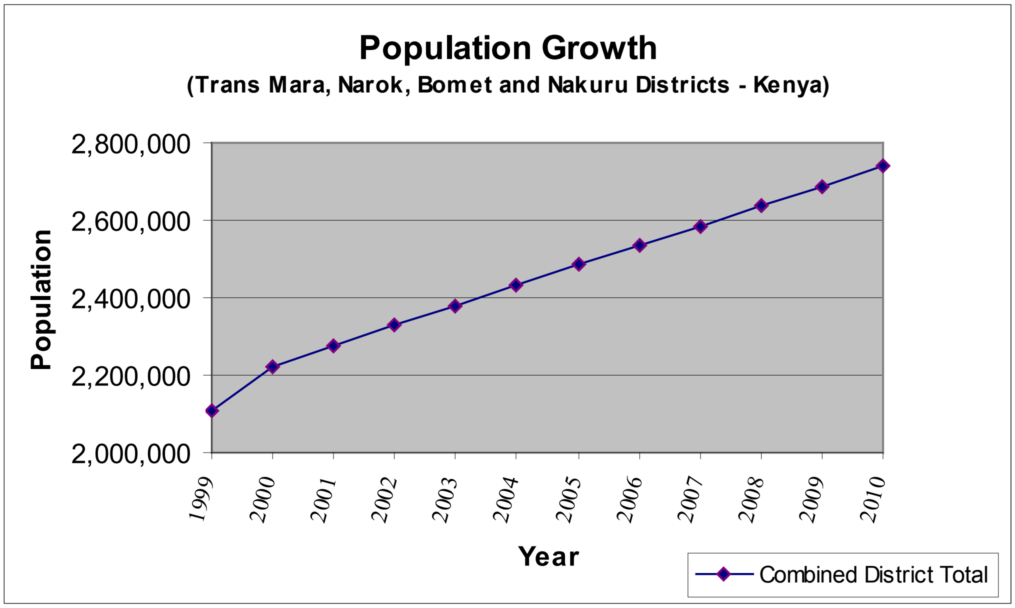

Figure 11: Predicted population growth from 1999 to 2010 for the four Kenyan districts making up the Kenyan portion of the MRB.

Source: Kenya National Bureau of Statistics, 2006.

Population within the Mara Region of Tanzania, which includes Tarime, Serengeti and Musoma districts, stood at 1,363,397 people for the 2002 census with a population growth rate of 2.5 percent (Tanzania NBS, 2005 and Tanzania NBS, 2003). The population for the Mara Region is projected to reach 1,666,169 people in the year 2010, as depicted in Figure 12 (Tanzania NBS, 2005 and Tanzania NBS, 2003).

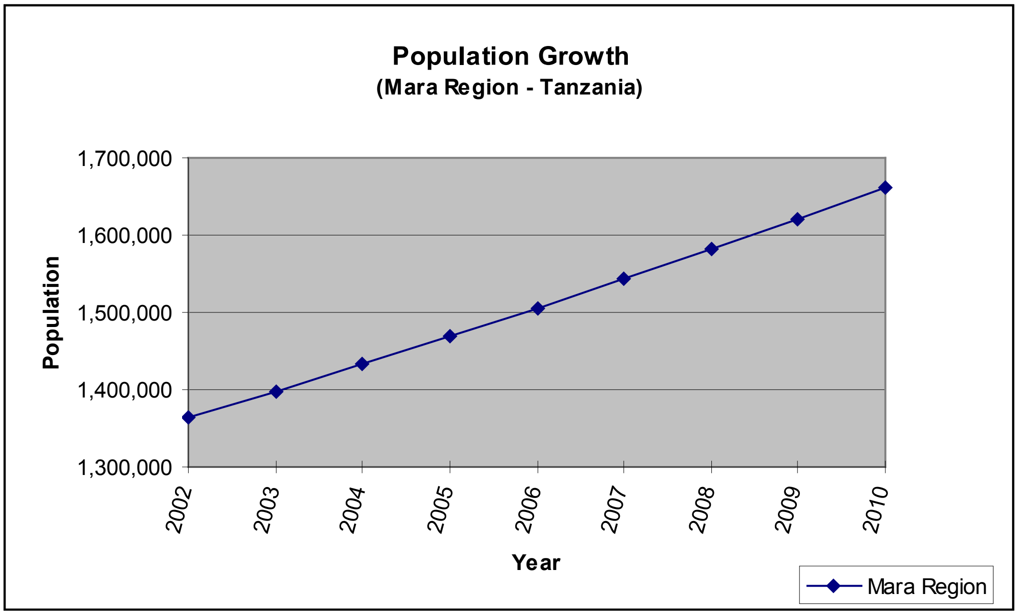

Figure 12: Predicted population growth for the Mara Region of Tanzania from 2002 to 2010.

Source: Tanzania National Bureau of Statistics, 2005

Human water use is affected by several factors. Ignoring environmental limitations, human water use is affected by the cost of water, the relative wealth of the family, the number of people in a household, and the proportion of children in a household. Furthermore, human water use also varies depending on whether or not the household is piped or unpiped. For piped households water use depends on the number of service hours that make water available, and in the case of un-piped households, water use depends on the location of the water source (Wong, et al, 2005). Research shows that people in an urban population tend to use approximately twice as much water as rural residents, and households with piped connections (mostly in urban areas) use, on average, three times more water than unpiped households (Katui-Katua, 2004). Piped water is often considered a privilege of the more affluent in urban area (WRI, 2007). Therefore, in looking at the dynamics of a population, one major consideration mandating water use and availability would be whether the population is in a rural or urban area.

According to the 2002 Tanzanian Population and Housing Statistics and the 1999 Kenyan Population and Housing Census, the vast majority of towns and villages that exist within the MRB are classified as rural areas. While there are a few community water schemes throughout the Basin that provide piped water to higher class housing areas, the majority of the population within the MRB relies on manual methods of retrieving water from the source. For example, in most rural areas of Kenya, people obtain their drinking water from untreated surface water, groundwater, or a combination of surface and groundwater (WRI, 2007). Water obtained in this manner must be carried by hand or with the assistance of domestic animals (i.e. donkeys) back to the village or location of inhabitance. Often times, rural water use takes place at the water source, where bathing, washing and even drinking are common practices. According to a household survey of 124 randomly selected households located on or near the Mara River sixty-five percent carry water away from the source and use it elsewhere, while nineteen percent of the households use the water at the riverbanks (Aboud, 2002). Furthermore, results from this household survey found that sixty-two percent of the households rely on water from the Mara River, twenty-six percent use springs, nineteen percent rainwater, fifteen percent wells, seven percent boreholes, four percent dams, and two percent swamps.

A study conducted in the Mwanza region of Northern Tanzania found that distances traveled to obtained water could equate to a four or five kilometer walk to the source for some villagers (Zaba and Madlu, 1998). Furthermore, a study conducted in the Isiolo district in Kenya suggested the maximum roundtrip travel distance to a water source is ten kilometers in drought conditions (Mati, et al, 2006). However, it is important to note that distances traveled to the water source vary with season and location, for many sources of water, such as small streams and tributaries as well as shallow ponds and wells, are likely to disappear during the season making is necessary to travel to alternative water sources.

With a large percentage of the population in both Kenya and Tanzania already lacking adequate access to safe water, increasing human populations will only add to the water challenge. According to the World Health Organization (WHO), only sixty-two percent of the rural population in Tanzania and forty-six percent of the rural population in Kenya have access to safe drinking water (Gleick, 2006). Furthermore, barely sixty-five percent of urban and forty-three percent of rural residents in Tanzania have access to potable water within 400 meters (UNCSD, 1997).

2.2.3.2 Livestock

Livestock production is a major source of income throughout the MRB, providing both employment opportunities and food supply to its inhabitants, as well as serving important social and cultural values that exist within the basin. Livestock rearing is the second most important contributor to the economy behind agriculture, and consists mainly of rearing cattle, goat, and sheep (Yanda and Majule, 2004). Furthermore, it is estimated that more than two-thirds of the MRB is rangeland (Onjala, 2004).

Livestock rearing is undertaken as small and middle scale enterprise in the upper portions of the basin while activity in the mid region is more closely associated with extensive ranching enterprises (see Figure 13). Small and middle scale livestock rearing consists of pastoral herdsman, like the local Massai tribesman, who herd their cattle based on environmental conditions, in search of both adequate grazing grounds and water supplies.

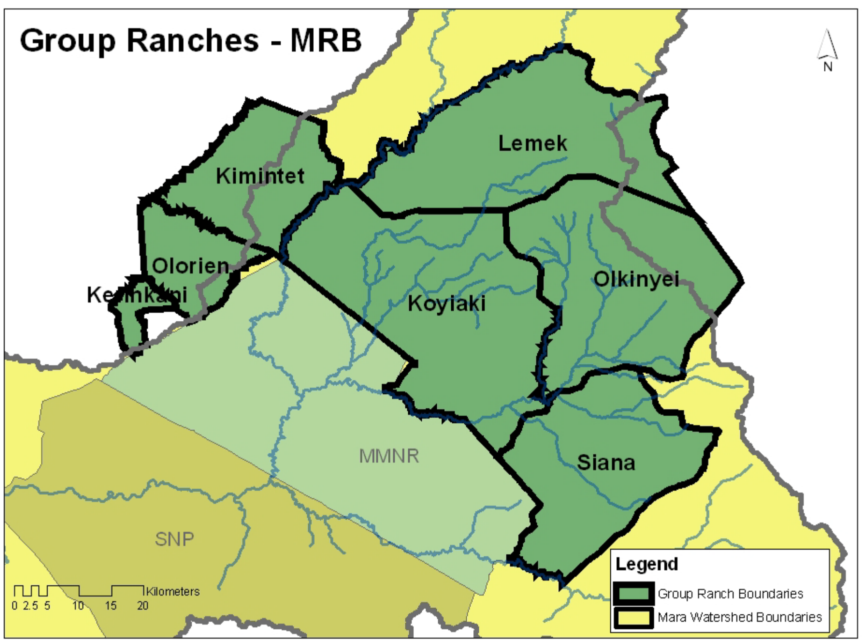

Figure 13: Group ranch boundaries within the MRB

Most of the livestock kept in the MRB is grazed in the floodplain of the Mara River in the dry season and grazed in the uplands during the rainy season (Yanda and Majule, 2004). One of the major issues with livestock in the basin is that there is no proper land allocated for their grazing. Furthermore, dry season conflicts can arise when there is insufficient water to support livestock, requiring herders to travel to distant locations to find water. Increases in clashes over land rights and livestock-wildlife conflicts are augmented as well as the potential for disease due to low river levels which force cattle are to walk into the river for water (Penden, 2004 and WRI, 2007).

Livestock population trends show that in the Mara Region of Tanzania, both cattle and goat populations have increased according to 1984, 1998 and 2000 census numbers, while the sheep population for the same periods has slightly declined as seen in Figure 14 (Yanda and Majule, 2004). It is estimated that twenty percent of Tanzania's livestock population lives in the lower portion of the Mara River Basin, including 2.1 million head of cattle, sheep and goats (Nile Basin Initiative, 2004).

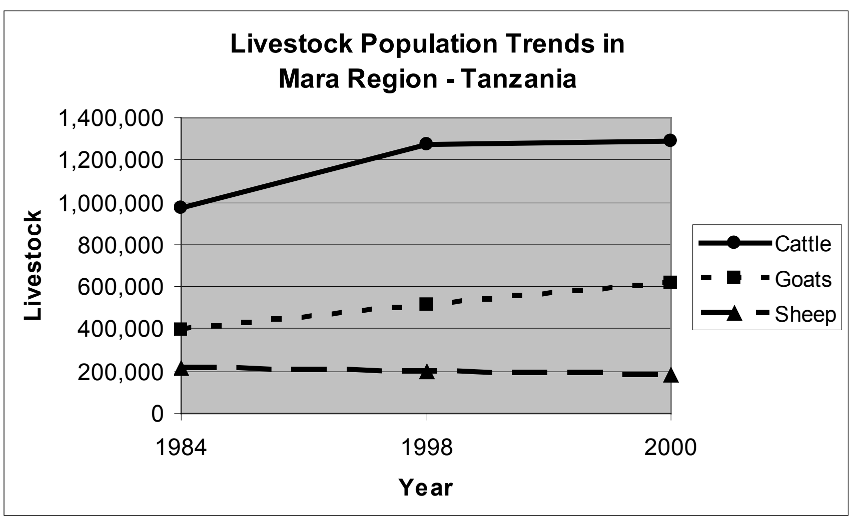

Figure 14: Livestock population trends in Mara Region, Tanzania from 1984 to 2000.

Source: Yanda and Majule, 2004

Unlike the Tanzanian portion of the MRB, livestock population trends within the Kenyan portion of the basin did not follow this overall increasing trend. In a study on wildlife and livestock populations in the Masai Mara ecosystem (the MMNR and adjoining group ranches), Ottichilo et al (2000) find that cattle populations either declined or remained stable from the period of 1977 to 1997. For the same period, sheep and goat populations did not significantly increase or decline but the donkey population declined by approximately sixty-seven percent.

Based on a 1992 study by the Japan International Cooperation Agency, the livestock water demand in the Kenyan portion of the Mara River catchment was estimated to be 159.11 m /year in 1990, with predictions of 190.31 m /year in 2000 and 227.68 m /year in 2010 (Krhoda, 2001).

2.2.3.3 Wildlife

Wildlife is the backbone for tourism within the Mara River Basin and the annual migration is one of the magnificent spectacles that fuel this industry. As the world's largest migration of mammals, people travel from all areas of the globe to witness the annual trek of over 1 million wildebeest, Thompson Gazelles, and zebras, as well as the 3,000 lions that prey upon these species, to their dry season refuge in the northern part of the SNP and the MMNR (Wolanski et al, 1999). Much of the wildlife within the Mara River Basin depend on the Mara River as their only flowing dry season water source.

The Serengeti-Mara ecosystem is composed of the MMNR and its surrounding group ranches as well as the SNP. The Serengeti-Mara ecosystem is home to approximately 1.3 million wildebeest. While the larger migratory wildebeest population of the Serengeti has remained fairly consistent since the 1970's, the Kenyan wildebeest population has declined significantly to around 31,300 animals, which is approximately twenty-five percent of the population size at the end of the 1970's (Serneels and Lambin, 2001). The decline of the Kenyan wildebeest population has been attributed, in large part, to land-use changes surrounding the MMNR, where rapid agriculture expansion has occurred (Serneels and Lambin, 2001 and Ottichilo et al, 2000).

In addition to the species that make up the annual migration, the Serengeti-Mara ecosystem is also home to vast numbers of wildlife that include elephants, black rhinoceroses, buffalo, giraffe, impala, eland, topi, kongoni, waterbuck, warthogs, ostrich, lions, cheetahs and spotted hyenas to name a few. However, Ottichilo et al (2000) reveals that population trends for non-migratory wildlife species within the Masai Mara ecosystem (inclusive of the MMNR and its surrounding group ranches) show declines averaging fifty-eight percent in the twenty year period prior to 2000.

Moreover, herbivore populations are largely limited by the availability of water and forage as noted by Mduma et al (1999). This is especially true in drought years, when water shortages severely affect water and forage availability, causing declines in wildlife populations through reduced reproduction, starvation, or insufficient water consumption.

Gereta et al (2002) predict that if water in the Mara River were to dry out, wildlife would start dying at an estimated rate of thirty percent per week starting from the first week.

2.2.3.4 Tourism

In addition to augmenting resident populations within the MRB, the number of tourists visiting the Masai Mara National Reserve and the Serengeti National Park are also inclining as seen in Figures 15 and 16. Tourist numbers have increased from 133,000 visitors in 1995 to 240,000 in 2004 in Masai Mara National Reserve and from 59,564 visitors in 1990 to 378,218 in 2002 in the Serengeti National Park (Kenya CBS, 2005 and Tanzania NBS, 2002). This rise in tourism leads to escalating revenues, providing a vital source of income for the region.

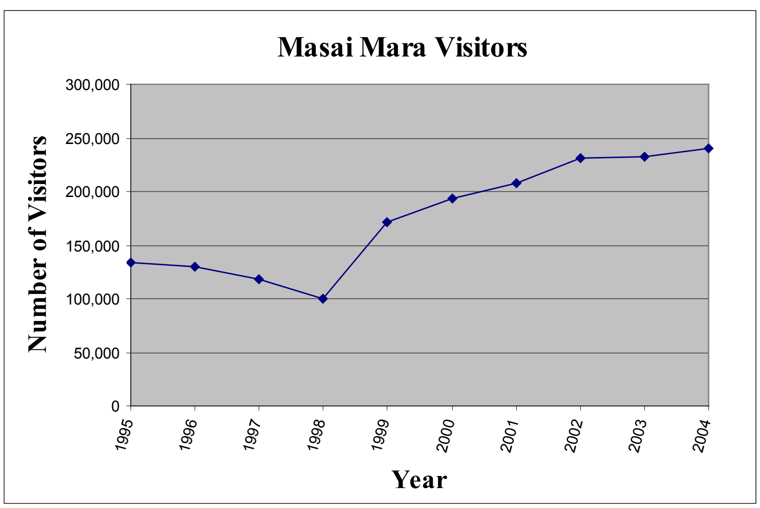

Figure 15: Visitor trends to MMNR between 1995 and 2004

Source: Kenya CBS - Statistical Abstract, 2005

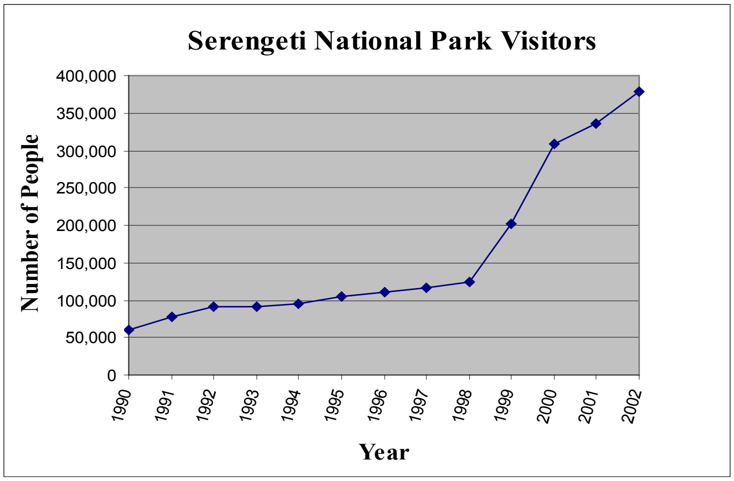

Figure 16: Visitor trends to SNP between 1990 and 2002

Source: Tanzania NBS - Economic Survey, 2002

Figure 17 shows annual increases in revenue as collected by SNP authorities from 1990 to 2001 which equates to an increase of approximately 580,008,000 TZ shillings or USD 464,750. While this figure only shows increases in revenues collected by park

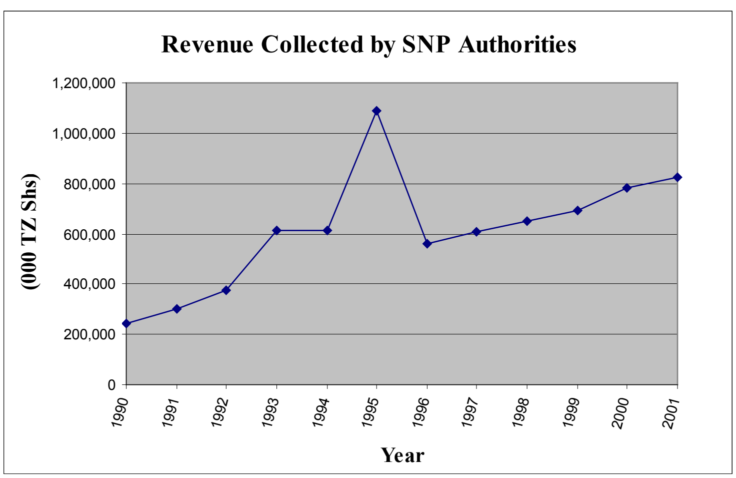

Figure 17: Annual revenue collected by SNP authorities from 1990 to 2001

Source: Tanzania NBS – Economic Survey, 2002 authorities, it is estimated that SNP tourism generated approximately USD 6,040,291 from 2000 to 2001, rising from USD 3,547,778 generated in the period of 1995 to 1996 (WWF, 2006).

While escalating tourism brings in much needed revenue to the region, it also leads to additional demands for tourist lodging facilities and additional water supplies to support these facilities. As seen in Figure 18, the majority of tourists visit the park between the months of June and August, which also overlaps with the northward migration of wildlife from the SNP to the MMNR.

