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EVALUATION OF WATER QUALITY AND AQUATIC ECOSYSTEM HEALTH IN THE MARA RIVER BASIN EAST AFRICA

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ABSTRACT OF THE THESIS

EVALUATION OF WATER QUALITY AND AQUATIC ECOSSTEM HEALTH IN THE MARA RIVER, EAST AFRICA

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Limited capacity and lack of urgency have left many regions of the Mara River Basin unexplored resulting in uncertainty and ambiguity when forming management strategies. Eutrophication, flow alteration, landuse conversion, pathogens and suspended sediment are of concern throughout the region. This study provides a better understanding of baseline conditions, river status and health, throughout the Basin using in-situ water chemistry parameters, nutrient analysis and macro invertebrate indicators, in coordination with a geographic information system. Additionally, visual assessments were conducted to note local users, immediate land-uses and riparian condition. Though basin scale trends were generally not evident, some sites exhibited locally elevated parameter levels. The effects of local land-use and observed degradation were evident. Though pollution and poor ecosystem health do not appear to be widespread, the long term repercussions of land conversion, climate change and resource demands will warrant more consistent, in depth monitoring of the system.

Table of Contents

Chapter Page

List of Tables

List of Figures

1. Introduction

In recent history, the once regional focus on environmental degradation has shifted to a global scale. Expanding concerns include population growth, climate change and, increasingly, issues of water scarcity and water quality. Nations must address universal concerns such as climate change in addition to tackling local issues. In many cases this must be done in a cooperative, trans-boundary fashion analogous to the Mara River Basin in East Africa where increased sedimentation, eutrophication and water bourne illness threaten the local ecosystem. Countries continue to face development pressures, and, at the same time, must confront the ramifications of this pressure on environmental and human health. Furthermore, many countries lack the capacity, equipment and guidance to effectively assess impacts to these environments.

Despite being called the blue planet, Earth's freshwater resources are severely limited, comprising less than three percent of global reserves. Furthermore, the bulk of this quantity is frozen or otherwise inaccessible (Miller 2003). The uneven distribution of water and variations in precipitation further complicate access to, and exploitation of freshwater. Unfortunately, in many regions, viable freshwater resources are often unusable due to pathogenic contamination or other types of pollution.

Although progress has been made in providing more people with access to safe drinking water and sanitation, many regions continue to suffer. Globally, "lack of access to safe drinking water and sanitation is the single largest cause of illness" (NRDC 2007). Furthermore estimates attribute 80 percent of diseases and 33 percent of deaths to the "consumption of contaminated water" in developing nations (Hornberger 1998). An estimated 1 billion people lack access to improved drinking water while 2.6 lack appropriate sanitation (UNICEF 2006). According to the World Health Organization, improved water includes enhanced facilitation, i.e. house connections, protection of water sources and rain water harvesting practices (WHO 2010). Millennium Development Goals set in 2000 by the United Nations General Assembly, strive to halve these numbers by 2015 (Carr 2006).

While issues of scarcity and pollution are of obvious concern to human health, increased focus is being placed on their effects to overall ecosystem health and the impacts on ecosystem services. Ecosystem services, sometimes referred to as environmental values, can be viewed as "the conditions or processes through which natural ecosystems and the species that make them up, sustain and fulfill human life" (Hart 2001; En Chee 2004). These services may include pollutant assimilation or dilution, timber and food production (En Chee 2004).

The abundant services provided by aquatic ecosystems are largely a function of their diversity. Freshwater supports as much as 40% of global fish species and 25% of vertebrate species. An estimated 6% of the world's total known species live in freshwater environments (Dudgeon 2006). Though some freshwater ecosystems are considered to be biodiversity hotspots, they may also be "one of the most endangered ecosystems in the world" (Dudgeon 2006).

Aquatic ecosystems are vulnerable to a number of threats, the most significant being overexploitation, contamination, flow modification, habitat destruction and the introduction of exotic species (Dudgeon 2006). While each of these has the singular potential for significant degradation the combined effects are potentially catastrophic.