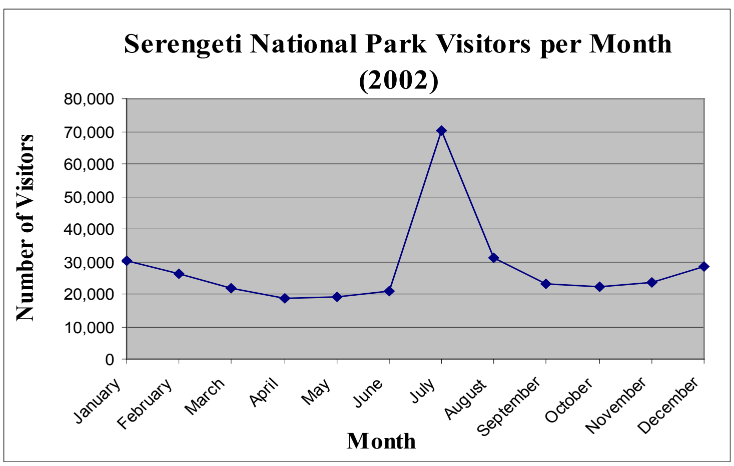

Figure 18: Monthly visitors to the SNP in 2002

Source: Tanzania NBS – Economic Survey, 2002

The annual migration begins at the start of the dry season and arrives within the MRB between the months of July and October (Gereta et al, 2002). The migration moves through the SNP into the MMNR in a quest for water and vegetation provided by the

Mara River. Figure 19 depicts tourist increase for the month of July from 1992 to 2002, showing that tourism has increased by an average of 15.4 percent annually. Therefore, tourism not only places strain on the Mara River when water flows from the Mara are already low, but tourism in SNP is experiencing the greatest growth during the dry season as well.

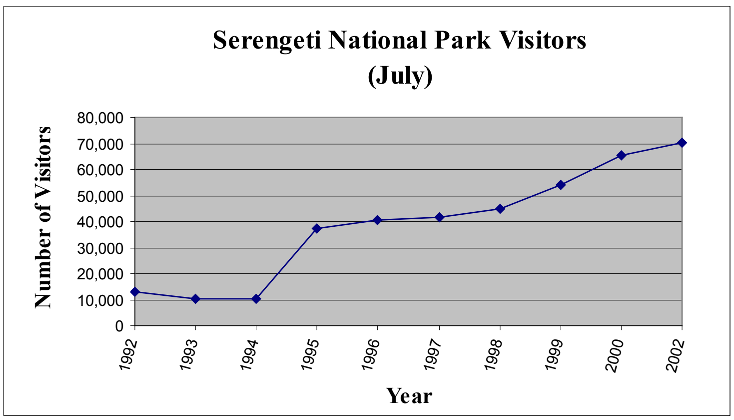

Figure 19: Visitors to the SNP during the month of July, from 1992 to 2002.

Source: Tanzania NBS - Economic Survey, 2002

Currently, no hotel facilities exist within the SNP portion of the Mara River Basin. However, the number of tourist lodging facilities located in and around the MMNR has shown an increasing trend over previous years. According to Fielding's Guide to Kenya's Best Hotels, Safari's and Lodges and Homestays (1997), there were at least twenty places to stay in and around the MMNR in 1997, which was more than double the number of places available in 1991. More recently in 2003, it was estimated that there were a total of twenty-four permanent camps and lodges in and around the MMNR, not including the numerous seasonal facilities that pop up during the height of the tourist season (Walpole et al, 2003). As a result of this crowding trend of lodges and camps in the MMNR, the National Environmental Management Authority currently has a moratorium on any further buildings and expansions within the Reserve until a review is conducted and new management plan is created. The moratorium is aimed at stopping unplanned and uncontrolled development within the park, but has not managed to halt development outside of the reserve (Walpole et al, 2003).

2.2.3.5 Irrigation

There are two main types of agriculture that take place within the MRB; smallholder mixed farming and large-scale commercial farming. Typically, smallholder mixed farms within the MRB are about two to five hectares and grow maize, wheat, beans and vegetables while large-scale commercial farms produce barely, pyrethrum, maize, sunflower, wheat and beans as their main crops (Onjala, 2004) Smallholder mixed farming exists primarily on the subsistence level within the basin and is typically rain fed. Currently, only a small number of large-scale farms operating within the Kenyan portion of the basin, as well as a handful of small-holder farms throughout the basin utilize irrigation.

In 2004, within the Kenyan portion of the MRB, it was estimated that there were seven smallholder irrigation schemes that covered approximately 165 hectares of land, as well as four individual and eight private farms (Onjala, 2004 and Krhoda, 2001). Furthermore, it was estimated that the current water demand for irrigation on the Mara River from the Kenyan portion of the basin equaled .019 m /second and .059 m /month, with total potential for irrigation being estimated at 32,000 hectares for upland crop (Onjala, 2004 and Krhoda, 2001). Gereta, et al. (2002) state that water permits to abstract water from the Mara River were issued to irrigate 520 hectares of mechanized farms in the Loita Plains, which equated to twenty-five percent of dry weather flows in the Mara River. On the other hand, as of 2002, small-scale irrigation schemes within the Tanzanian portion of the MRB (Musoma, Tarime, and Serengeti) are said to have totaled eighty-five hectares under irrigation, with a surveyed potential of 2,192 hectares (URT, 2003b).

A complete inventory of the irrigation schemes operating within the basin is difficult to obtain. Permitting and monitoring systems are weak and numerous illegal water abstraction operations exist. However, a consensus within the literature seems to conclude that 1) irrigation agriculture has expanded within the basin over recent years and 2) there is considerable development potential for irrigation schemes throughout the basin in the future (Nile Basin Initiative, 2004 and Onjala, 2004). Specifically, the Nile Basin Initiative has dedicated funds to implement small-holder irrigation development projects within Tarime District, Tanzania beginning early in 2007 (Nile Basin Initiative, 2004).

2.2.3.6 Mining

Industry is very limited within the MRB and consists mostly of large-scale mining activity within the Tanzanian portion of the basin. Industrial use of public water in the Kenyan portion of the MRB is little, as it is throughout the entire county. As a whole, industry in Kenya consumes only about four percent of the country's total water supply (WRI, 2007).

However, mining is a water consuming industry that is expected to expand in the Tanzanian portion of the MRB due to its richness in minerals, namely gold, kaolin, limestone, and gemstones (Yanda and Majule, 2004). In 2004, mining and quarrying made up 3.2 percent of Tanzania's nominal gross domestic product. Furthermore, since 2000, Tanzania's mineral exports have risen substantially, with most of this increase coming from gold exports (see Figure 20), which increased in value from USD 504 million in 2003 to USD 597 million in 2004 (Yager, 2004). In 2003, Tanzania became the third ranked gold producer in Africa.

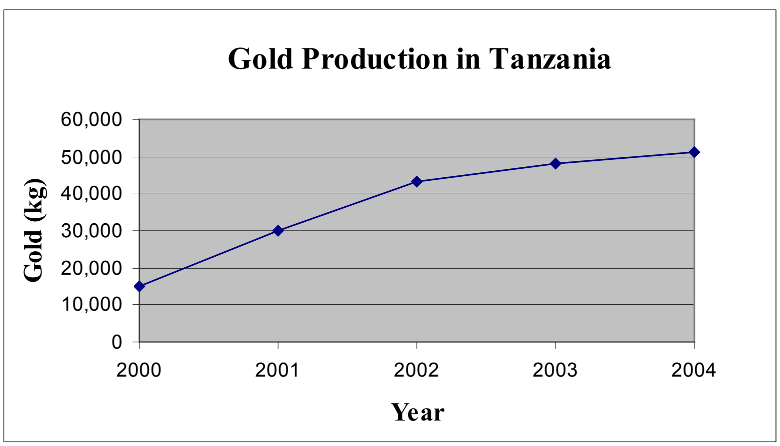

Figure 20: Gold production in Tanzania showed an increasing trend between 2000 and 2004.

Source: Yager, 2004

In the Mara River Basin, both large and artisan mining take place. Artisan mining is an illegal activity that occurs on small scales, usually around the large-scale mining operations. While artisan mining is not a direct concern when it comes to water quantity, large-scale mining operations are a consideration because water is used in the gold-mining process. Currently, there are two large-scale gold mining corporations operating within the basin; Meremeta Co. Ltd. and Barrick Gold Corporation.

Meremeta is a state-owned company that operates the Buhemba Mine, located near the border of the MRB, approximately 47 km southeast of Musoma (Yager, 2004). Buhemba is an open pit/carbon-in-leach mining operation that began operation in February 2003 with an expected life span of eight years (Yager, 2004). Through 2004, Buhemba's monthly production amounted to between 240 and 250 kilograms of gold from approximately 100,000 metric tones of ore, with future increases in ore production expected (Yager, 2004).

The second gold mining operation within the MRB is the North Mara Mine (NMM), run by Barrick Gold Corporation of Canada. The NMM is located just over ten km south of the Kenyan border in western Tanzania (Tarmine District), approximately twenty km west of the SNP (NMM, 2006). Originally, the mine started production in September of 2002 under East African Gold Mines Ltd. before being purchased by Placer Dome Gold Inc. of Canada in July of 2003. Barrick Gold Corporation took over NMM in early 2006, which encompasses the Gokona, Nyabigena and Nyabirama (Rama) pits. This open pit gold mining operation produced 6,485 kilograms of gold from approximately 2,130,000 tones of ore in 2004, with expected increases in gold production from 2.13 Mt/yr to 2.8 Mt/yr in 2005 due to the expansion of ore treatment capacity in 2005 (Yager, 2004).

3. METHODOLOGY

3.1 Study Area

The study area is an international river basin known as the Mara River Basin situated between the bordering countries of Kenya and Tanzania. Approximately sixty-five percent of the basin exists within Kenya, more specifically within the districts of Nakuru, Narok, Bomet and Trans Mara. The remaining portion of the basin lies in Tanzanian territory, within the districts of Tarime, Serengeti, and Musoma. The MRB also includes the entire area of the Masai Mara National Reserve, as well as a portion of the Serengeti National Park, which is listed as a UNESCO World Heritage site (see figure 2 for a reference map of the MRB).

The MRB consists of forested areas in the North, small and large scale agricultural landscapes, group ranches, urban settlements, and swamp land in the southern portion of the basin. Additionally, land cover within the national parks ranges from savannah grasslands to taller stands of grass in areas with more moisture to areas covered by *Acacia* woodland (Krhoda, 2001). Within the MRB, the Mara River has five main tributaries including the Amala, Nyangores, Engare Ngobit, Talek and Sand Rivers.

In both the Kenyan and Tanzanian sections of the MRB, agriculture and livestock keeping are the main sources of economic activity for the population. Outside of tourist lodges, there are no major industries operating within the Kenyan portion of the basin; however, there are two large-scale mining facilities in commission in the Tanzanian section.

3.2 Geographic Information Systems

A geographic information system is "an integrated collection of computer software and data used to view and manage information about geographic places, analyze spatial relationships, and model spatial processes." (ESRI, 2006). Such systems are capable of integrating and displaying geographically-referenced data so that the data can be visually analyzed and the issues better realized. A GIS can produce various outputs, including detailed maps that aid researchers in communicating certain ideas and/or concepts to an audience.

GIS software utilized in this project included ArcMap 9.1 and ArcPad 3.3 which are both a part of the ArcGIS family of ESRI (Environmental Systems Research Institute) GIS applications. ArcGIS was utilized for desktop applications including data integration and management, visualization and spatial modeling and analysis. ArcPad, on the other hand, was the software used in the field in combination with a mobile Geographic Positioning System (GPS) unit. This application was used to collect data in the field, which mainly consisted of GPS location points.

3.2.1 Value and Use of GIS

Geographic information systems have significant value when it comes to analyzing issues where geographic location is a major component of the study. GIS allows data to be entered into a system and manipulated so that data specific to a region of interest can be displayed and viewed. Subsequently, this educates decision makers and stakeholders as to the potential problems or issues that may exist in an area, giving insight into later actions that may need to be taken.

The possible uses of a GIS are extremely vast, with analysis of land use patterns, distribution and use of natural resources and demographic patterns being just some of the many feasible applications. Once relevant data are stored in the system, there is an increased potential and ability to share data amongst agencies and concerned parties. Data sharing facilities an increasing knowledge of the study area, leads to better informed decision making and maximizes management potential. Moreover, once the data are incorporated into a GIS, it can easily be built upon, modified or updated. A GIS allows data to be easily located and transferred, and limits the potential destruction of data that could otherwise occur with paper documents and records. Furthermore, the analysis and modeling potential for an area is significantly increased when geographic data are utilized in conjunction with a GIS.

3.2.3 Role in Research

The sustainability issues faced in the Mara River Basin are not easily solved, and to a large extent, are still tied to a substantial degree of uncertainty. One way to gain a better understanding of the hydrology of the Mara Rive Basin is through the use of Geographic Information Systems. By using GIS, the spatial context of the issue can be incorporated into the analysis, providing a visual means in which to view the problem, as well as a tool for further analysis and modeling. Specifically, GIS is used to visually define the study area, give spatial attributes to water-demand factors, to incorporate GPS points and in hydrologic modeling of the Mara River.

This research used a Geographic Information System to explore water demand factors within the Mara River Basin. Factors placing demand on the water resources of the area are incorporated into the project and spatially analyzed. These factors include large-scale irrigation, human populations, livestock populations, tourist facilities within the basin, wildlife populations and large-scale mining operations. This thesis incorporated available research, as well as new data and information collected in the field, in an effort to realize and understand water use in the area. Utilizing this data, base predictions are made as to the amount of fresh water that will be required to sustain the basin now and in the future.

3.3 Data Type and Collection

Data collection for this research project included a five-week field study in the Mara River Basin, with extensive research and analyses outside of this period. The field study was conducted from mid-June 2007 through the later portion of July 2007. Approximately one week of this time was spent working out of the WWF East Africa Regional Program Office in Nairobi, in conjunction with the USAID Global Water for

Sustainability Program (GLOWS). While in Nairobi, meetings were conducted with several organizations including the Food and Agriculture Organization of the United Nations (FAO), the Regional Centre for Mapping of Resources for Development (RCMRD), the Kenyan Wildlife Service (KWS), the International Livestock Research Institute (ILRI), the Kenyan Central Bureau of Statistics, the Kenyan Ministry of Tourism and Wildlife, and Ramani Communications, Ltd. Additionally, outside of the basin, a site visit was made to the Water Resource Management Authority in Kisumu, Kenya. In Tanzania, site visits outside of the Mara River Basin were made to Tanzanian National Parks (TANAPA) headquarters in Arusha, the WWF Tanzania Program Office, the Tanzanian National Bureau of Statistics in Dar Es Salaam, and the Lake Victoria Basin Office in Mwanza.

The majority of the data collection occurred while traveling the length of the Mara River Basin, from the Mau Forest in Kenya to the draining point of the basin at Lake Victoria in Tanzania. While traveling within the Kenyan portion of the basin, specific site visits were made to the Mara River Water Users Association, WWF – Mara River Basin Office in Narok, Narok District Water Office, Bomet District Water Office, Tenwek Dam, Siliwet pumping station, Bomet pumping station, Olerai Limited Mara Farm, and to several lodges within the Masai Mara National Reserve including Kichwa Tembo Camp, Mara Serena Lodge, Mara Fig Tree Camp, Mara Intrepid Club, Mara Simba Lodge, Mara Sarova, Mara Safari Club and Keekorok Lodge. While in the Tanzanian portion of the basin, site visits were made to the Serengeti National Park, the North Mara Mine, and the Tanzanian Ministry of Water in Musoma.

Data for this research were collected in a number of ways including literature reviews of scholarly journals and articles, online searches of various organizations and agencies involved in the study area, data collected from the USAID Global Water for Sustainability Program, site visits to water-use factors (irrigation schemes, mining operation, lodges and tent camps, etc.), as well as site visits and interviews with local and state agencies associated with the Mara River Basin. Data obtained through these efforts included notes from on-site interviews, booklets and policy regulations collected from organizations and agencies, water permitting data from regulating agencies, digital data including various GIS datasets, statistical data, and onsite GPS points taken with a mobile GPS unit. In instances where copy facilities were not available for data collection, a digital camera was used to photograph data stored on paper files.

3.4 Data Analysis

Data analysis for this project included the use of ArcMap in conjunction with the numerous types of data on water-use and demand collected for this research. General techniques utilized include topological modeling, map overlay and data extraction as described below for each of the six water demand sectors.

3.4.1 Human Population

The most recent national population census counts were conducted in 1999 in Kenya and 2002 in Tanzania (Kenya CBS, 2001 and Tanzania NBS, 2005). Populations for both countries were recorded at the national, regional, district, ward, and village levels. For this analysis, populations at the ward level were utilized for the Kenyan portion of the basin due to a lack of correlating spatial data at the village level. For the Tanzanian portion of the basin, ward populations were also utilized but in conjunction with village level data obtained from the WWF offices in Musoma, Tanzania. It is important to note that the natural boundaries of the MRB do not follow the political boundaries of the wards as seen in Figure 21. Therefore, spatial analysis was a useful tool in estimating population counts existing only within the portion of the wards contained by the basin.

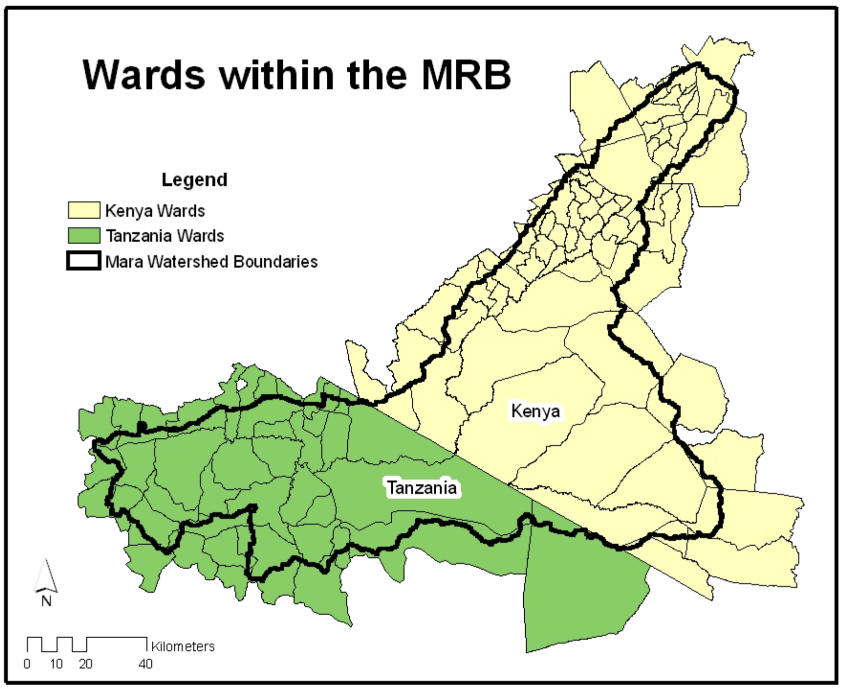

Figure 21: Administrative boundaries at the ward level for both Kenya and Tanzania with an overlaying boundary of the MRB.

In order to determine the human population for the Kenyan portion of the basin, the 1999 population census data were obtained from the Central Bureau of Statistics in Nairobi, Kenya (Kenya CBS, 2001). For the spatial portion of the analysis, a GIS shapefile titled

“Kenya Poverty Density 1999” was downloaded from the International Livestock Research Institute website (www.ilri.org). This shapefile was used to obtain the Kenyan administrative boundaries down to the ward level. Additionally, a GIS shapefile of the MRB boundary was obtained from the Geographic Information Systems – Remote Sensing Center at Florida International University.

The geographic coordinate system (GCS) utilized for this research is World Geodetic System (WGS) 1984 and the projected coordinate system is Universal Transverse Mercator (UTM) Zone 36S. While the MRB boundary shapefile was obtained in this projection, a geographic transformation was performed on the “Kenya Poverty Density 1999” shapefile, converting the data from their original GCS of ARC 1960 to WGS 1984 and then projecting to UTM Zone 36S. ArcMap was then used to estimate the portion of the Kenyan population residing within the MRB based on ward population data. Figure 22 shows the administrative districts and wards for both Kenya and Tanzania that exist within the MRB.

In order to manipulate the GIS layers for analysis, ward boundaries were clipped to follow the boundaries of the MRB and new shapefiles were created (Figure 22). Using the new areas for the clipped wards, modified population numbers were calculated based on the population density associated with the original ward area. Population numbers for wards not clipped to meet the boundaries of the MRB remained the same. Attribute tables for the new shapefiles were then modified to reflect the area and population count changes.

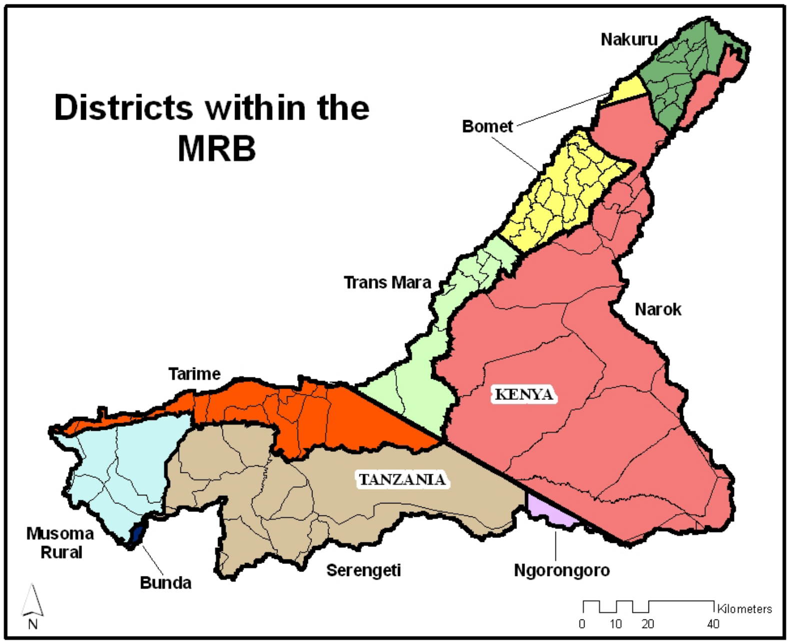

Figure 22: Administrative districts and wards within the MRB.

Due to the lack of correlating spatial and statistical information down to the village level, calculations for the Kenyan portion of the basin were based on population densities at the ward level. This is somewhat of a generalization because it does not take into consideration the exact location of villages within the ward. Population density assumes a constant and equal distribution of numbers, therefore ignoring the fact that village populations are more concentrated, and could fall either within, on, or outside MRB boundaries. Therefore, population counts for the clipped wards are estimates of the true population. Table 1 below shows the resulting human population numbers for each ward within the Kenyan portion of the MRB, based the population density. The human population counts were calculated based on data from the "1999 Population and Housing Census" data collected from the Kenya Central Bureau of Statistics Library in Nairobi, Kenya.

Table 1: Population estimates for Kenyan wards existing within MRB

District: Bomet

Ward	Area (km2)	Population
Cheboin	34.96	10,061
Chebunyo	33.35	8,992
Chemaner	32.75	9,069
Kaboson	56.6	10,162
Kapkesosio	28.41	6,595
Kapkimolwa	43.68	11,421
Kembu	36.69	13,155
Kimunchul	16.65	6,219
Kiplabotwa	41.83	10,190
Kipreres	29.93	7,213
Kiromwok	27.35	9,863
Kongasis	17.77	4,897
Lelaitich	39.49	7,762
Merigi	30.85	11,898
Mugango	20.68	6,566
Ndareweta	13.4	4,162
Sigor	48.6	10,695
Singorwet	1.01	482
Siongiroi	38.28	7,070
Sugumerga	33.65	8,369
Tegat	20.25	8,222
Tinet Forest	73.02	368
Township	84.27	26,577
District Total:	**803.47**	**200,008**

District: Nakuru

Ward	Area (km)	Population (
Amalo	33.22	4,826
Chebara	37.56	3,135
Cheptuech	19.6	3,412
Emitik	18.22	3,586
Kaplamai	46.27	6,948
Kapsimbeiywo	23.44	3,922
Keringet	50.8	7,185
Kipsonoi	16.92	2,394
Kiptagich	29.4	8,232
Mariashoni	107.95	1,546
Nyota	2.9	543
Silibwet	31.34	2,682
Sinendet	25.04	3,235
Tinet	79.61	5,041
District Total:	**522.27**	**56,687**

District: Trans Mara

Ward	Area (km)	Population
Angata	115.95	3,498
Emarti	81.49	12,871
Emurua Dikirr	15.92	3,395
Esoit Naibor	14.23	285
Kimintet	129.9	4,192
Murkan	49.14	7,730
Ntulele	47.87	2,746
Oldonyo Orok	1.4	111
Olorien	410.92	4,441
District Total:	**866.82**	**39,269**

District: Narok

Ward	Area (km)	Population
Aitong	669.98	5,748
Enelerai	89.82	8,836
Enelerai	60.29	11,268
Ilkerin	45.82	966
Koyaki	1167.81	5,992
Lemek	543.97	7,854
Loita	5.79	40
Maji Moto	92.28	759
Melelo	45.83	4,141
Morijo Loita	115.26	838
Mulot	72.64	17,276
Naikara	522.78	7,883
Naroosura	34.13	817
Olderkesi	425.15	5,988
Olkinyei	537.47	3,362
Olkurto	4.68	10,340
Olmesutie	12.3	140
Ololunga	100.37	5,044
Olpusimoru	171.45	7,139
Sagaamian	370.49	11,433
Siana	945.47	11,621
Sogoo	25.02	5,257
District Total:	**6058.8**	**132,742**

The human population for the Tanzanian portion of the MRB was calculated in a similar manner as was the Kenyan portion of the basin. Data from the 2002 Tanzanian Census (Tanzania NBS, 2005) were utilized in combination with a GIS shapefile titled "TZ Wards and Shehia Boundaries 2002" from the ILRI online website (www.ilri.org). Additionally, the same MRB boundary was used for Tanzania as was for Kenya, as mentioned above. Using ArcMap a geographic transformation was performed on the ILRI data, converting it from Arc 1960 to WGS 1984. Tanzanian wards were then clipped to follow the boundaries of the MRB, and the new area for the clipped wards was recorded in the attribute tables. However, greater accuracy in calculating the clipped ward population was obtained through the use of village location and population data, obtained from the WWF office in Musoma, Tanzania. As a result, population estimates for wards split by the MRB boundary take into account the placement of the villages within the ward. Therefore, population estimates reflect the location of villages and whether or not their populations fall within the ward as opposed to population estimates based on the population density of the entire ward, as in the analysis for Kenya. Table 2 below shows the resulting human population numbers for each ward within the Tanzanian portion of the MRB. The human population counts were calculated based on the Tanzania Census 2002, (Tanzania NBS, 2005) and a Baseline Survey, 2004 obtained from WWF Musoma Office.

Table 2: Population estimates for Tanzanian wards existing within MRB

District: Tarime

Ward	Locality	Area (km)	Population (2002)
Binagi	Rural	5.75	0
Gorong'a	Rural	138.32	9,951
Kemambo	Rural	116.89	10,105
Kibasuka	Rural	148.23	10,741
Kisumwa	Rural	56.33	7,374
Komuge	Rural	22.26	3,147
Manga	Rural	73.52	7,904
Matongo	Mixed	65.53	11,052
Muriba	Rural	25.21	0
Nyamwaga	Rural	18.99	0
Nyandoto	Rural	43.02	1,620
Nyanungu	Rural	20.06	8,450
Nyarero	Rural	5.87	0
Nyarokoba	Rural	49.72	11,283
Rabour	Rural	5.63	0
Turwa	Mixed	5.33	0
District Total:		**800.66**	**81,627**

District: Serengeti

Ward	Locality	Area (km)	Population (2002)
Busawe	Rural	246.96	10,593
Kebanchabancha	Rural	175.32	10,929
Kenyamonta	Rural	126.83	9,496
Kisaka	Rural	165.61	8,805
Kisangura	Rural	272.42	9,520
Kyambahi	Rural	14.99	0
Machowe	Rural	1225.41	13,931
Mugumu Mjini	Mixed	44.33	0
Nyamatare	Rural	184.09	11,833
Nyambureti	Rural	9.6	0
Nyamoko	Rural	152.35	10,189
Rigicha	Rural	3.22	0
Ring'wani	Rural	266.7	5,775
Rungabure	Rural	88.57	7,802
District Total:		**2976.4**	**98,873**

District: Musoma Rural

Ward	Locality	Area (km)	Population (2002)
Buhemba	Rural	137.49	14,061
Bukabwa	Rural	35.98	7,101
Buswahili	Rural	405.66	8,553
Butuguri	Rural	8.71	0
Bwiregi	Rural	160.13	8,750
Muriaza	Rural	73.93	1,794
Nyamimange	Rural	123.43	10,855
District Total:		**539.67**	**51,114**

District: Bunda

Ward	Locality	Area (km)	Population (2002)
Mihingo	Rural	17.4	0
Salama	Rural	2.91	0

District: Ngorongoro

Ward	Locality	Area (km)	Population (2002)
Sooil Sambu	Rural	111.49	0

Based on 1999 Kenyan census data and 2002 Tanzanian census data, it is estimated that a total of 660,320 people live within the MRB. Of this number 428,706 Kenyans and 231,614 Tanzanians reside within the basin. Using these population numbers, water-use within the MRB can be calculated by using established water-use data for both Kenya and Tanzania. However, in order to determine a per person water-use quantity, it is necessary to look more closely at the specific population.

The majority of the populations residing within the MRB live in rural areas. All of the wards within the MRB are classified as rural areas, with the exception of three wards in Tanzania: 1) Matongo, 2)Turwa, and 3) Mugumu Mjini. All three of these wards are classified as mixed, meaning that the wards possess both rural and urban characteristics. However, only a portion of Turwa (Tarime District) and Mugumu Mjini (Serengeti District) lie within the confines of the basin boundary, and within this portion, no villages exist. Therefore the population count for both is equal to zero for this analysis. Matongo (Tarime District) is also split by the basin boundary, but both villages that exist within this ward reside within the confines of the MRB. Therefore the entire population of 11,052 people is counted in the analysis, and is the only portion of the population within the MRB whose locality type is not classified as rural. However, because no further breakdown is given other than the fact that the locality type is "mixed", for the purposes of this analysis water-use for the entire MRB population will be calculated using water-use standards for a rural population.

A year-round availability for per capita domestic water consumption in the rural areas of both Kenya and Tanzania is considered to be twenty liters per day (Mati, et al, 2005 and Zaba and Madulu, 1998). Rural domestic water use entails water used for drinking, bathing, washing and cooking. This statistic was used to calculate the quantity of water required to sustain the population within the MRB.

3.4.2 Livestock Populations

Livestock farming is second only to agriculture in economic importance to the MRB (Yanda and Majule, 2004). The main types of livestock reared within the MRB include zebu cattle, small east African goats, and red Maasai hair sheep (Onjala, 2004). While less numerous, there are also a significant number of donkeys within the basin.

In determining water quantity demanded by livestock residing within the MRB, population totals must first be examined. However, unlike the human population, there are no estimated growth rates for livestock within the MRB and population numbers are more susceptible to environmental conditions such as drought, leading to potentially large fluctuations from year to year. Figure 14 in section 2.2.3.4 provides a graph of livestock trends for the years 1984, 1998 and 2000 for the Tanzanian portion of the MRB, while Appendix I shows livestock population numbers for districts in the Kenyan portion of the basin for periods ranging from 1991 to 1995, both of which are provided for comparison purposes.

Data collection for livestock population counts for this research was derived from various sources for varying years (referenced in Table 3 below). As a result, the methods for which these numbers were derived differ. For example, livestock population numbers for the Narok and Trans Mara districts of Kenya were obtained from a United Nations Environment Program (UNEP) report that examined the effect of drought in Kenya using population statistics from the years 1996 and 2000 (UNEP, 2002). For this analysis, the 2000 livestock population statistics provided in the report were used, which were based on aerial survey data obtained from the Kenyan Department of Resource Surveys and Remote Sensing. However, the remaining data came either from District Livestock offices within the basin or from the United Republic of Tanzania, Mara Region Socio-Economic Profile. Subsequently, there are two main data types, namely aerial survey data and census data.

Table 3 below shows the resulting livestock population numbers obtained for each district existing within the MRB. The Bunda and Ngorongoro districts in Tanzania are not included in the livestock analysis due to the small portion of area within MRB boundaries and their lack of significant human settlement (i.e. a village population) as seen in Table 2. Furthermore, in the tables below, goats and sheep are categorized together as "shoats" and will be observed as a single group for this analysis.

Using the data provided in Table 3, estimates were calculated using proportional ratios comparing district livestock population for the entire district area to the area of the district that exists within the MRB. The resulting number is the livestock count for the

Table 3: Livestock populations for districts existing within the MRB

KENYA

District	Cattle	Shoats	Donkey
Bomet*	277,673	99,367	22,600
Narok and Trans Mara (combined)**	559,252	595,588	14,901
Nakuru***	343,649	229,138	71,088
Total Livestock	**1,180,574**	**924,093**	**108,589**

TANZANIA

District	Cattle	Shoats	Donkey
Musoma	363,108	176,450	3,024
Serengeti	273,749	294,160	769
Tarime	401,800	165,915	1,193
Total Livestock	**1,038,657**	**636,525**	**4,986**

*Department of Livestock Production, Bomet District, 2006 (2005 population numbers)
**UNEP Report, 2002. (DRSRS Aerial survey counts)
***District Livestock Office, Nakuru, 1996 (1995 population numbers)
Source: URT (2003b) (2002 population numbers)

portion of the district residing within the MRB, essentially based on livestock population densities. Areas for each of the districts were obtained through the use of a GIS (ESRI ArcMap 9.1), in conjunction with the shapefiles utilized to derive human population counts described in section 3.4.1. Calculations, as mentioned above, were made at the district level, with the exception of the Narok and Trans Mara districts in Kenya which were combined. Furthermore, area for both the MMNR and SNP were subtracted from this calculation because it is assumed that livestock populations do not exist within park boundaries. Table 4 below depicts the resulting livestock population numbers for the portion of the districts residing within the boundaries of the MRB.

Table 4: Proportional livestock populations for districts existing within the MRB

KENYA

District	Cattle	Shoats	Donkey
Bomet	94,137	33,688	7,662
Narok and Trans Mara (combined)	183,774	195,715	4,897
Nakuru	23,597	15,734	unknown
Total Livestock	**301,508**	**245,137**	**12,559**

TANZANIA

District	Cattle	Shoats	Donkey
Musoma	115,573	56,162	963
Serengeti	109,307	117,459	308
Tarime	84,959	35,082	253
Total Livestock	**309,839**	**208,703**	**1,524**

Livestock population estimates provided in Table 4 show that there are approximately 611,347 cattle, 453,840 shoats, and 14,083 donkeys within the boundaries of the MRB. The Kenayn portion of the MRB has an estimated total of 559,204 livestock, while the Tanzanian portion of the basin has slightly less at 520,066, totaling 1,079,270 livestock living within the MRB.

Once livestock populations within the basin have been established, it is necessary to quantify daily water use in order to determine overall water-demand. However, in developing estimates on water-use for a species, there is an assumption that each individual requires the same daily amount, which is obviously not the case. Water intake depends on numerous conditions including environmental factors, the availability and type of forage available for grazing, metabolic processes, the individual weight of the species, the amount of travel time to and from the watering source, etc. Furthermore, water requirements not only differ between individuals but they also differ within the same individual through seasons. For example, seasonal weight loss is a strategy used to support higher livestock populations in arid, water-limited environments (King, 1983).

However, given the need to establish a constant demand, daily drinking water requirements for this analysis are based on estimates given for non-lactating livestock under African ranching conditions provided by King (1983) as illustrated in Table 5. Further, while listed separately in Table 5, goats and sheep (shoats) are combined into one category for this analysis. Subsequently, the category of "shoats" will follow the daily drinking water requirements listed for a goat, which is 2.0 liters for mean daily intake and 5.0 for a practical guideline for development. As defined by King (1983), a practical guideline for development reflects the maximum requirements of the animal, both in terms of its daily requirements and the amount it can drink in one visit.

Table 5: Estimated daily drinking water requirements for non-lactating livestock under African ranching conditions

Species	**Weight (kg)**	**Daily Drinking Water Requirements (liters)**	
		Mean	**Practical guideline for development**
Zebu bovine	350	16.4	25
Goat	30	2.0	5.0
Sheep	35	1.9	5.0
Donkey	120	12.4	not provided

Source: King, 1983

3.4.3 Wildlife Populations

Both the Masai Mara National Reserve and the Serengeti National Park are home to a wide array of wildlife that relies on the dry season flow of the Mara River for survival. A large portion of this demand not only comes from the wildlife populations that live within the MRB year-round, but also comes from the seasonal migration of wildlife that enters the basin in search of water during the dry season. Each year, an estimated one million wildebeest and approximately 300,000 of each Thomson gazelle and zebra migrate from the Serengeti plains northwards to the MMNR to drink from the Mara River when water sources further south have dried up (Wolanski et al, 1999). This massive migration is estimated to move into the MMNR from July to October (Gereta et al, 2002) or from August to November (Musiega and Kazadi, 2004). Regardless of the variations, both estimates place the migration within the MMNR for an approximate four month span.

Due to the complexity of wildlife movements over the landscape, only wildlife populations within the Narok and Trans Mara districts of Kenya (which includes the MMNR in entirety) will be included in this water-demand analysis, in addition to the migrating species that enter into the basin during the dry season. Wildlife population counts for the Narok and Trans Mara districts of Kenya are taken from a study conducted by the United Nations Environment Program (UNEP) (2002) using data provided from aerial censuses provided by the Department of Resource Surveys and Remote Sensing (DRSRS) in Kenya. Wildlife population counts from this study, for the year 2000, are integrated into Table 6 below. However, it is important to note that the 2000 wildlife population counts taken from the UNEP study were taken at the height of the year 2000 drought. During this drought more than fifty percent decline in wildlife population numbers was seen when compared to 1996 census data (UNEP, 2002).

Furthermore, it is likely that this census data includes some animal populations from the annual migration, as referenced above, instead of solely year-round resident wildlife populations. This is assumed from the example of the wildebeest population, derived from the UNEP report, which shows a 2000 wildebeest count of 88,256, while 2001 estimates put the Kenyan resident population at approximately 30,000 animals (Serneels and Lambin, 2001). Nevertheless, the portion of the annual migration population within the aerial census range at the time of counting is not known.

Furthermore, the portion of the SNP wildlife population existing and remaining solely with the MRB is not considered in this water-demand analysis due to its complexity. This results from the fact that the SNP is split by basin boundaries, leaving the majority of the park outside of the MRB.

In conjunction with wildlife population numbers referenced above, Table 6 shows coinciding estimated daily water requirements for the selected wildlife (du Toit, 2002). Daily water requirements adapted from du Toit (2002) were calculated at four percent of the body weight of an adult male. While water consumption rates vary by species, consumption is directly proportional to each animal's body weight (Peden et al., 2003). Water consumption requirements are used purely for the task of estimating the possible water-demand and are likely to vary from individual to individual and depend on a wide-range of considerations from diet to climactic conditions, etc.

Since neither the Thomson gazelle nor the Grant's gazelle are included in du Toit's estimates, daily water requirements are calculated at four percent of the average weight of an adult male (http://library.thinkquest.org/16645/ wildlife/bovid_family.shtml). Furthermore, the daily water requirement for an elephant is calculated at 150 liters per day, based on a range of 150 to 300 liters per day (du Toit, 2002).

Table 6: Estimated daily water requirements for wildlife populations within the MMNR

Animal	**2000 Population**	**Individual Daily Water Requirements (liters)**
Buffalo	4,733	31
Eland	1,025	23
Elephant	989	150*
Gran't Gazelle	13,353	2.6
Thomson's Gazelle	32,880	1
Maasai Giraffe	2,213	40
Impala	36,929	2.5
Hartebeest	1,295	5.5
Topi	6,244	5
Warthog	1,889	3.5
Waterbuck	143	9
Wildebeest	88,256	7
Burchell's Zebra	43,624	12
Total	**233,573**	**292.1**

*It is estimated that the daily water requirement is150-300 liters
Source: UNEP, 2002 and du Toit, 2002

As mentioned earlier, the wildlife population counts for the Narok and Trans Mara Districts do not fully take into consideration the extent of the annual migration, which is estimated at approximately one million wildebeest and 300,000 of each Thompson Gazelle and zebra (Wolanski et al, 1999). The annual migration places these animals within the MRB for an approximate four month span. Therefore, a more accurate annual water demand from wildlife can then be calculated by adding the four month water demand of the annual migration to the water demand of other wildlife species with the basin. Due to the difficulty in separating out the resident populations of wildebeest, Thompson Gazelle, and zebra (seen in the 2000 Narok and Trans Mara counts), only the annual migration numbers of one million wildebeest and 300,000 of each Thompson Gazelle and zebra will be used in estimating the water demand for the four month period when the annual migration is in the MRB, leaving out the resident population. However, the annual migration water demand is combined with the water demand of the other wildlife species within the basin for the remaining months of January through June and November through December. Water demand for the months when the migration is not within the MRB include buffalo, eland, elephants, Grant's Gazelles, Maasai Giraffe, impala, hartebeest, topi, warthog, and waterbuck populations listed in Table 6.