Over the last century, African nations have achieved independence, some as recently as the 1990's. However, many continue to struggle as they form their national identities often battling large scale corruption and political instability. These internal struggles pose a significant risk to aquatic ecosystems as they inhibit the development of appropriate management strategies and the implementation of sound environmental practices, which are essential in addressing environmental issues (Fredriksson 2003).

Freshwater resources in Africa are extremely vulnerable. A number of issues contribute to this. Current practices including land alteration, deforestation, adaptation of natural flow regimes, pollution (organic and inorganic), and destruction of riparian and wetland habitat threaten to exhaust and degrade this resource permanently and irreversibly. These activities result in biodiversity loss, eutrophication, resource scarcity and decreased ecosystem resilience. Among African nations, concerns regarding insufficient resources of freshwater and poor water quality are significant (UNEP 2002). In 1997, 778 million people suffered from "water-related diseases" (WWF 2002).

Currently fourteen African countries are considered water stressed, and predictions place another eleven in that category by the year 2025 (WWF 2002). Climatic variability and the uneven distribution of freshwater resources further exacerbate this vulnerability (UNEP 2002). Agricultural demands and rapid population growth place significant strain on these resources. Issues of water quantity are closely tied with quality as well. Globally, issues of scarcity are magnified when poor water quality limits "beneficial use" (Ongley 1999).

Though large scale contamination is not presently a critical issue in many regions of Africa, future development and intensification of existing practices will inevitably place aquatic ecosystems at risk. An increased focus on sustainable management (Ongley 1999) and sincere efforts to better understand the implications of these risks are paramount. Additionally, many of the rivers in Africa are trans-boundary in nature. This, coupled with the large number of users and stakeholders, complicates resource management and necessitates concerted coordinated management often referred to as Integrate Water Resource Management (IWRM).

Weather patterns in East Africa are highly variable, not only from country to country but from year to year and season to season. High instances of drought and signs of “increasing climatic instability” continue to threaten the region (UNEP 2002). This instability points towards an increase in the severity and frequency of droughts in an already water stressed area. This instability also manifests in less predictable rain seasons, i.e. a shift from the normal historic patterns. Though groundwater recharge may be more substantial in some areas, surface water is the primary freshwater resource in East Africa (UNEP 2002).

In 2001, Lake Nakuru and Lake Bogoria, freshwater lakes which are critical habitat for Greater Flamingos (*phoenicopterus ruber*), suffered a large number of bird deaths most likely due to contamination from agricultural runoff (UNEP 2002). Mombasa, a popular Indian Ocean coastal city in Kenya, has a waste water system in place, however, its capacity covers only seventeen percent of the current population (UNEP 2002).

The African continent houses some of the last undisturbed landscapes and ecosystems on the planet. With 12.3% and 39.6% of land area designated as protected respectively, Kenya and Tanzania exceed the sub-Saharan average (EarthTrendsKE 2003; EarthTrendsTZ 2003) . The Mara River and its associated resources are of critical importance, not only ecologically but culturally, as they provide essential services to the people. Dependence on this water supply has initiated concerns pertaining to scarcity and quality. Large scale agriculture and, to some extent, mining operations rely on significant water extraction from the Mara River system. Small scale farmers and domestic users rely less on conveyance systems and more on the resource in the channel.

The Mara River serves as a last resort for wildlife in the dry season, most evident in the massive wildebeest (*connochaetas taurinus*) migrations from Tanzania each year. During the dry season the Mara is often the only flowing surface water available in northwest Tanzania and studies suggest it is also the least saline making it even more enticing to wildlife (Gereta 1998). Following seasonal rains the Mara has been observed to sustain higher discharge via baseflow for months versus weeks or days for nearby rivers. Ultimately, water quality and quantity are the primary factors that guide the migration and influence vegetation (Wolanski 2001).