3.4.4 Lodges and Tent Camps

As tourism continues to rise within the MMNR and SNP (see section 2.2.3.4), it is foreseeable that the demand for tourist lodging facilities within access of the parks will also rise. This increased demand will facilitate a rise in the resources required to support tourist accommodations in the area, heightening the strain on water resources within the

MRB which can become quite scarce during the dry season. This section looks at the water demand from tourist facilities located within the Mara River Basin, namely those associated with both the MMNR and SNP.

Since the focus of this research is inclusive of the MRB, tourist facilities associated with the parks, yet outside of the Basin, will not be considered in this research. While several lodges and camps do exist within the SNP, none exist within the MRB and therefore will not be considered in this analysis. The MMNR on the other hand, exists in entirety within the Basin, and therefore all tourist facilities within the park, as well as those outside of the park, yet still within the confines of the MRB, will be considered.

In order to determine the number of lodges and tented camps operating within and around the MMNR and their subsequent water use, an inventory of existing facilities was taken. This was done through a combination of site visits, on-line searches and literature reviews, a review of Kenya travel books and a visit to Kenya's Ministry of Tourism and Wildlife in Nairobi, Kenya. According to a list obtained from Kenya's Ministry of Tourism and Wildlife, there are fifty-three lodges and camping facilities within the Narok and Trans-Mara Districts of the Mara River Basin (see complete list obtained from the Ministry in Appendix II). However, in conducting a comprehensive review (using all of the above listed sources) of tourist accommodations within the MRB, the current number of lodges and tent camps found to be operating in or near the reserve is approximately sixty-five (see complete list is Appendix III). The discrepancy in the number of accommodations could be the result of outdated information or inconsistencies in the names of the facilities. It is also important to note that specific location information is difficult to obtain for the smaller and less utilized travel accommodations, and therefore some degree of error could arise from an inability to determine an exact facility location, thus resulting in the improper inclusion or exclusion of facilities in the analysis.

The spectrum of accommodations offered in and around the MMNR range from very basic camping facilities to elaborate and exclusive lodges and tented camps, complete with luxury bathrooms, swimming pools and electric fences. Of the sixty-five lodges and tent camps found to be operating within the MRB, thirty-six of these accommodations can be considered basic in regards to the types of facilities and amenities offered (see Appendix III for complete listing of all accommodation facilities). Basic camp sites usually offer short-drop toilets and safari showers (which entail water being hand-carried to the room) while some also offer flush toilets. The number of basic facilities serving tourists does however have the potential to fluctuate throughout the year, as some of the sites are seasonal in operation, and might only be open during the height of the tourist season and closed for the rainy seasons. Additionally this number has the potential to fluctuate if new campsites are permitted to open as well as if old sites close down.

While a number of basic accommodations (i.e. campsites) are available to tourists traveling to the Masai Mara National Reserve, analysis done for this research focuses on higher-end accommodations that offer running water and flush toilets to their guests. Higher-end facilities are more significant in a water-use-demand analysis since the amenities offered require larger quantities of water to operate and therefore produce a greater water demand than the basic camping sites. Higher-end facilities are seen in the form of permanent lodges and semi-permanent and permanent tented camps. Both types of accommodations tend to posses plush beds and en suite bathrooms, complete with flush toilets, hot showers and sinks with running water. Many of the higher-end lodges and camps offer the same luxuries to be expected at accommodations within major cities, such as high-end dining, laundry and maid service, and entertainment.

The majority of the uncertainty revolving around the exact number of tourist facilities within the MRB is eliminated in the water-demand analysis because the facilities considered have comparatively more information available on them than the smaller, seasonal locations. Of the sixty-five tourist accommodations found to be located within the MRB, Table 7 below lists the twenty-nine facilities considered in this water-demand-use analysis. Twelve of these facilities are located inside the MMNR and seventeen are located beyond its boundaries.

Table 7: Tourist accommodations within the MRB used in analysis

	Name of Hotel	**Within MMNR (Y/N)**	**Number of Beds**	**Number of Tents**
1	Base Camp Explorer (Dream Camp)	Yes	32	15 tents
2	Bush Tops	No	9	5 tents
3	Cheli & Peacock's Cottars 1920's Camp	No	16	8 tents
4	Governors Camp (Senior)	Yes	76	38 tents
5	Governor's Ilmoran Camp	Yes	20	10 tents
6	Ilkeliani Camp (Africa Eco Lodge Holding Company)	Yes	24	12 tents

7	Keekorok Lodge*	Yes	202	74 rooms
8	Kichwa Tembo Bateleur Camp	No	18	9 tents
9	Kichwa Tembo Tented Camp*	No	84	40 tents; 2 cottages
10	Little Governors Tented Camp	Yes	36	17 tents
11	Mara Buffalo Camp	No	126	*63 (estimate)*
12	Mara Explorer Camp	Yes	20	10 tents
13	Mara Fig Tree Camp*	No	140	30 tents; 30 cabins
14	Mara Hippo Tented Camp	No	94	*47 (estimate)*
15	Mara Intrepid Club*	Yes	60	30 rooms
16	Mara River Camp	No	32	16 tents
17	Mara Safari Club*	No	100	50 rooms
18	Mara Sarova Camp (Sarova Mara)*	Yes	155	75 tents
19	Mara Serena Lodge*	Yes	148	76 rooms
20	Mara Simba Lodge*	Yes	196	84 rooms
21	Mara Sopa Lodge	No	144	60 double rooms; 12 suites
22	Mpata Investment Club (Mpata Safari Club)	No	46	10 suites; 12 deluxe units
23	Olonana Tented Camp	No	24	12 tents
24	Private Camp (part of Governors)	Yes	4 to 16	Private camp *(8 tents estimated)*
25	Saruni Safari Camp	No	12	6 cottages
26	Sekenani Camp^	No	30	15 tents
27	Serian Camp^	No	16	8 tents
28	Siana Springs Intrepids Lodge	No	76	38 rooms
29	Voyager Safari Lodge	No	164	78 rooms

* Sites visited (GPS data collected)
^ Site location estimated

Once the accommodations to be utilized in the analysis were determined, the twenty-nine camps and lodges listed above were plotted in a GIS and a shapefile was created. Eight of the facilities included in the analysis were visited during the initial field work period. During these visits, a mobile GPS (Trimble Geoexplorer) was used to obtain XY coordinates with a position dilution of precision (PDOP) of five or less for all points taken (see Table 8). The mobile GPS was set to WGS 1984 UTM Zone 36 to coordinate with other spatial data utilized in the analysis. The majority of the remaining locations were plotted with the aid of a map entitled “A Map of the Masai Mara Ecosystem” created by Friends of Conservation in conjunction with Patrick Kirby and Ramani Communications, Ltd. This map depicts several of the camping and lodging facility locations within and surrounding the MMNR. Additionally, the map contains GPS reference points throughout the map as well as a network of road paths existing within and around the MMNR. These reference points were then cross-referenced with GPS point locations collected in the field as well as to a GIS shapefile of the road network (the same road network used in the referenced map) provided by Ramani Communications, Ltd. Exceptions to this method are Serian Camp and Sekenani Camp which were plotted freely based on limited location information. Therefore, both of these location plots are estimates and are not exact.

Table 8: GPS locations of lodges and/or tent camps visited

Name of Lodge/Tent Camp	Location
Mara Serena Lodge	1°24’.09” S and 35°01’34” E
Mara Safari Club	1°5’32.75” S and 35°12’22.78” E
Mara Fig Tree Camp	1°26’04.90” S and 35°11’27.42” E
Kichwa Tembo Tented Camp	1°14’59.40” S and 35°00’40.79” E
Mara Intrepids Club	1°24’55.82” S and 35°06’39.28” E
Keekorok Lodge	1°35’22.40” S and 35°14’09.97” E
Mara Simba Lodge	1°28’16.06” S and35°17’39.28” E
Mara Sarova Camp (Sarova Mara)	1°31’48.26” S and 35°19’04.34 E

Figure 23 below depicts the twenty-nine tourist camps and lodges that were utilized in the water-use-demand analysis for this research. Additionally, Figures 24 and 25 are magnified maps of the lodges and tent camps that exist in the northeastern and southwestern portions of the MMNR, respectively.

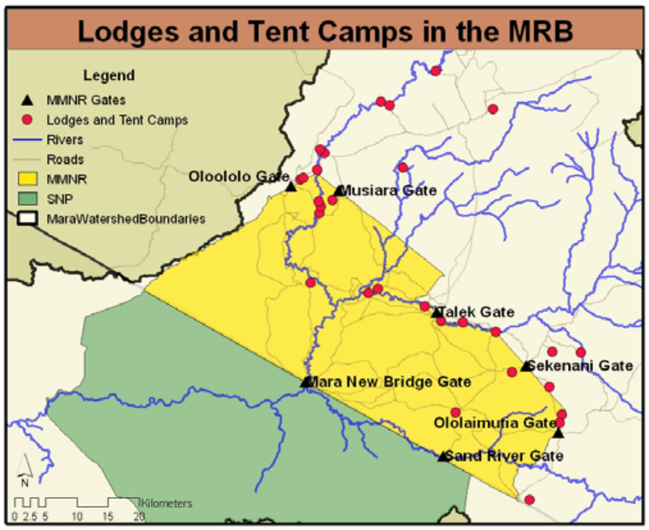

Figure 23: Locations of lodges and tent camps in and around the MMNR

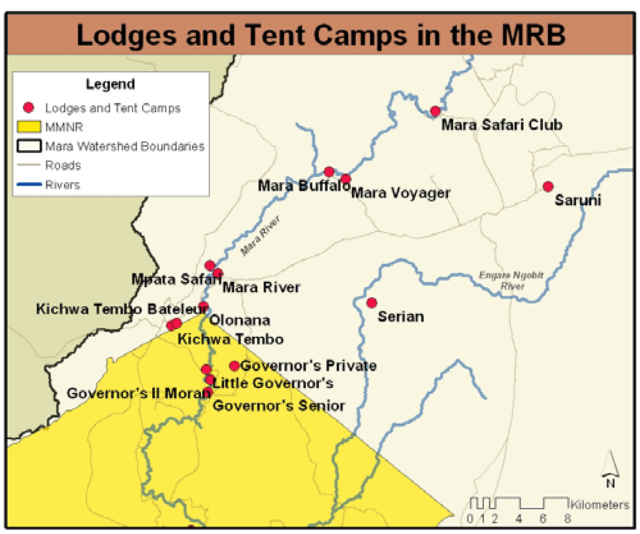

Figure 24: Lodges and tent camps in and around the northwestern portion of the MMNR.

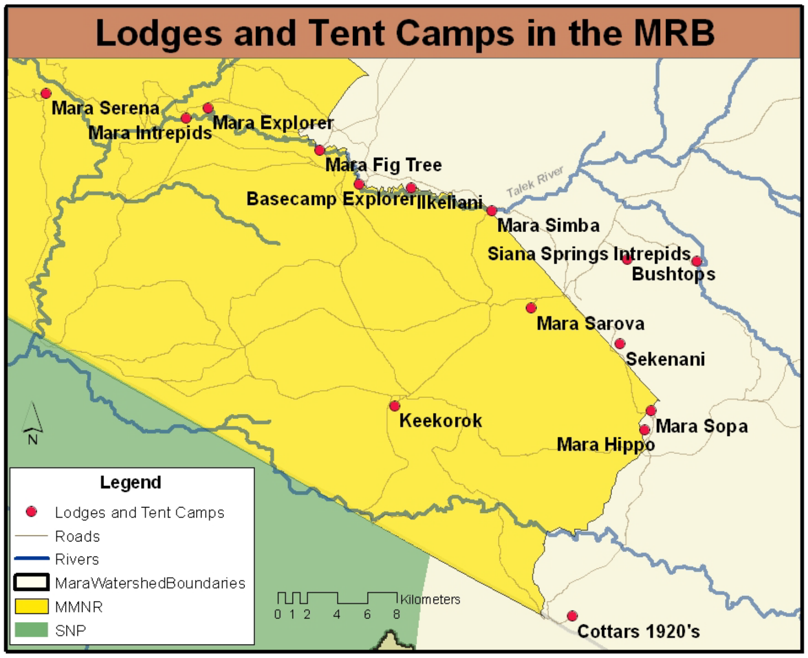

Figure 25: Lodges and tent camps in and around the southeastern portion of the MMNR.

The lodges and tent camps scattered in and around the MMNR obtain their water in one of two ways: either from flowing rivers or streams located near the facility or from boreholes dug deep into the ground. Of the eight lodges and tent camps visited, three obtain water used for facility operations from boreholes (Figtree, Mara Intrepids and Keekorok) and five obtain water from nearby rivers and streams (Kichwa Tembo, Mara Serena, Mara Safari Club, Mara Simba, and Mara Sarova). Mara Sarova has a rather unique situation in that it is located near two underground streams or springs, which are the source from which they abstract their water.

Geospatial analysis shows that sixteen of the twenty-nine lodges and tent camps analyzed lie within 500 meters from a major river within the MRB. Ten of the accommodations that are less than 500 meters away are located next to the Mara River and include the Mara Safari Club, Mara Buffalo, Mara Voyager, Mpata Safari Club, Mara River Camp, Mara Serena, Olonama, Governor's Bateleur Camp, Governor's Senior Camp, and Little Governor's. The other six accommodation facilities lie along the Talek River and include Mara Intrepids, Mara Explorer, Mara Fig Tree, Basecamp, Ilkeliani and Mara Simba. Furthermore, Siana Springs is located less than 500 meters from a tributary of the Talek River and both Kichwa Tembo and Kichwa Tembo Bateleur are located next to Sabaringo Stream. Therefore, at least nineteen of the twenty-nine lodges and tented camps that utilize running water and flush toilets to support their guests lie within 500 meters of a flowing river or stream within the MRB. Furthermore, it is possible that more facilities could be located within this same proximity to one of the many smaller streams that exist within the MRB during the wet season, however, many of these streams dry up during the dry season. Additionally, it is important to note that proximity to a river does not necessarily reveal that these facilities obtain their water directly from the river or stream next to them, for it is possible that they obtain their water from a borehole instead as do Mara Fig Tree and Mara Intrepids (even though they are located on the Talek River).

The twenty-nine tourist accommodation facilities considered in this analysis provide a combined total of approximately 1000 rooms and 2116 beds to tourists visiting the MMNR and/or the SNP. In order to determine how many tourists utilize accommodations within the MRB, the total number of beds available from the twenty-nine lodges and tented camps were taken and multiplied by the average monthly bed occupancy rate for the MMNR throughout the year. The mean monthly bed occupancy rates listed in Table 9 were adapted from a study entitled, "Wildlife and People: Conflict and Conservation in the Masai Mara, Kenya conducted by the Durrell Institute of Conservation and Ecology, University of Kent. These bed occupancy rates were based on a sample of lodges and camps in the MMNR from 1997 through 2000 (Walpole et al. 2003). Note the peak during July, August and September, months that correlate with the annual migration as well as summer holidays for Americans and Europeans.

Table 9: Number of beds occupied per day in the MMNR based on mean monthly bed occupancy rates

Month	Bed Occupancy Rate	Number of Beds Occupied (of the 2116 available)
Jan.	50	1058
Feb.	58	1228
March	47	995
April	43.5	921
May	32.5	688
June	50	1058
July	66	1397
Aug.	77	1630
Sept.	57.5	1217
Oct.	55	1164
Nov.	42.5	899
Dec.	45	953

Source: Bed occupancy rates are adapted from Walpole, et al, 2003

Once the number of beds occupied per day throughout the year is determined, the next step in determining water-use and demand comes in figuring out how much water is being used per person per day in the tourist facility. However, each of the twenty-nine lodges and camps utilized in this analysis varies to some extent in the amenities and facilities offered. For example, fifteen of the twenty-nine accommodations have swimming pools on site. Additionally, variations are possible in the services offered (i.e. laundry), hotel practices (i.e. cleaning, cooking, lawn maintenance), and the type of equipment used (i.e. types of shower heads, toilets, faucets, etc.). Additionally, each location is maintained differently, making it possible for there to be leaks in pipes and out of faucets that are not consistent. Only some of the lodges and tent camps within and around the MRB have meters to monitor and record water use, making estimates the only feasible way to calculate likely water demand.

A general guideline for water demand for non-residential use estimates the average daily water use per person staying at a luxury camp to be between 100 and 150 gallons per day (gpd) or 380 to 570 liters per day (Water Systems Design Manual, 2001). This estimate can be broken down further when looking at the individual components of water use. For example, The United States Geological Survey (USGS) estimates showers use two gallons of water per minute, baths use an average of fifty gallons per bath, and flushing a toilet uses an average of three gallons per flush. Additionally, teeth brushing, hands/face washing, face/leg shaving use approximately one gallon of water per activity (USGS, 2006). Therefore, a person taking one ten minute shower per day, who flushes the toilet four times a day, brushes their teeth and washes their face twice a day, washes their hand three times a day, and shaves once a day would use approximately 40 gallons of water per day according to USGS estimates.

However, while staying at a safari camp or lodge there are numerous other water use factors that must also be included in the equation. Many of the lodges and tent camps used in this analysis include food as a part of a tourist's stay and therefore food preparation must be taken into consideration. Additionally, cleaning, landscaping, laundry, and pool use should be considered. Based on hotel averages, cleaning can use eight percent of daily water usages, kitchens can use six percent and landscaping can use seventeen percent (SFWMD, 2003). According to commercial laundry equipment manufacturers, institutional washing machines use about two and a half gallons per pound of linen laundered. Linen use estimated per double occupancy room average eight to twelve pounds per day (Gerston, 2002). Furthermore, it is estimated that staying at a site that has a swimming pool adds ten gallons per day to water use for maintenance per 100 square feet (Water Systems Design Manuel, 2001).

While the above estimates were not taken directly from lodges and tent camps existing within the MMNR, they do begin to paint a picture of water use quantities that are likely to exist at the tourist accommodations in this analysis. For the purpose of this study, it will be assumed that the average water use per day per guest is 100 gallons or 380 liters.

3.4.5 Large-Scale Irrigation Farming

The two main types of agriculture that take place within the MRB are smallholder mixed farming and large-scale commercial farming. Typically, only the large-scale commercial farms within the MRB utilize irrigation schemes, for smallholder mixed farming exists primarily on the subsistence level and is usually rain fed. Therefore, for this analysis, water demand for agricultural purposes within the MRB will be focused on large-scale irrigation farming. Data collection for this section of the analysis was collected mainly through a site visit with Tarquin Wood of Olerai Limited Mara Farm, GIS data layers providing daily rainfall data for irrigated areas, and from permitting data collected from the Narok and Bomet District Water Offices as well as the Water Resources Management Authority - Lake Victoria South Catchment Region Office in Kisumu, Kenya.

Currently, within the Kenyan portion of the MRB, there are 690 hectares under irrigation from four farms including Olerai Limited Mara Farm , Lemontoi, Shimo Limited and Ndakaini Farm Limited, as seen in Figure 26. Of this total, 660 hectares are under pivot irrigation and 30 hectares are under floppy irrigation, which is a new South African method of overhead irrigation. In total, these farms have ten irrigation pivots which are fed by water abstracted directly from the river via large, diesel pumps. Currently, there are five pumps abstracting water from the river for these farms.

Almost all horticultural production for export cropping is done by some form of irrigation (Okado, 2000). Specifically, Olerai Limited Mara Farm consists of 600 hectares of farmland, of which approximately 300 hectares are under irrigation, including both pivot and floppy irrigation. The farm produces seed maize, French beans and gum trees, of which only the seed maize and French beans are irrigated. French beans are produced for export to foreign markets and is an important cash crop, for it has a relatively short growing period (Okado, 2000). Olerai Limited Mara Farm grows French beans year round, planting 4 hectares a week regardless of climactic conditions. Maize on the other hand, is slightly more sensitive because the preferred harvest time occurs during the dry season. Therefore, harvesting and planting dates vary, but planting mainly takes places in early February and harvesting occurs six months later in July or August.

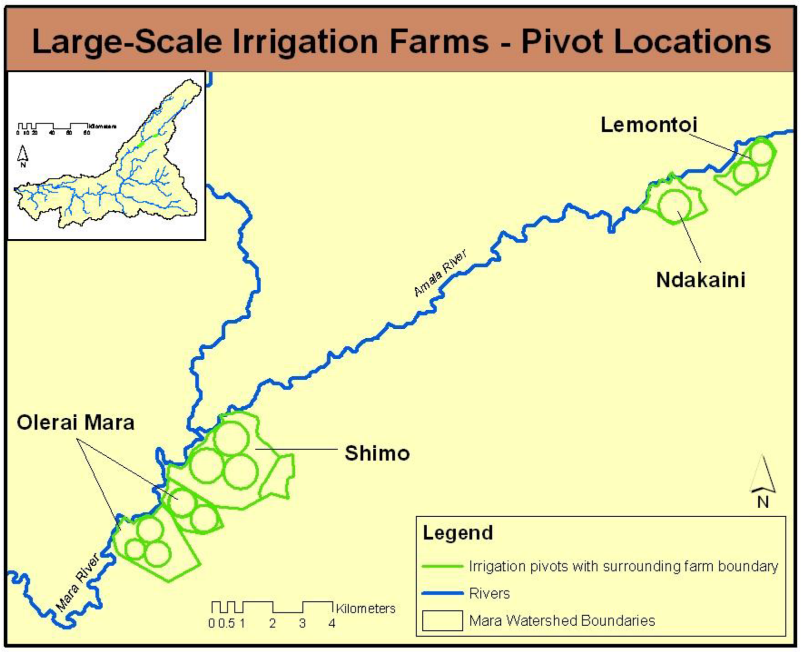

Figure 26: Large-scale irrigation farms within the MRB and their associated pivot locations.

Source: Shapefile of pivot locations and farm boundary locations provided by Ramani Communications, Ltd

Note: Although the map depicts a total of eleven irrigation pivots, there are currently only 10 pivots operating. Shimo Limited has two pivots to date, with a third pivot planned. The two pivots in place, as well as the pivot that is planned, each have the capability of irrigating 100 hectares. Furthermore, Figure 26 does not depict the thirty hectares under floppy irrigation at Olerai Mara Farm.

While irrigation timeframe and quantities vary with rainfall, it is estimated that each hectare of land under irrigation uses approximately five to seven mm of water per day as estimated by Tarquin Wood of Olerai Limited Mara Farm. To determine the amount of irrigation required to make up for insufficient rainfall (assuming a daily irrigation requirement of 7 mm), GIS data layers showing daily rainfall amounts were used. The GIS shapefiles, provided by GLOWS, supply 2006 daily rainfall amounts in 123 square kilometer blocks throughout the MRB. Since irrigation areas fall within several blocks, the average rainfall for the blocks was calculated and utilized. Figures 27 and 28 show the GIS rainfall shapefiles overlaid with boundary shapefiles of the MRB and large-scale irrigation farms within the basin. The circles in each of the maps represent the cropland area that is under pivot irrigation.

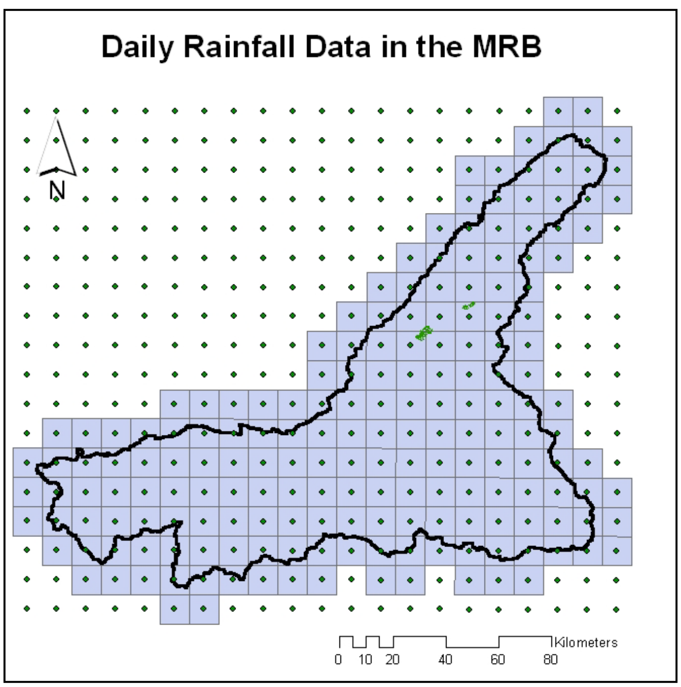

Figure 27: GIS data shapefiles used to calculate daily rainfall amounts in MRB.

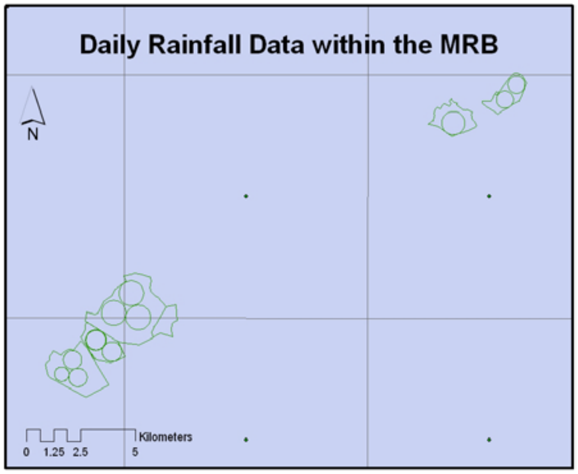

Figure 28: Magnified image of GIS shapefiles used to calculate daily rainfall in MRB.

Table 10 below shows the average daily amount of rainfall received in 2006 for areas under pivot irrigation within the MRB and the number of days in which that amount of rainfall was received. The table also shows the amount of water required (mm) for a given day due to insufficient rainfall amounts, based on a daily water demand of seven mm. Using this rainfall data, annual irrigation requirements can be calculated for the 690 hectares under irrigation within the basin.

Table 10: Daily rainfall amounts and requirements for cropland within the MRB

Rainfall Received (mm)	Number of Days per Year	Daily Quantity of Irrigation Required (mm)
0	202	7
1	21	6
2	19	5
3	22	4
4	15	3
5	12	2
6	11	1
7	7	0
Greater than 7	56	0

3.4.6 Large-Scale Mining

The Behumba Mine and the North Mara Mine are the two gold mining facilities operating within the MRB (see Figure 29). The Behumba Mine underwent initial production in 2003 under the state-owned company Meremeta Ltd. As of 2004, the annual capacity of the Behumba Mine was 1,200,000 metric tons of ore processing and 3,300 metric tons of gold (Yager, 2004). Production at the North Mara Mine was initially started under East African Gold Mines, Ltd in the third quarter of 2002 before being purchased by Placer Dome Gold Inc. in 2003 and then by Barrick Gold Corporation Inc. in August of 2006 (Yager, 2004 and Mfanga, 2006). As of 2004, the annual capacity of the NMM was 2,800,000 metric tons of ore processing and 10,000 metric tons of gold (Yager, 2004).

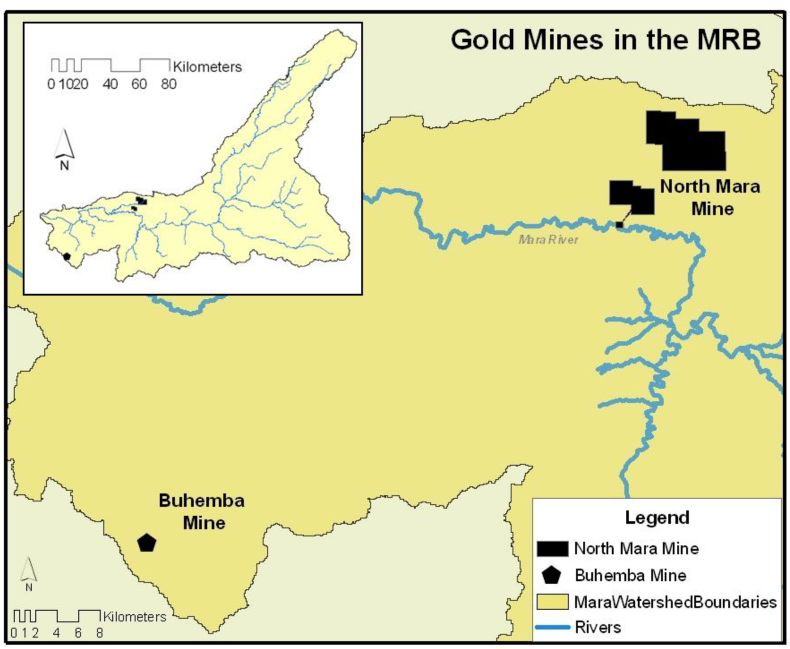

Figure 29: Large-scale mining operations within the Tanzanian portion of the MRB.

Source: Buhemba coordinate location obtained from Intierra Ltd (Intierra Mapping)

North Mara Mine shapefile obtained from GLOWS program

For the purpose of this research, only the NMM will be considered in the water-use and demand analysis due to location and availability of data. The Buhemba Mine is located near the edge of the MRB and does not appear to have proximity to the Mara River or its tributaries. This would seem to be especially true during the dry season since the Mara River is the only perennial river in the lower portion of the basin. Most of the smaller tributaries of the Mara tend to dry out during the dry season. This is not to say that the Buhemba Mine does not impact the MRB, for it is likely that the water used in the mining process does play into the hydrology of the MRB. However, due to limited information on the Buhemba Mine and its water use practices, the mine will not be considered in the analysis and the focus will instead be on the NMM.

The NMM is located in the Tarime District in the Tanzanian portion of the MRB, approximately ten kilometers south of the Kenyan-Tanzania border. Since it began operation in the third quarter of 2002, the NMM project has encompassed three pits: the Gokona, the Nyabigena, and the Nyabirama pits as seen in Figure 30 (Yager, 2004). Under ownership of Placer Dome Inc. of Canada, the project began a comprehensive environmental monitoring program that is being continued by the mines current owner, Barrick Gold Corporation of Canada. The program is responsible for the production of an annual environmental monitoring report (first released in 2004).

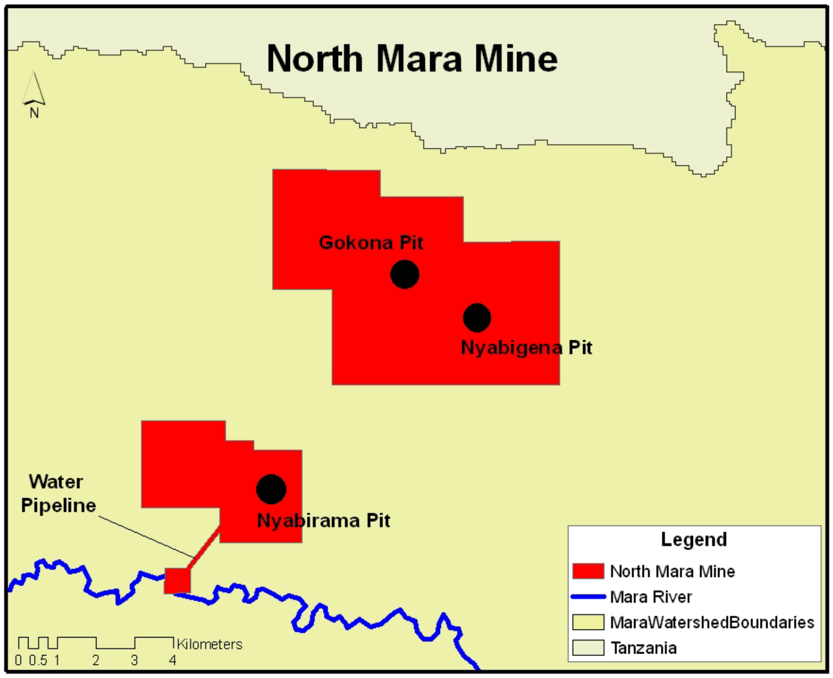

Figure 30: Estimated pit locations for North Mara Mine

Source: Approximate Pit locations are taken from NMM, 2006 (Figure 1.1)

Gold mining can often be a water intensive process. Water aiding in the operation of the NMM is pumped out of the Mara River and is then piped to the processing plant. During the initial phase of processing, ore is brought to the processing plant where it is crushed. A cyanide solution is then applied, dissolving the gold and allowing it to be collected. The collected gold then goes on to be refined further whereas the waste or "tailings" is washed away and stored in a tailings pond. The NMM, recycles the waste water from the tailings pond back to the processing plant, where it re-enters the cycle. However, the "waste" water is not sufficient for all processes and there needs to be a continuous supply of "clean" water to aid in the gold washing process, as well as a supply of water to help run the facility (i.e. bathrooms, living quarters, etc.). For this analysis, the 2005

Environmental Monitoring Report provided sufficient water-use data to calculate water demand for the NMM (NMM, 2006).

3.5 Limitations of the Study

There are a number of limiting factors in this study. Potential limitations arise from variations in data across national boundaries and from differences in how data are collected, stored and made available. Temporal differences in data also occur, as seen in the variations of census data within and between the different water use factors. For example, temporal differences occur within the water demand factors of human and livestock populations based on when the population data were collected. More specifically, the national human census data used were collected in 1999 in Kenya and 2002 in Tanzania where as livestock data used range from 1995 to 2005.

Furthermore, data also varies temporally between the different water demand factors. As mentioned, human population data were collected in 1999 and 2002 whereas livestock data used range from 1995 to 2005. These dates differ with the time frames of the other factors as well, for wildlife data are from 2000, bed occupancy rates used to calculate tourist lodging water demand was taken from a study conducted between 1997 to 2000, general irrigation data are from 2006, and mining data are based on 2005 data (see sections 3.4.1 to 3.4.6 for more detail).

Accuracy for this analysis could be improved with the acquisition of more consistent and up-to-date data for better defined and more localized areas. For example, livestock population data were derived from different sources, from varying dates and were limited to the district level. More accurate water demand calculations could be obtained if data were obtained more locally (at the ward level instead of district level) and if the data were collected from a current and similar time period. More accurate data would not only provide better estimations on the number of livestock existing within the MRB, but would also aid in more accurate assessments of the other water demand factors as well.

Limitations in this study also occur due to data gaps. In this analysis, water-demand estimates are affected by a lack of available and consistent data. For example, water demand estimations for lodges and tent camps within and around the MMNR could be improved with increased data on the number, type, and location of lodges and tent camps. Data gaps also affect calculations predicting the water-demand of gold mining facilities within the basin, due to a lack of available data from the Buhemba Mine, located near the southern boundary of the MRB.

Moreover, water usage estimates for human, wildlife and livestock populations, as well as water usage estimates for lodges and tent camps, vary on an individual basis. For human, livestock and wildlife populations, usage depends on a wide variety of factors including climactic conditions, metabolism, and diet. Water usage at tourist accommodations will not only vary between guests, but will differ depending on the amenities offered and how each individual facility operates. Furthermore, for each water demand factor, variations will also occur seasonally and annually.

Another significant limiting factor of this study is the exclusion of water demand quantities required to sustain environmental flow that supports aquatic and riparian life within the basin. Additionally, requirements to sustain non-consumptive uses within the basin such as hydroelectric power and water needed to support fisheries (water that flows into Lake Victoria) are also not considered.

All of these variables affect the precision and accuracy of this water demand analysis and offer suggestions as to how to more accurately assess the water need within the basin. However, baseline estimations established in this paper do offer insight into each of the water-demand factors, highlighting areas that might necessitate further and more exact assessment.

4. RESULTS AND DISCUSSION

4.1 Human Population

The human population is the second largest water-demand factor within the MRB, with an annual water demand of 4,820,336 m . It is estimated that the total human water use within the MRB is 13,206,400 liters or 13,206.4 cubic meters (m) per day. Table 11 below shows the daily water need from both the Kenyan and Tanzanian portions of the basin, which are 8,574,120 liters per day (lpd) and 4,632,280 lpd respectively.

In order to calculate monthly totals, the daily total water demand within the basin was multiplied by the number of days in each month. Therefore, monthly totals for water use range between 409,398.4 m , 396,192 m , and 369,779.2 m per month, depending on

Table11: Human water demand within the MRB

KENYA

District	Population	Water Quantity Required (lpd)
Bomet	200,008	4,000,160
Nakuru	56,687	1,133,740
Narok	132,742	2,654,840
Trans Mara	39,269	785,380
Total Water Required:	**428,706**	**8,574,120 liters per day**

TANZANIA

District	Population	Water Quantity Required (lpd)
Musoma Rural	51,114	1,022,280
Serengeti	98,873	1,977,460
Tarime	81,627	1,632,540
Total Water Required:	**231,614**	**4,632,280 liters per day**

whether the month has twenty-eight, thirty or thirty one days. Results are displayed in Figure 31 below. The total quantity of water required to sustain the human population within the MRB for one year equals 4,820,336 m .

The water demand calculated in Figure XXX is based on human population statistics from 1999 for Kenya and 2000 for Tanzania, and therefore is an underestimate of current demand based on up-to-date population estimates. In order to achieve more accurate water-demand estimates, as well as to make future predictions on water-demand, the annual growth rates for each country need to be considered. Based on a growth rate of

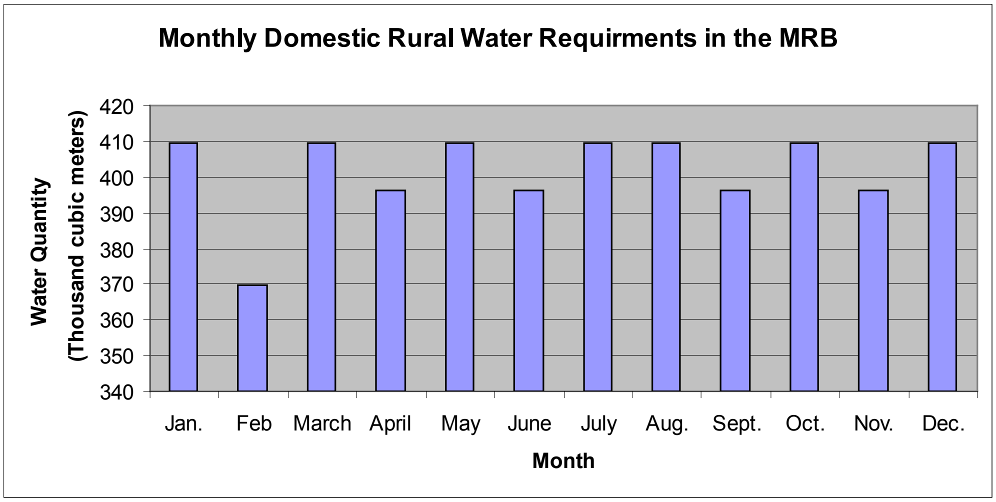

Figure 31: Monthly domestic rural water requirements in the MRB

2.4 percent for the Kenyan portion of the MRB (Kenya NBS, 2006), and a growth rate of 2.5 percent for the Tanzania portion of the basin (Tanzania NBS, 2003), Table 12 shows human populations estimates and their corresponding water demand for the years 2010, 2020, and 2030.

Table 12: Human population projections and their corresponding daily water demand

	2010		2020		2030	
	Population	**Daily Water Demand (m)**	**Population**	**Daily Water Demand (m)**	**Population**	**Daily Water Demand (m)**
KE	556,497	11,129.94	705,448	14,108.96	894,268	17,885.36
TZ	282,204	5,644.08	361,251	7,225.02	462,437	9,248.74
Total	**838,701**	**16,774.02**	**1,066,699**	**21,333.98**	**1,356,705**	**27,134.10**

Based on the above human population predictions, water-demand will increase from the current estimated daily demand of 13,206.4 m to 16,774.02 m in 2010, to 21,333.98 m in 2020, and to 27,134.10 m in 2030. These estimates show that the water-demand from the human population within the basin will more than double by the year 2030, compared to 1999 Kenyan and 2002 Tanzanian census data.

4.2 Livestock Populations

Livestock populations form the third greatest water-demand factor within the MRB. The estimated mean daily drinking water requirement for livestock populations in the MRB is 11,108,401 liters or 11,108.401 m . The practical guideline for development daily water requirement is estimated at 17,727,504, or 17,727.504 m . Moreover, the total estimated annual mean drinking water requirement for livestock populations in the MRB is 4,054,566.37 m whereas the practical guideline for development annual water requirement equals 6,470,538.96 m .