Furthermore, the Mara River's connection to Lake Victoria is significant considering that the Lake is a major supplier of freshwater to, among others, Tanzania, Kenya, and Uganda and eventually feeds the Nile River (UNEP 2002). At present, the Mara is credited with being "one of the more pristine catchments" of the upper Nile basin (Mati 2008). Significant alteration to the quantity or quality of this river has the potential for serious ramifications downstream. However, water borne illness, expansion of pastoralism, intensification of agriculture and rapid population growth continue to place environmental and human health at risk.

Despite capacity and resource challenges, a number of water quality programs are currently in place. The Kenyan Ministry of Water and Irrigation designated two water quality offices, one in Narok and another in Bomet. Though no systematic sampling program currently exits, the offices measure discharge regularly and water quality and sediment load occasionally.

The Tanzanian based Lake Victoria Environmental Management Programme (LVEMP), established in 1995, and the Lake Victoria South Catchment Management Authority (LVSCMA), based in Kisumu Kenya, focus on permitting, invasive species control, land management, pollution and fisheries (UNEP 2002). Although the focal point of LVEMP and its Kenyan counterpart is the lake itself, assistance is also given to catchment oriented activities.

LVEMP is currently developing a Catchment Management Strategy. The Strategy will serve as a “guide for management, use, development, conservation, protection and control of water resources” (WRMA 2008). The LVSCMA was to conduct a comprehensive survey of the Kenyan portion of the basin in June and July 2008 in an effort to better account for existing permits and to assess future water quality monitoring efforts. Furthermore the Tanzanian Ministry of Water and Livestock, designated a water quality facility in the city of Musoma which works in coordination with LVEMP (Singler 2006).

The large number of stakeholders, effects on critical wildlife areas and other downstream implications of the Mara River waters have also attracted the attention of the academic community, initiating the involvement of Jomo Kenyatta University, the University of Nairobi, University of Dar es Salaam and Florida International University. However, understanding the long term repercussions of land conversion, climate change and resource demands will warrant more consistent, in depth monitoring of the system, including seasonal comparisons and in depth flow assessments.

None the less, limited capacity and a lack of urgency have left many regions of the Mara River Basin unexplored. Gaps of this nature create uncertainty and ambiguity when forming comprehensive management strategies. Effective management and sound decision making necessitates an inventory of these areas. A better understanding of baseline conditions, i.e. the rivers quality status, is required before managers and policy makers can make any determination of how the ecosystem ranks with regard to environmental standards. Furthermore, while baseline conditions provide a snapshot of the system at a very specific time, anthropogenic forces are increasing at an alarming rate and identifying areas that are most susceptible or vulnerable is critical for the long term health of the system. Therefore, a baseline water quality and vulnerability study was conducted through the Global Waters for Sustainability Program (GLOWS), from May to August, 2007 and 2008. GLOWS is a consortium funded by the United States Agency for International Development (USAID).