Table 13 below lists the daily drinking water requirements for district livestock populations residing within the MRB. Both the mean daily drinking water requirements and practical guideline for development estimates are listed. However, since a practical guideline for development quantity was not known for the donkey, the mean daily drinking water requirement was substituted so that MRB totals could be calculated.

Table 13: Daily drinking water requirements for MRB district livestock populations

Kenya	Daily Drinking Requirements (liters)					
	Mean			Practical guideline for development		
District	**Cattle**	**Shoats**	**Donkey**	**Cattle**	**Shoats**	**Donkey***
Bomet	1,543,847	67,376	95,009	2,353,425	168,440	95,009
Narok and Trans Mara (combined)	3,013,894	391,430	60,723	4,594,350	978,575	60,723
Nakuru	386,991	31,468	unknown	589,925	78,670	Unknown
Total drinking water requirements:	**4,944,732**	**490,274**	**155,732**	**7,537,700**	**1,225,685**	**155,732**

Tanzania	Daily Drinking Requirements (liters)					
	Mean			Practical guideline for development		
District	**Cattle**	**Shoats**	**Donkey**	**Cattle**	**Shoats**	**Donkey***
Musoma	1,895,397	112,324	11,941	2,889,325	280,810	11,941
Serengeti	1,792,635	234,918	3,819	2,732,675	587,295	3,819
Tarime	1,393,328	70,164	3,137	2,123,975	175,410	3,137
Total drinking water requirements:	**5,081,360**	**417,406**	**18,897**	**7,745,975**	**1,043,515**	**18,897**

*Practical guideline for development daily water requirement is not known for the donkey; therefore, the mean daily water requirement is utilized in its place for the purpose of estimating overall totals.

For this analysis, the practical guideline for development is provided for comparison purposes, as a way of showing optimal requirements. However, for this discussion section, and in adding the cumulative water-demand for all water-use factors, the mean livestock water requirements are used.

Unlike the human population within the MRB, livestock populations do not have a steady annual growth rate and are more likely to fluctuate with variations in climate. Within the Tanzanian portion of the basin, both cattle and goat populations show increasing trends (see Figure 14) while the sheep population within the Tanzanian portion of the basin, and livestock populations within the Kenyan portion of the basin, have either remained the same or declined (as described in section 2.2.3.2). Regardless, the potential variations in livestock population growth patterns remain high and the fact that livestock populations are the third largest consumers of water within the basin warrants a closer look at the potential affect increasing populations could have on the hydrology of the basin.

Based on water demand calculations, cattle are by far the largest consumers of water among livestock within the basin. With a mean daily demand of 10,026.091 m and a mean annual demand of 3,659,523.142 m , cattle makeup approximately ninety percent of the total water demand from livestock. Based on livestock population increases of ten, twenty-five, and fifty percent, the annual water demand for cattle alone would raise to 4,025,477.252 m , 4,574,405.424 m , and 5,489,287.706 respectively, as seen in Table 13. On the other hand, shoats account for just over eight percent of the water demand from livestock in the MRB and donkey account for just fewer than two percent. The resulting water demands from population increases of ten, twenty-five, and fifty percent are listed in Table 14.

Table 14: Estimated annual water demand (m) for livestock populations within the MRB, including hypothesized population increases and their associated water demand.

	Factor	Base Statistic*	10% Increase	25% Increase	50% Increase
Cattle	Population	611,347	672,482	764,184	917,021
	Annual Water Demand	3,659,523.142 m	4025477.252 m	4574,405 m	5,489,287.706 m
Shoats	Population	453,840	499,224	567,300	680,760
	Annual Water Demand	331,303.2 m	364,433.52 m	414,129 m	496,954.8 m
Donkey	Population	14,083	15,492	17,604	21,125
	Annual Water Demand	63,739.658 m	70,116.792 m	79,675.704 m	95,611.75 m
Total Annual Water Demand		**4,054,566.43 m**	**4,460,027.56 m**	**5,068,210.13 m**	**6,081,854.26 m**

* Base statistics represent the mean annual water demand calculated in section 3.4.2.

Based on a 1992 study by the Japan International Cooperation Agency (JICA), the livestock water demand for the Kenyan portion of the Mara River catchment was estimated to be 159.11 m per year in 1990, with predicted increases to 190.3 m per year in 2000 and 227.68 m per year in 2010 (Krhoda, 2001). However, compared to calculations provided in Table 14, these estimations are extremely low and do not seem to account for total livestock population counts within the MRB.

4.3 Wildlife Populations

Wildlife populations are the fourth largest consumer of water within the MRB. Table 15 below shows that the daily water demanded for wildlife populations within the Narok and

Trans Mara districts is approximately 1,754,611 liters, while the yearly water demand is approximately 640,433.015 m per year.

Table 15: Daily water demand from wildlife within the MRB

Animal	**Total Daily Water Requirements (liters)**
Buffalo	146,723
Eland	23,575
Elephant	148,350
Gran't Gazelle	34,718
Thomson's Gazelle	32,880
Maasai Giraffe	88,520
Impala	92,323
Hartebeest	7,123
Topi	31,220
Warthog	6,612
Waterbuck	1,287
Wildebeest	617,792
Burchell's Zebra	523,488
Total	**1,754,611**

However, the above estimate does not take into consideration the water demand of the annual migration. It is estimated that during the four month period (approximately 123 days) when the annual migration exists within the MRB, there is an additional water demand of approximately 1,340,700 m . In total, the water demand for the four month period when the annual migration is within the MRB (including the resident wildlife populations) is approximately 1,412,095.5 m . In comparison, the annual water demand for both resident and migrating wildlife is 1,836,711.3 m . Therefore, the four month period when the annual migration is within the MRB accounts for over seventy-six percent of the total yearly water demand from wildlife. Figure 32 below shows a monthly breakdown of wildlife water demand within the MRB.

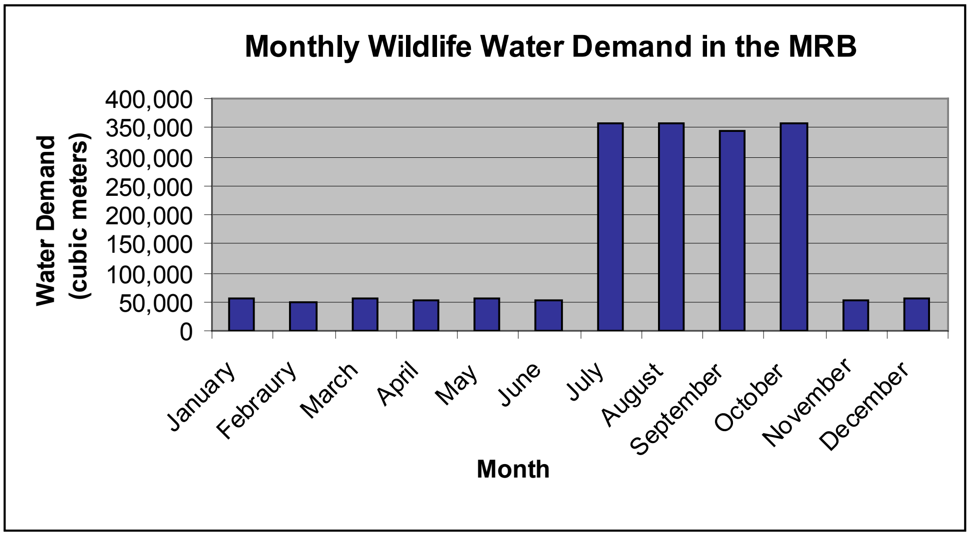

Figure 32: Monthly wildlife water demand within the MRB

While the accuracy of the water demand is based on estimations in wildlife population numbers and usage amounts, the analysis does begin to show the extent of water demand from wildlife, especially in considering the water demand from the annual migration. Overall estimates of wildlife water demand are an underestimate of the total water demand that wildlife places on the MRB. First, only a select number of wildlife species were included in the analysis. While the list includes the species that would seem to have the greatest quantitative impact on water use, numerous other species were excluded. Secondly, only wildlife species counted in the Trans Mara and Narok districts of Kenya were considered, due to the difficulty in distinguishing wildlife populations for only the portion of the SNP that lies within the MRB boundaries. Moreover, the 2000 wildlife population numbers utilized in this analysis were taken at the height of the year 2000 drought, when a more than fifty percent decline in wildlife was seen when compared to 1996 census data (UNEP, 2002).

In looking at the current and future water demand from wildlife in the MRB, it seems that the greatest impact lies not within the non-migrating wildlife species within the MRB, but with the migratory species that migrate to the Mara River during the dry season. In looking at the non-migratory wildlife within the Masai Mara ecosystem, significant population increases do not seem likely, as seen in Ottichilo et al (2000) which shows declines averaging fifty-eight percent over the twenty year period prior to 2000 for this population. Therefore, in assessing the total water demand from wildlife in the MRB, the annual migration is an essential consideration for it largely determines the overall quantity of water demanded.

4.4 Lodges and Tent Camps

Lodges and tent camps within the MRB demand the least amount of water out of the six water demand sectors considered in this research. Table 15 below shows combined daily and monthly water use for the twenty-nine lodges and tent camps considered in this analysis, based on the monthly bed occupancy rates. Estimated annual water-use for the twenty-nine facilities utilized in this analysis is 152,634,220 liters or 152,634.2 cubic meters.

Table 16: Daily and monthly water use for twenty-nine lodges and tent camps in MRB

Month	Number of Beds Occupied (of the 2116 available)	Water Usage per Day		Water Usage per Month	
		gallons	Liters	Gallons	Liters
Jan.	1058	105,800	402,040	3,279,800	12,463,240
Feb.	1228	122,800	466,640	3,438,400	13,065,920
March	995	99,500	378,100	3,084,500	11,721,100
April	921	92,100	349,980	2,763,000	10,499,400
May	688	68,800	261,440	2,132,800	8,104,640
June	1058	105,800	402,040	3,174,000	12,061,200
July	1397	139,700	530,860	4,330,700	16,456,660
Aug.	1630	163,000	619,400	5,053,000	19,201,400
Sept.	1217	121,700	462,460	3,651,000	13,873,800
Oct.	1164	116,400	442,320	3,608,400	13,711,920
Nov.	899	89,900	341,620	2,697,000	10,248,600
Dec.	953	95,300	362,140	2,954,300	11,226,340
Water Use Totals		**1,320,800**	**5,019,040**	**40,166,900**	**152,634,220**

However, with tourism to both the MMNR and the SNP continuing to rise, it seems unlikely that the water demanded from tourist accommodations in and around the MRB will recede anytime into the future. On the contrary, it is more likely that bed occupancy rates within the lodges and tent camps will increase. While there is currently a moratorium in place that that bans further development within the MMNR, this does not eliminate the possibility that additional sites could be erected outside park boundaries, placing further demand on the Mara River and its tributaries.

As tourism continues to rise, so will bed occupancy rates, regardless of whether or not further development is permitted. With no further building within the region, the water demand potential for tourist accommodations within the MRB can reach 293,489.2 m per year at full occupancy. This is more than double the current water demand based on 1997 to 2000 occupancy rates. If broken down on a monthly basis, full occupancy creates a monthly water demand of approximately 24,457.4 m .

Moreover, it is likely that the calculated current water demand is an underestimate because only select facilities thought to have the greatest water demand were considered in this analysis, leaving several accommodation facilities unaccounted for. For example, of the sixty-five lodges and tent camps found to exist within and around the MRB, only twenty-nine were analyzed in this research. These were the facilities thought to possess the greatest water demand because they each have running water and flush toilets. While the other thirty-six facilities might not hold the same standards, they still utilize water and therefore, would place additional water demand on the basin especially since their combined bed capacity is approximately 617 beds (see Appendix III). Unfortunately, due to limited knowledge of the water use practices of these facilities, as well as limited knowledge of their operating seasons, it would not be realistic to try and quantify their water demand for the purpose of this analysis.

During site interviews with facility managers/operations personnel, the question of permitting was brought up. Of the eight lodges and tented camps visited, six of the facilities said that they did have a permit to abstract water, while two facilities said that permits were not needed. Kichwa Tembo and Mara Intrepid both stated that they had permits that needed to be renewed annually for abstraction from the river and from a borehole, respectively. Mara Fig Tree said that they possessed a permit for a borehole, which was a one-time permit, while Keekorok said that they had a ten year permit for their borehole. Both representatives at Mara Serena and Mara Simba said that their facility did not hold a permit for their method of abstraction, which was from the river, but Mara Serena was under the impression that the permitting system was under reconstruction and that they would soon be required to obtain a permit.

Table 17 and Table 18 show a combination of permitting data obtained in the field for lodges and tent camps within the MRB. Site visits were made to Lake Victoria South Water Catchment Authority Office in Kisumu, Kenya, the Bomet District Water Office in Kenya, the Narok District Water Office in Kenya, and the Lake Victoria Basin Water Office in Mwanza, Tanzania. Both photocopies and digital photographs were utilized in obtaining permitting records from the above locations.

Table 17: Permits existing within the MRB related to lodges and tent camps

Hotel	River	Permit No.	Use
Mara Landmark Ltd (Hotel)	Talek River	29606	Domestic/Irrigation
Mara Holdings Ltd (Fig Tree Camp)	Talek River	29592	Domestic/Irrigation
Lonrho Hotels	Mara River		Domestic/car wash
Mpata Investment Ltd (Mpata Safari Club)	Mara River	25952	
Masai Mara (SOPA) Lodge	Mara River	23632	
Mara Buffalo Camp	Mara River	22442	
Glen Cottar Safaris	Mara River	21443	
Tourism Promotion Services	Mara River	13895	

Table 18: Lodges and tent camp permits for boreholes within the MRB

Hotel	Borehole Number	Total Depth
Mara River Camp	4715	87
Keekorok Lodge	12832	65.5
Mara Intrepid Club	6068	111
Fig Tree Camp	10732	65

As is apparent from the above tables, the number of water abstraction permits collected is significantly less than the number of lodges and tent camps currently operating within the MRB. A portion of this gap could be due to an inability to collect comprehensive information on all existing permits. Regardless, this data shows that there is a significant gap in permitting consistency, a lack of knowledge from the managers and operations personnel in the facilities on permitting requirements and practices, and a definite lack of enforcement that would otherwise ensure that permits were in place.

Due to insufficient information, including a lack of permitting data and scarce metering of abstraction amounts, obtaining exact figures on water-use and demand from lodges and tent camps within the MRB is impossible. However, insight into the accuracy of the water demand for lodges and tent camps calculated in this analysis can be seen in looking at a sample of water use statistics collected from site interviews at seven camps and lodges visited during the field research portion of this research. Below, Table 19 shows comparisons between the amount of water used according to site interviews with facility managers and/or employees and quantities derived in this analysis. Water quantities from site interviews are given as daily averages over the period of an entire year. Therefore, for comparison purposes, monthly occupancy rates were averaged together to get a daily occupancy rate of fifty-two percent, which was then multiplied by the number of beds offered at each lodge or camp. The number was then multiplied by the general daily water demand amount of 380 liters as calculated in section 3.4.4.

Table 19: Water-use per day comparisons between site interview data and analysis data

	Average Water Use Per Day (liters)	
Hotel	**Quantity Used based on Site Visit Interviews**	**Quantity Used based on Occupancy Rates***
Kichwa Tembo Camp	5,000	16,598
Mara Serena Lodge	80,000	29,245
Mara Fig Tree Camp	15,000	27,664
Mara Intrepids Club	60,725	11,856
Mara Simba Lodge	100,000	38,730
Mara Sarova	144,000	30,628
Keekorok	100,000	39,915
Total Daily Use	**504,725**	**194,636**

* Quantity determined based on occupancy rates, bed capacities, and water use statistics described in section 3.4.4.

Based on Table 19, the water use quantity given by the lodge or tent camp is higher than the estimate based on occupancy rates and general water use statistics in five out of the seven examples. The overall difference is significant, as site interview statistics are more than double the calculated amount used in this analysis. If total annual averages are calculated based on the two categories above, the annual demand for the seven lodges and camps above would be 184,224,625 liters based on site interviews and 71,042,140 liters based on analysis calculations.

Based on the above examples, it is quite possible that the water demand estimates for the twenty nine lodges and camps used in this analysis are considerably underestimated. Since site visits to all twenty-nine of the lodges and tent camps were not possible, it must be assumed that calculations derived from this analysis are baseline estimates, and are most likely greater than the quantities provided. However, it is also important to note that water use estimates given by site managers and personnel are most likely estimates, for not all facilities have the equipment needed to monitor water use. Furthermore, site interview estimates also depend on how honestly each facility reported water use.

4.5 Large-Scale Irrigation Farming

Irrigation from large-scale farming is the largest water demand sector within the MRB, with an annual water demand of approximately 12,323,400 m , as shown in Table 20. Furthermore, Table 21 shows a monthly breakdown of irrigation water demand within the MRB based on 2006 rainfall data.

However, it is important to note the estimates assume year-round irrigation of the 690 hectares of cropland under irrigation within the MRB. Realistically, however, this might not be the case because crops are often rotated to some extent and might not require irrigation year-round. Furthermore, rainfall between years varies, and will not likely be consistent with 2006 daily rainfall amounts.

Table 20: Water demand from irrigated cropland within the MRB

Daily rainfall received (mm)	Number of days rainfall was received	Irrigation needed (mm)	Irrigation needed (m)	Area of cropland requiring irrigation (m)	Irrigation Volume (m)
0	194	7	0.007	6,900,000	9,370,200
1	20	6	0.006	6,900,000	828,000
2	26	5	0.005	6,900,000	897,000
3	20	4	0.004	6,900,000	552,000
4	23	3	0.003	6,900,000	476,100
5	8	2	0.002	6,900,000	110,400
6	13	1	0.001	6,900,000	89,700
7	3	0	0	6,900,000	0
Greater than 7	58	0	0	6,900,000	0
Total annual irrigation demand in cubic meters					**12,323,400**

1 ha = 10,000 m
1 mm = 1/1000 m
Daily irrigation requirement = 7 mm

Table 21: Monthly irrigation water demand for cropland within the MRB

Month	Additional Rainfall Required (mm)	Monthly Water Demand
January	188	1,297,200
February	146	1,007,400
March	101	696,900
April	90	621,000
May	132	910,800
June	203	1,400,700
July	204	1,407,600
August	183	1,262,700
September	176	1,214,400
October	199	1,373,100
November	89	614,100
December	75	517,500

Previous estimates of water demand from irrigation approximate the monthly water demand at .059 m per month which equates to approximately .708 m annually, according to the 1992 *The Study on the National Water Master Plan* conducted by the Kenya Ministry of Water Development (MoWD) and Japan International Cooperation Agency (Onjala, 2004 and Krhoda, 2001). Therefore, it can be seen that past assumptions on irrigation water demand within the MRB are greatly underestimated based on current uses.

Furthermore, a consensus within the literature seems to conclude that there is considerable development potential for irrigation schemes throughout the Mara River Basin (Nile Basin Initiative, 2004 and Onjala, 2004). For example, according to the national average only nineteen percent of Kenya's potential area is under irrigation (FAO, 2005). More specifically, it was estimated that the total potential for upland crop within the basin is approximately 32,000 hectares (Onjala, 2004 and Krhoda, 2001), which is more than forty-three times the current irrigated cropland existing within the MRB. While large-scale irrigation operations currently only exist within the Kenyan portion of the basin, within the Tanzanian portion of the MRB it is estimated that there is the potential to irrigate 2,192 hectares. Currently, there are approximately eighty-five hectares under small-scale irrigation (URT, 2003b).

There are plans to expand irrigation within both the Kenyan and Tanzanian portions of the basin. For example, the Study on the National Water master Plan emphasizes the importance of investing in water resources development and has proposed eighteen major irrigation schemes and 140 small irrigation schemes for 2010 (WRI, 2007). Additionally, the Nile Basin Initiative has dedicated funds to implement small-holder irrigation development projects within the Tarime District, Tanzania beginning early in 2007 (Nile Basin Initiative, 2004).

Challenges in quantifying water demand from irrigation in the MRB, now and in the future, seem inevitable for the extent to which irrigation is currently permitted within the MRB is not clear. Table 22 and 23 below show irrigation permit information collected from the Water Resources Management Authority - Lake Victoria South Catchment Region Office, the Narok District Water Office and the Bomet District Water Office. However, irrigation permitting information could not be found for all large-scale irrigation schemes operating within the basin. It is possible that the permit information listed is not exhaustive of what exists, but was the available data from the listed locations at the time of collection. For example, no specific permit data was listed for Lemontoi Farm.