2. Research Questions

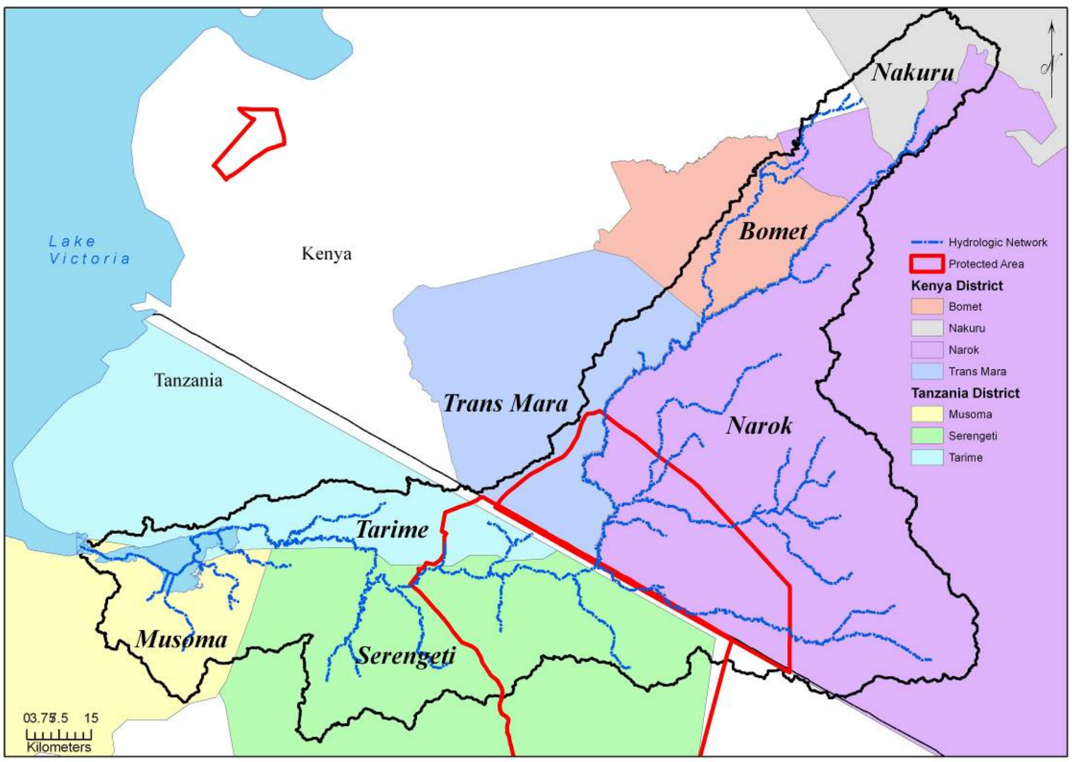
- What is the status of Mara River aquatic ecosystems?
- What is the health of Mara River aquatic ecosystems?
- Which areas are most vulnerable to future degradation?

3. Study Area

3.1 Area/geographic features

The Mara River Basin extends primarily through the Bomet, Narok and Trans Mara districts on the Kenyan side and the Tarime, Serengeti and Musoma districts on the Tanzanian side (Figure 1).

Figure 1: Administrative Districts of Kenya and Tanzania



(WRI 2003; URT 2009)

The waters of the Mara River originate in the Mau Forest complex of the Kenyan highlands in the Enupuiyapi Swamp. The Mau forest is an essential water catchment zone from which a number of other rivers originate. As such, the forest was gazetted, i.e. designated reserved, in the early 1900’s. However, at present, degazettement of some areas, illegal settlements and poaching of timber products threaten this critical resource.