It is important to realize that permitted water abstraction amounts do not necessarily depict how much water is used, for usage depends in part on weather conditions at a given time and not on maximum allowable amounts. Table 22 lists permits found that correspond to the large-scale irrigation farms discussed in this analysis while Table 23 lists miscellaneous permits existing within the MRB that are also related to irrigation.

Table 22: Permits corresponding to the large-scale irrigation farms within the MRB

Name of Applicant	River	Permit Number	Use
Olerai Limited	Mara	29647	Domestic/Irrigation
Olerai Limited	Mara	29646	Domestic/Irrigation
Olerai Limited	Olchoro Dry Water Course		Domestic/Irrigation
Shimo Limited	Mara		Irrigation
Shimo Limited	Amala		Irrigation
Ndakaini Farm Limited	Amala	29501	Irrigation
Ndakaini Farm Limited	Amala	26405	Domestic/Irrigation
Ndakaini Farm Limited	Amala	29769	Domestic/Irrigation

Table 23: Permits relating to irrigation within the MRB

Name of Applicant	River	Permit Number	Use
Sahakar Limited	Mara		Irrigation
Mara Land Mark Hotel	Talek	29609	Domestic/Irrigation
Mara Holdings Hotel Fig Tree Camp)	Talek	29592	Domestic/Irrigation
Mara Water Users Association	Amala		Irrigation
Agnes Wambui Waweru	Amala		Irrigation

4.6 Large-Scale Mining

Large-scale mining is the fifth largest water demand factor within the MRB. Figure 33 below shows the NMM's average daily abstraction rate for each month in 2005. The quantity of water abstracted from the Mara River is compared to the daily allowable abstraction rate of 4200 cubic meters. According to data provided in the NMM 2005 Environmental Monitoring Report, the monthly amount of water withdrawn from the

Mara River was 15,058 m in February, 5,204 m in March, 52,828 m in June, 180,015 m in July, 136,120 m in August, 110,789 m in October, and 124,685 m in November (NMM, 2006). There was minimal abstraction from the river for the months of January, April, and May due to sufficient amounts of rainfall being collected in the raw water dam as well as recycling of water from the tailings pond. However, for the months of September and December, water abstraction from the Mara River was not physically possible because the level of the river fell below the pipe intake point (NMM, 2006). For the months of July and August, the mine exceeded its daily allowable abstraction rate by 1607 m per day and 191 m per day respectively. As mentioned above, the monthly abstraction for July was 180,015 m and for August was 136,120 m compared to an allowable abstraction rate of 130,200 m for each month. It is important to note that there are some conflicting quantities in the 2005 NMM Environmental Monitoring Report for the months of July and August, so it is possible that abstraction amounts vary for the amounts listed above. The discrepancy is seen in Figure 3-4 of the NMM Environmental Monitoring Report, which shows the extraction rate as being 4,350 m per day in July and 1000 m per day in August as opposed to the amounts listed above, which are taken from Table 3-5 in the 2005 Environmental Monitoring Report. Nevertheless, using the 1607 m per day in July and 191 m per day in August measurements, the total amount of water abstracted by the NMM from the Mara River in 2005 totaled 624,810 m .

In quantifying water demand from large-scale mining facilities within the MRB, only the NMM was considered due to a lack of available information on the other gold mining facility within the basin, Buhemba Mine. Therefore it is likely that water-use from this demand factor was underestimated.

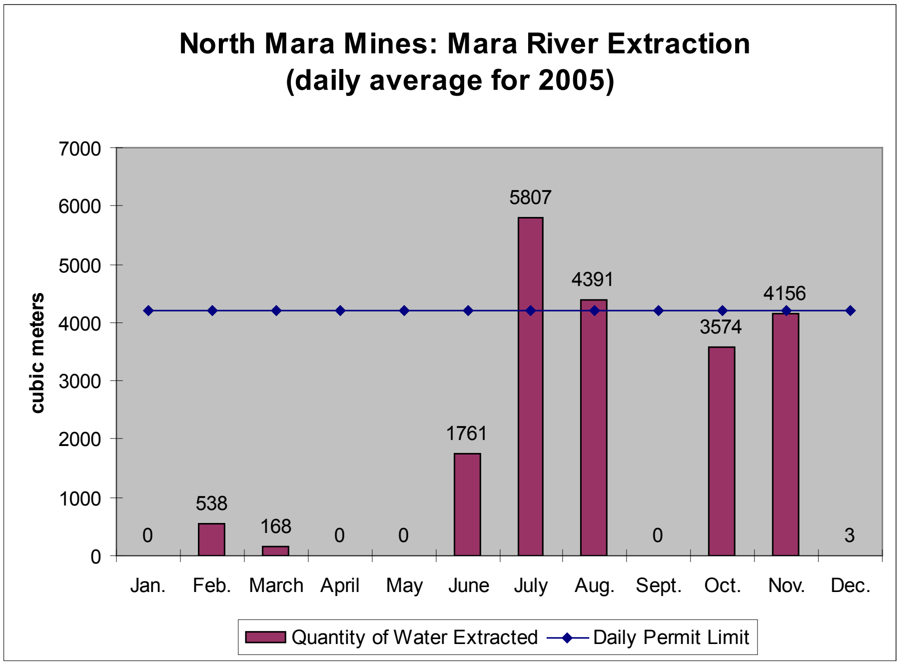

Figure 33: North Mara Mine 2005 average daily extraction from the Mara River. Note that abstraction was not possible due to low river flow for September and December and was not needed due to rainfall for January, April and May.

Source: NMM, 2006

In looking at water abstraction data obtained on the NMM (Figure 33), it can be seen that the daily permitted water abstraction from the Mara River is 4,200 m . If utilized to the daily quantity permitted, monthly water use would rise to 130,200 m (based on a thirty-one day month) or 1,533,000 m annually. However, as seen in Figure 33, permitted abstraction does not necessarily define abstraction rates. The permitted daily quantity was exceeded during the months of July and August, was not able to be utilized for the months of September and December because the level of the river fell below the pipe intake point, and abstraction was not needed during the months of January, April and May due to sufficient rainfall amounts. However, if the mining efforts within the basin expand, additional water resources will be required, making it more likely that the allotted abstraction quantities would be fully utilized, or further exceeded as was already the case for the months of July and August. Since gold mining is a growing industry in Tanzania (see section 2.2.3.6), expansion seems inevitable and therefore increases in water demand from this sector are most likely also inevitable. Permitting and enforcement will play a role in the growth of the mining sector, for growth will depend in part on the amount of water that is available and the amount of water that is permitted for mining use.

4.7 Cumulative Water Demand

The total annual water demand from the six water-use factors considered in this analysis is 23,812,454.2 m . The largest water-use factor within the MRB is large-scale irrigation with an annual water demand of 12,323,400 m , followed by the human population (4,820,336 m), livestock populations (4,054,566 m), wildlife populations (1,836,711.1 m), large-scale mining (624,807 m), and lodges and tent camps (152,634.1 m), which are displayed graphically in Figure 34. Furthermore, Table 24 portrays these annual water-demand totals, while also showing the quantity of water demand each month for the various water-use factors. The month of July has the highest monthly water demand at 2,713,726.5 m , followed by October (2,607,258.7 m), August (2,527,675.2 m), September (2,302,131.3 m), June (2,247,673.5 m) and January (2,117,814.9 m). The remaining months of February through May and November and December have lower monthly water demand requirements ranging from 1,336,972.8 m in December and 1,727,056 m in February. Total monthly water demand quantities are greatly affected by variations in large-scale irrigation water demand and seasonal increases in wildlife water demands.

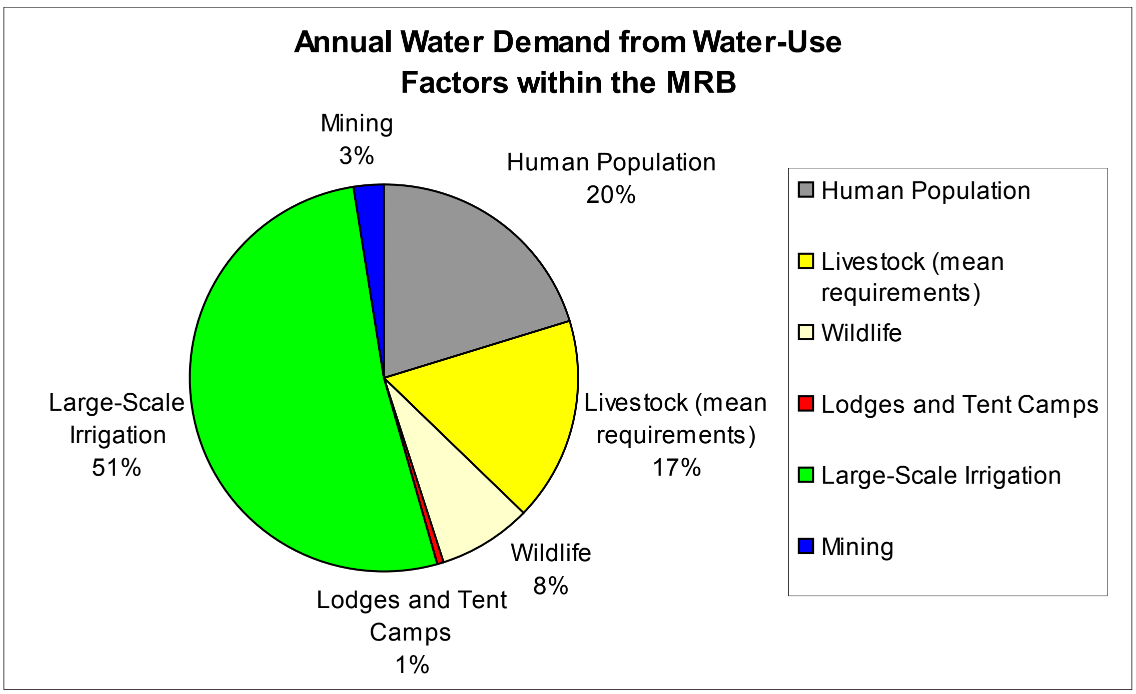

Figure 34: Annual Water Demand from six water-use factors existing within the MRB.

Industrial water use within the MRB is limited with the exception of large-scale mining. However, it is important to note that in the Kenyan portion of the MRB, the Tenwek Missionary Hospital Community does abstract water from the Nyangores River to run its facility and support its community. The hospital uses approximately 100,000 liters of water per day, which equates to a total annual demand of 36,500 m^3. This water supports hospital activities and the surrounding community. While the human population water demand was previously accounted for in section 3.4.1, the water demand to support hospital facilities and patients was not included. The Tenwek Hospital has a staff of approximately 500 people and maintains 350 beds.

Table 24: Monthly and annual water demand requirements (m) for water-use factors within the MRB

Month	Human Population	Livestock (mean requirements)	Wildlife	Lodges and Tent Camps	Large-Scale Irrigation	Mining	Total Water Demand per Month (m)
January	409,398.4	344,360.4	54,392.9	12,463.2	1,297,200	0	**2,117,814.9**
February	369,779.2	311,035.2	49,129.1	13,065.9	1,007,400	15,064	**1,765,473.4**
March	409,398.4	344,360.4	54,392.9	11,721.1	696,900	5,208	**1,521,980.8**
April	396,192.0	333,252.0	52,638.3	10,499.4	621,000	0	**1,413,581.7**
May	409,398.4	344,360.4	54,392.9	8,104.6	910,800	0	**1,727,056.3**
June	396,192.0	333,252.0	52,638.3	12,061.2	1,400,700	52,830	**2,247,673.5**
July	409,398.4	344,360.4	355,894.0	16,456.7	1,407,600	180,017	**2,713,726.5**
August	409,398.4	344,360.4	355,894.0	19,201.4	1,262,700	136,121	**2,527,675.2**
September	396,192.0	333,252.0	344,413.5	13,873.8	1,214,400	0	**2,302,131.3**
October	409,398.4	344,360.4	355,894.0	13,711.9	1,373,100	110,794	**2,607,258.7**
November	396,192.0	333,252.0	52,638.3	10,248.6	614,100	124,680	**1,531,110.9**
December	409,398.4	344,360.4	54,392.9	11,226.3	517,500	93	**1,336,971.0**
Annual Water Quantity Demanded (m)	**4,820,336.0**	**4,054,566.0**	**1,836,711.1**	**152,634.1**	**12,323,400**	**624,807**	**23,812,454.2**

*Assumes the annual migration is within the MRB for the four month period from July through October (Gereta et al, 2002)

** Abstraction was not possible for September and December due to insufficient rainfall and was not needed in January, April, and May due to sufficient rainfall (NMM, 2006)

4.8 Water-Demand and Supply Comparisons

In order to compare the water demand results found in this analysis to water supply within the MRB, flow data collected by the GLOWS program from the Ministry of Water and Irrigation (Kenya) were utilized. These data included flow data from the Nyangores gauging station in the Kenyan portion of the basin, which is shown in Figure 35.

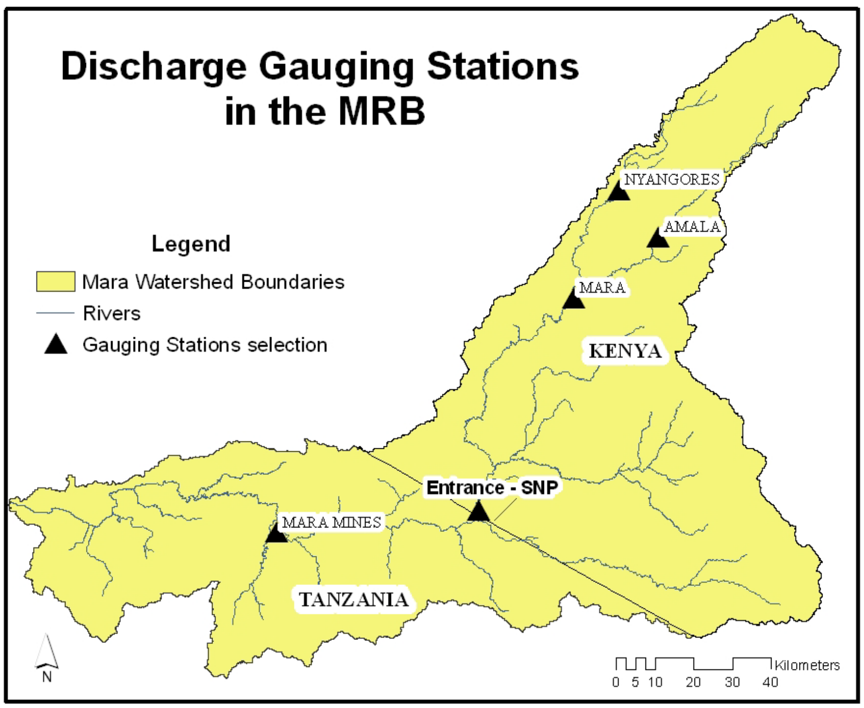

Figure 35: Discharge gauging stations and drainage lines within the MRB.

Data from the Nyangores station was utilized because the gauging station exists at the headwaters of the Mara River and therefore, most closely reveals the flow of the river prior to abstractions and water use from the water sectors. However, it is important to note that data at this gauging station possesses numerous data gaps and discontinuities, but it is the best data available in regards to discharge. Figures 36 and 37 below show monthly average minimum flow and monthly average mean flow for the Nyangores gauging station from1963 to 2000.

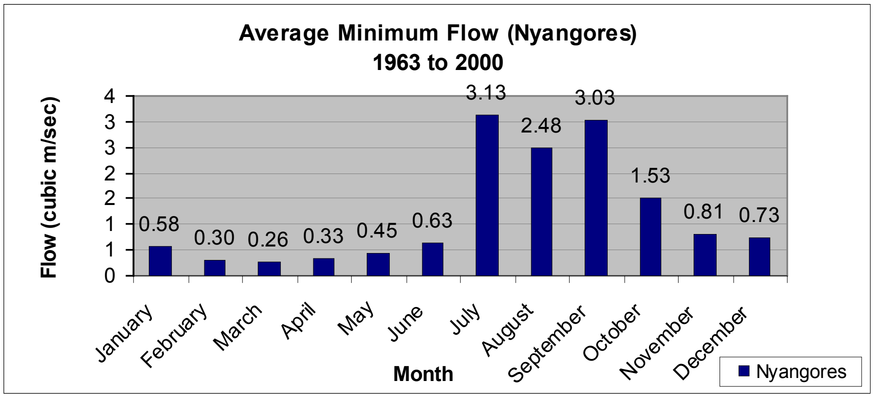

Figure 36: Monthly average minimum flow from the Nyangores gauging station between 1963 and 2000.

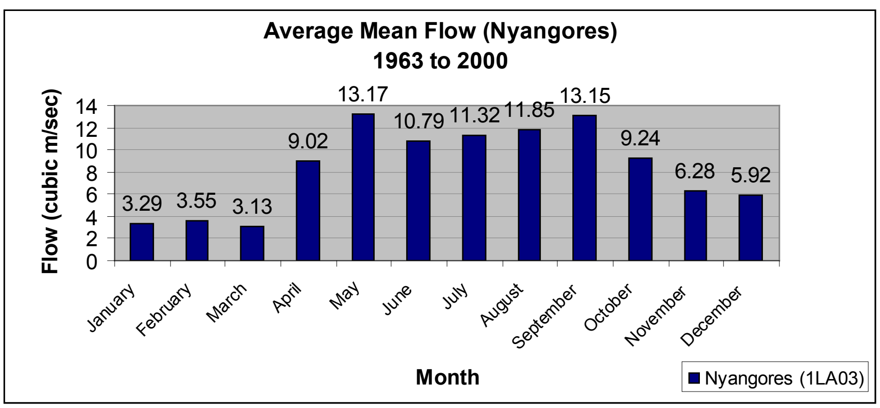

Figure 37: Monthly average mean flow from the Nyangores gauging station between 1963 and 2000.

Using monthly average minimum flow data and monthly average mean flow data illustrated in the flow hydrographs above, flow was compared to the current total quantity of water demanded each month from the six water-use sectors utilized in this analysis. Table 25 below shows the monthly average minimum flow at the Nyangores gauging station compared to the current total water demanded per month within the MRB. Shaded boxes within the table highlight months when estimated demand is greater than the minimum flow. Therefore, the current water demand within the basin already threatens water supply when river flows are low.

Table 25: Total monthly water demand compared to average minimum flow at Nyangores gauging station within the MRB

Month	Total Current Water Demand* (cubic m/sec)	Nyangores - Average Minimum Flow (cubic m/sec)
January	0.791	0.58
February	0.730	0.30
March	0.568	0.26
April	0.545	0.33
May	0.645	0.45
June	0.867	0.63
July	1.013	3.13
August	0.944	2.48
September	0.888	3.03
October	0.973	1.53
November	0.591	0.81
December	0.499	0.73
Total	**6.938**	**14.26**

* The water demands are basin wide

Furthermore, Table 26 below shows the monthly average mean flow for the Nyangores gauging station compared to the current total water demanded per month within the MRB. Unlike comparisons made using the monthly average minimum flow, the monthly average mean flow does not show periods when it would be eclipsed by current water demand within the basin.

Table 26: Total monthly water demand compared to average mean flows from Nyangores gauging station within the MRB

Month	**Total Current Water Demand* (cubic m/sec)**	**Nayagores - Average Flow (cubic m/sec)**
January	0.306	3.29
February	0.313	3.55
March	0.308	3.13
April	0.306	9.02
May	0.305	13.17
June	0.327	10.79
July	0.488	11.32
August	0.979	11.85
September	0.927	13.15
October	0.968	9.24
November	0.861	6.28
December	0.813	5.92
Total	**6.938**	**100.71**

* The water demands are basin wide

5. CONCLUSTIONS AND RECOMMENDATIONS

5.1 Conclusions

Due to insufficient data and gaps in existing data, it is not possible to make exact and definite conclusions on the water availability-demand-use within the MRB. However, based on the data utilized in this analysis, it is possible to make estimations and predictions on current and future water supply and demand scenarios for the MRB.

Based on water demand and supply comparisons made in section 4.8, it is apparent that in minimum flow conditions, the water supply within the MRB is already threatened based on the current water demand. This is of definite concern, especially when it is inevitable that the water demand within the basin is expected to increase with time (see sections 4.1 through 4.6).

Based on monthly average mean flow at the Nyangores gauging station, the current water demanded within the MRB does not seem to pose an immediate threat on the water resources within the basin. However, mean flow data used in this analysis is based on flow averages taken over an extended period of time (1963 to 2000) and therefore does not highlight the extreme variations in conditions, such as periods of drought, limited rainfall and periods of excessive rainfall and/or flooding.

Furthermore, comparisons to monthly average minimum flow and monthly average mean flow are made based only on the six water demand factors utilized in this analysis. Therefore, the calculated demand does not take into consideration the need to maintain a minimum flow to sustain the ecosystem as a whole. This is an essential consideration when looking at water quantity requirements since rivers must maintain a minimum flow to sustain the aquatic and riparian species that depend on them (WRI, 2007). However, the MRB does not have an established environmental flow requirement, which is a proportion of flow intended to maintain river condition at some designated acceptable level on an annual/seasonal/monthly basis (IWMI, 2007). While general “rules of thumb” guidelines do exist for minimum flow requirements, they set broad guidelines that do not take into consideration the variations between ecosystems. Such general guidelines range from minimum flow requirements of one-third to two-third's of river flow, based on percentages of natural mean or median annual flow (Arthington et al., 2006). While this does not provide an exact requirement in the case of the MRB, it does show that a certain level of flow must be maintained in the Mara River to sustain environmental factors. This amount is in addition to the quantity of water required to sustain the six demand factors within the basin because, ultimately, the water demanded by these factors will be removed from the system.

Furthermore, both future climate change and land use and land cover changes need to be factored into the water demand and supply equation. Climate change projections for East Africa forecast less precipitation during already dry months, leading to drought and increased desertification (IPCC, 2001). Projections estimate a five to twenty percent increase in precipitation from December to February (wet months) and a five to ten percent decrease in precipitation from June to August (dry months) (Humle et al., 2001; IPCC, 2001). Moreover, as a result of the strong links between land cover and climate, changes in land use and land cover are important contributors to climate change and variability (CCSP, 2006). Land use and land cover are linked to climate and weather in complex ways including the links between the exchange of greenhouse gases between the land surface and the atmosphere (CCSP, 2006). This is of special concern in the MRB, due to the vast amount of deforestation that is occurring in the headwater area in the Mau Forest as a result of agricultural expansion and population increases.

Therefore, in conclusion, the current total water demand from the human population, livestock, wildlife, tourist lodges and camps, irrigation, and mining do not pose a threat to the water resources of the basin during periods of average mean flow or during periods of maximum flow. However, during periods of minimum flow (based on monthly minimum flow averages) the current total water demand within the MRB does pose a threat to the hydrology of the basin. However, in addition to considering the six water demand sectors that exist within the MRB, it is also necessary to take into consideration minimum environmental flow requirements, as well as the potential affects that climate change and land cover and land use changes will have on the hydrology of the MRB. Furthermore, water demand will continue to rise since increases in the quantity of water demanded from the water demand factors discussed in the analysis are inevitable.

5.2 Recommendations

In order to obtain more accurate and reliable estimations on both the water demand and supply within the MRB, improvements need to be made in data collection. While monetary concerns are most definitely a limiting factor in this regard, conclusions and recommendations are only as good as the data on which they are based. Water availability-demand-use comparisons could be greatly improved with more reliable and functional equipment, in combination with a trained personnel to record and monitor data results.

Furthermore, water-use factors must be more closely monitored. Metering equipment measuring water use should be mandatory for large-scale users, in combination with an established and uniform method to record water-use data. Additionally, improvements need to be made to the permitting system so that water abstractors are not only required to obtain a permit, but are made aware of the need to permit and the reasoning behind it. Furthermore, increased scrutiny for handing out water abstraction and borehole permits should be considered in light of increasing water demands and a potentially decreasing water supply.

Lastly, further research on water quantity within the MRB will continue to produce a more accurate idea of the water resources within the basin, as well as an increased knowledge of the limitations of the hydrologic system. Environmental flow requirements for the MRB need to be established and climate change and land use/land cover changes need to be considered. It is essential that a reliable knowledge base is maintained in regards to water supply and demand, for ignorance and negligence will have disastrous effects on the sustainability of the entire basin.

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APENDICES

Appendix I

Bomet

Type of Livestock	1992	1993	1994	1995
Zebu Cattle	371,623	354,550	354,556	233,730
Grade Cattle	194,336	194,530	194,530	191,950
Sheep	55,245	91,340	57,248	116,950
Goats	133,785	64,636	133,785	75,800
Donkey	Unknown	unknown	unknown	20
Total Livestock	**754,989**	**705,056**	**740,119**	**618,450**

Source: District Livestock Production Office, Bomet, 1996 (Aboud, 2002)

Narok

Type of Livestock	1992	1993	1994	1995
Beef Cattle	843,570	826,224	494,500	504,765
Dairy Cattle	64,394	65,038	36,722	36,772
Sheep	1,364,227	1,336,942	489,500	498,660
Goats	783	797	270	1,061
Donkey	226,967	224,697	117,471	117,571
Total Livestock	**2,499,941**	**2,453,698**	**1,138,463**	**1,158,829**

Source: District Livestock Production Office, Narok, 1996 (Aboud, 2002)

Nakuru

Type of Livestock	1993	1994	1995
Dairy Cattle	195,700	211,799	217,449
Beef Cattle	155,300	137,900	126,200
Sheep	150,270	155,250	158,050
Goats	71,176	74,754	71,088
Total Livestock	**572,446**	**579,703**	**572,787**

Source: District Livestock Office, Nakuru, 1996 (Aboud, 2002)

Trans Mara

Type of Livestock	1991	1992	1993	1994	1995
Beef Cattle	272,100	285,700	300,000	315,000	362,250
Dairy Cattle	30,210	31,720	33,300	35,000	40,250
Sheep	29,940	31,430	33,000	35,000	40,250
Goats	25,940	27,240	28,600	30,000	34,500
Donkey	136	143	150	180	Unknown
Total Livestock	358,326	376,233	395,050	415,180	477,250

Source: District Livestock Production Office, Kilgoris, 1996 (Aboud, 2002)

The above tables shows livestock populations for Kenyan Districts within the MRB from select years ranging from 1991 to 1995

Appendix II: Lodges and Camps in Narok and Trans-Mara Districts of Kenya existing in or around the Masai Mara National Reserve as collected from the Ministry of Tourism and Wildlife.

Name of Hotel	Location	District	Number of Beds
Little Governors Tented Camp	Masai Mara	Narok	36
Governors Camp (Senior)	Mara Triangle	Narok	76
Mara Serena Lodge	Mara Triangle	Trans Mara	148
Mara Sopa	Masai Mara	Narok	144
Voyager Safari Lodge	Mara-Lemek	Narok	164
Mara Fig Tree Camp	Mara Triangle	Narok	140
Kichwa Tembo	Oloololo	Trans Mara	102
Kichwa Tembo Bateleur Camp			18
Mara Buffalo Camp	Masai Mara	Narok	126
Mara Intrepids	Talek	Narok	60
Ol-Kuruk Mara Lodge (Olkurruk)	Mara Triangle	Trans Mara	Closed
Mara Safari Club	Masai Mara	Narok	100
Mara Explorer Camp	Masai Mara	Narok	20
Masai Mara River Camp	Lemek	Narok	32
Keekorok Lodge	Masai Mara	Narok	202

Bike Treks	Sekenani	Narok	20
Sekenani Camp	Masai Mara	Narok	30
Ebra Tours and Safaris	Masai Mara	Narok	10
Safari Seekers Kenya Ltd	Sekenani	Narok	24
Savuka Tours and Safaris	Siana Area	Narok	40
Christal Camp	Sekenani	Narok	12
Exotic Safaris and Travel	Masai Mara	Narok	
Nyawira Hotel	Majengo	Narok	9
Bilsmet Guest House		Narok	19
Kamiti Guest House	Mai Mahiu Rd	Narok	13
Mara Simba Lodge	Talek	Narok	196
Mara Hipo Tented Camp	Ololai Mutia	Narok	94
Talek Springs Hotel		Narok	20
Mateso Bila Chuki	Sekenani Gate	Narok	7
Base Camp (Dream Camp)	Talek	Narok	32
Olarro Camp (Lodge)	Maji Moto	Narok	Dormant
Enkang Oloirien	Talek	Narok	24
Tumaini Guest House	Mai Mahiu Rd	Narok	10
Ol Dobe	Lemek	Narok	10
Kicheche Mara Camp	Masai Mara	Narok	22
Naibor Camp	Mara Rd	Narok	16
Mara Gypsy Luxary Safari Camp	Mara Rd	Narok	34
Mara Siria Camp	Masai Mara	Trans Mara	16
Acacia Camp	Ololai Mutia	Narok	25
Nyumbu Camp	Talek Area	Narok	26
Serian Camp	Mara River	Narok	16
Mara Porini Camp	Ol Kinyei	Narok	12
Ol Seki Mara Camp	Masai Mara	Narok	12
Rekero Kidogo	Koiyaki	Narok	18
Mpata Investment Club (Mpata Safari Club)	Masai Mara	Trans Mara	46
Leleshwa Camps and Lodges	Siana	Narok	14
Rekero Camp	Masai Mara	Narok	18
Mara Sarova Camp	Masai Mara	Narok	155
Iikiliani (Ilkeliani) Camp (Africa Eco Lodge Holding Company)	Ololai Mutia	Narok	30
Kenia Camp	Ololai Mutia	Narok	20
Olonana Tented Camp	Oloololo	Trans Mara	24
Off Beat Mara Camp	Koiyaki	Narok	12
Amicable Tent	Ololai Mutia	Narok	30

Source: Kenya Ministry of Tourism and Wildlife, 2006

Appendix III: List of all 65 lodges and tent camps found to exist in and around MMNR

	Name of Hotel	Within MMNR (Y/N)	Number of Beds	Number of Tents/Rooms	Accommodations
1	Little Governors Tented Camp**	Yes	36	17 tents	Adjoining tented bathrooms with flush toilets, bidets, running water (no electricity)
2	Governors Camp (Senior)**	Yes	76	38 tents	Private bathrooms, hot showers, flush toilets, wash basins, bidets (swimming pool?)
3	Governor's Ilmoran Camp**	Yes	20	10 tents	
4	Paradise Camp (part of Governors)	Yes	40	20 tents	Tented bathroom with flush toilet, water for washing and bathing is hand carried to the tents, hot water is supplied on request for the overhead gravity showers, no electricity - seasonal
5	Private Camp (part of Governors)**	Yes	4-16 people	Booked as a private safari camp (tents)	Flush toilets and showers (en suite), no electricity
6	Mara Serena Lodge*/**	Yes	148	76 rooms	Swimming pool, 24 hour electricity generators, en suite bathrooms
7	Mara Sopa Lodge**	No - located on the outer limits of MMNR, 2km off Ololamutiek Gate	144	60 double rooms and 12 suites	Swimming pool, en suite bathrooms
8	Voyager Safari Lodge**	No - located outside MMNR (built on a "bow" of the Mara River)	164	78 rooms	En suite bathrooms, hot and cold water, electricity, Laundry and valet service, swimming pool

9	Mara Fig Tree Camp*/**	No - located just outside the reserve near the Talek Gate	140	30 tents and 30 basic wood cabins	Swimming pool, 24-hour electricity, no fences
10	Kichwa Tembo Tented Camp*/**	No - located at the foot of the Oloololo Escarpement on western border of MMNR by Oloololo Gate	84	40 tents and 2 cottages	Laundry service, en suite bathrooms, swimming pool, electric fence
11	Kichwa Tembo Bateleur Camp**	No - located at the foot of the Oloololo Escarpement on western border of MMNR	18	9 tents	Expansive en suite bathroom with shower, toilet, and sink, swimming pool
12	Mara Buffalo Camp (Formerly Big Hunter's Camp)**	No - located on the banks of the Mara River at the foot of the Oloololo Escarpment, just outside the MMNR (NW dispersal area)	126	*63 (estimated)*	tents and chalets
13	Mara Intrepids Club*/**	Yes - located on the Talek River	60	30 rooms	En suite bathroom, hot showers, flush toilets electrified lanterns, swimming pool
14	Talek River Camp	Yes		8 tents	No fences, no electricity, flush toilets and running water. Sister camp is Mara Intrepids - 2km away
15	Olkurruk Mara Lodge (closed?)	Located in the Ololoolo Escarpment (has views of Olorukrti and Mara River)	38	19 thatched cabins	En suite bathrooms, showers with solar heated water, 24 hour electricity and electric security fence

16	Mara Safari Club**	No - located in the Ol-Choro Oiroua Conservation Area, bordering MMNR, at the foot of the Aitong Hills (located in dispersal area and surrounded on three sides by Mara River)	100	50 rooms	Heated swimming pool, electric fences, en suite bathrooms with sink, shower and flush toilets, electricity is on all night
17	Mara Explorer Camp**	Yes - located on a bend of the Talek river in MMNR	20	10 tents	En suite bathrooms, bathtubs, electricity
18	Mara River Camp**	No - located in the Koyaike Conservation Area near NW boundary of MMNR (in dispersal area)	32	16 tents	En suite bathrooms with flush toilets and hot/cold running water, electricity, no pool or electric fence
19	Keekorok Lodge*/**	Yes	202	74 rooms	Swimming pool, rooms have tubs and showers
20	Sekenani Camp**	No - located 6 kilometers from the Sekenani Gate in the Sekenani Valley, SE of gate	30	15 tents	Big bathtubs with individual gas water heaters, toilets, ho electricity (use hurricane lamps in tents)
21	Christal Camp		12	*6 (estimated)*	
22	Nyawira Hotel		9	*4 (estimated)*	
23	Bilsmet Guest House		19	*10 (estimated)*	
24	Kamiti Guest House		13	*6 (estimated)*	
25	Mara Simba Lodge*/**	Yes - located by the north boundary of MMNR on the Talek River, between Sekenani and Talek Gates	196	84 rooms	En suite shower and toilet, swimming pool, The grounds extend almost a kilometer along the river with the river bank, waste water treatment plant

26	Mara Hippo Tented Camp**		94	*47 (estimated)*	
27	Talek Springs Hotel		20	*10 (estimated)*	
28	Mateso Bila Chuki		7	*3 (estimated)*	
29	Base Camp Explorer (Dream Camp)**	Yes - located on the banks of the Talek River	32	15 tents	En suite bathrooms, hot showers. Both electricity and hot water are generated using solar power. All the wastewater from the tents is used to water over 3,000 trees and all the kitchen waste is separated and composted
30	Enkang Oloirien (owned by Osotua Camps)	Overlooks Talek River	24	10	No electricity, flush toilets, showers
31	Tumaini Guest House		10	*5 (estimated)*	
32	Ol Dobe		10	*5 (estimated)*	
33	Kicheche Mara Camp**	No - located in the Aitong Plains to the north of the MMNR in the Northern Koiyaki Lemek Palins	22	11 tents	En-suite bathroom and flushing toilet, bucket shower, low wattage lighting is supplied 24 hours
34	Kicheehe Bush Camp	No - located in the Olare Orok Conservancy (created from Koiyaki Group Ranch lands)	12	6 tents	Safari bucket shower, flush toilets,
35	Naibor Camp	No - located in the 'Ol Kinyei Wildlife Conservancy' between MMNR and Loita Plains	16	6 tents	en-suite with a flush toilet, pull shower (hot water safari shower) - seasonal camp in sit no longer than 4 months at a time

36	Mara Gypsy Luxary Safari Camp		34	*17 (estimated)*	
37	Mara Siria Camp	Located on top of the Siria Escarpment	16	8 tents	En-suite bathrooms with “safari” hot water showers and flush-toilets, solar power
38	Acacia Camp	No – located just outside MMNR Koiyaki Group Ranch	25	5 tents	Each tent is equipped with shower and toilet
39	Nyumbu Camp	No – located in the Ngila Plains at the edge of MMNR	26	*13 (estimated)*	Eco-friendly tent camp, seasonal – closed April and May
40	Serian Camp	No – NW of MMNR	16	8 tents	En suite bathroom with shower, tub, flush toilet, sink
41	Mara Porini Camp	No – located in Ol Kinyei, 18 kms from MMNR	12	6 tents	en-suite bathroom with flush toilet and safari shower
42	Ol Seki Mara Camp	No – located on the Innisikera River north of the MMNR	12	6 tents	En suite hot showers, solar lighting and flush toilets, operational from July to October
43	Rekero Tented Camp	Yes – located near the Mara and Talek Rivers	18	7 tents	Simple thatched bungalows with en suite bathrooms – Safari showers and flush toilets, Closed in April, May, And November [camp is set up seasonally (June – October, December – March)]
44	Rekero Kidogo Bush Camp	No – located outside MMNR in the Koiyaki Game Concession	12	6 tents	En suite toilets and bucket showers, hot and cold water is provided. Closed in April, May, And November [camp is set up seasonally (June – October, December – March)]

45	Mpata Investment Club (Mpata Safari Club)**	No - located approx. 25 km off Mara Bridge, north of the reserve and above Soit Oloololo Escarpement in the dispersal area	46	22 cottages	Each suite has its own private outdoor Jacuzzi and kitchenette, en suite bathroom, swimming pool
46	Leleshwa Camps and Lodges	No - Iocated in Siana Community Conservation Area on the north-eastern edge of the Maasai Mara Game Reserve	14	7 tents	En suite bathrooms with flushing toilets and a traditional safari shower. Although water is not piped to the tents, hot water is available at all times. Solar power provides lighting inside the tents.
47	Mara Sarova Camp (Sarova Mara)*/**	Yes - located by Sekenani Gate	155	75 tents	Swimming pool, permanent en suite bathrooms with showers
48	Ilkeliani Camp (Africa Eco Lodge Holding Company)**	On edge of MMNR - on the edge of the Talek River	30	12 tents	En suite bathrooms, each tent in on the river
49	Kenia Camp		20	*10 (estimate)*	
50	Olonana Tented Camp**	No - in Masai Mara Conservation area on the banks of the Mara River - Just outside MMNR on the western boundary - Mara Triangle	24	12 tents	En-suite facilities and hot running water, swimming pool, laundry service
51	Off Beat Mara Camp	No - located on the banks of the Olare Orok River in Koyiaki Group Ranch, just North of the MMNR	12	6 tents	Bucket showers, flush toilets. Camp is open from mid-Dec and the end of March as well as the end of June until the end of October
52	Amicable Tent		30	*15 (estimated)*	

53	Siana Springs Intrepids Lodge**	No - located on the eastern edge of MMNR on group ranch land at the base of Ngama Hills in the dispersal area	76	38 rooms	Electric fans, en suite bathrooms with super-large shower heads, and a separate, private toilet, electric fence, swimming pool, laundry service
54	Bush Tops**	No - located 4 kms from the main entrance to MMNR	9	5 tents	Farm/Ranch House with four double rooms and one single bedroom all with en suite bathrooms with hot showers and flush toilets
55	Cheli & Peacock's Mara Bush Camp	Adjoins MMNR	12	6 tents	Tents with en-suite hot showers, safari 'short-drop' toilets, washroom
56	Cheli & Peacock's Cottars 1920's Camp**	No - locaed in the Maasai Mara bordering the Serengeti and Loliondo reserves - SE of MMNR in the dispersal area	16	8 tents	En-suite bathrooms with tubs, showers, and flushing toilets
57	Paradise Mara Camp at Hippo Point	No - located just beyond the NW corner of the MMNR)			Guests stay in two-story huts. Each room has adjoining shower and bathroom
58	Duma Camp	Yes - located in the NW corner of MMNR	10	5 double tents	En suite bathrooms with flush toilets, solar lighting
59	Elephant Pepper Camp (formerly called Mara Camp)	Located on the northern edge of MMNR	16	8 tents	En suite bathrooms with bucket showers - hot water on request and flush toilets, seasonal
60	Oseur Tented Camp	No - located 8 km outside MMNR (Olemutiak Gate) in dispersal area	64	32 tents	Electric fence, swimming pool (planned)
61	Richard's Camp	No - in Masai Mara Consevation area NW of MMNR	10	5 tents	Flush toilets and heated showers

62	Sala's Camp	Yes - located on the Sand River at the southern end of MMNR	14	7 tents	En-suite bathrooms with flush toilets and hot water, solar powered electricity. Seasonal.
63	Saruni Safari Camp**	No - located in a private conservation area outside the MMNR	12	6 cottages	Hot and cold running water, electricity, en-suite bathrooms, showers
64	Saruni Tented Camp - Campi ya Tembo		6	3 tents	Flush toilets, hot and cold water, large showers
65	Sidai Camp	No - located outside MMNR on the edge of the Ewaso Nyiro River	8	4 tents	En-suite bathrooms with flush toilets and pull showers

* Sites visited

**Accommodations considered in analysis