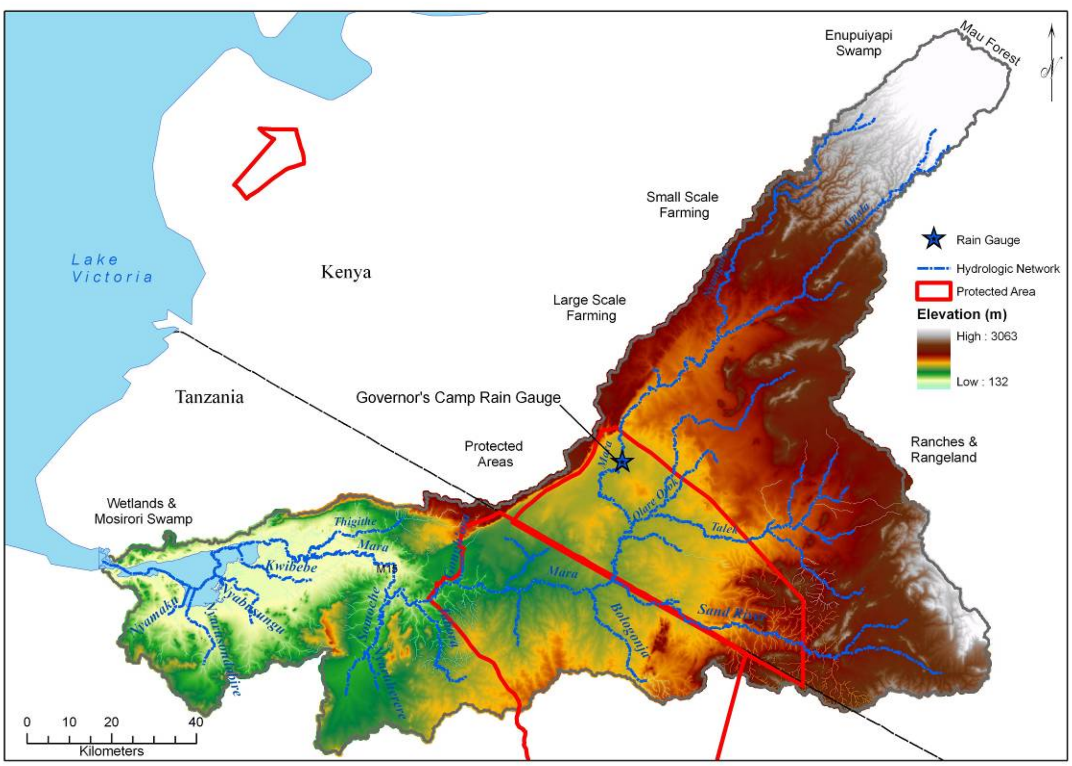
Studies indicate that forested area decreased by 259 km^2 between 1973 and 2000 (Gereta 2003). In the Mara Basin, these headwaters form 2 tributaries, the Nyangores to the west and the Amala to the east. This region is known as the Mau escarpment, which is characterized by small-scale farming in the northern, upstream reaches and large scale agriculture further downstream. The contribution of these 2 tributaries is thought to be responsible for the Mara's dry season flow while other rivers in Tanzania go dry (Gereta 2003).

The Nyangores and Amala merge to form the Mara River which flows out of the escarpment and into the grasslands or savannah. Historically, this region was woodland but transitioned to grassland as a result of tsetse fly remediation, increased burning and destruction by elephants (Lamprey 2004). Currently, this region is characterized by pastoralism and group ranches, converted from land held in trust for groups such as the Masai. However, conversion to private land has been recently advocated (Walpole 2003). Privatization of this nature and the expansion of agricultural activities from the north generate concerns regarding the impact of large scale land conversion on the Mara ecosystem.

To the south lies the world-renowned Masai Mara National Reserve. The Reserve was designated as a Wildlife Sanctuary in 1948. The area was extended and designated as a Game Reserve in 1961 and eventually reached National Reserve status in 1974 (Walpole 2003). Over the Kenya/Tanzania border lies another prominent protected area and designated UNESCO World Heritage site and Biosphere Reserve, the Serengeti National Park (SNP). The Mara flows out of SNP, through a mining region and eventually empties into Lake Victoria via the Mosirori wetlands. All of these components are critically linked to the freshwater resources of the Mara River and its tributaries.

The trans-boundary Mara River catchment (~13,570 km^2) is situated 65% on the Kenya side and 35% on the Tanzanian side. Elevations range from almost 3,000 meters in the Enupuiyapi Swamp to about 1,000 meters in the Lake Victoria region. Precipitation in the region is variable but generally entails a long wet season between the months of March and June and a shorter wet season that runs from September to December. Though volumes vary from year to year, the Mau region receives roughly 1,000 to 1,750 mm of annual precipitation, the grasslands range from 900 to 1,000mm and the Lake region records between 700 and 850mm (Mati 2005). Figure 2 provides a general layout of the Basin, as well as elevation.

Figure 2: General Layout and Elevation of the Mara River Basin



3.2 Climate/ Precipitation

Though some precipitation data has been collected for the region, data for 2007 and 2008 were sparse. However, the Governor's Camp has collected daily rain data since 1999. Monthly precipitation was summed for 2007 and 2008 (Figures 3 & 4). The gauge recorded an annual sum of 1,264 mm of rain for 2007 and 1,102 mm for 2008, a 13% decrease from 2007. Precipitation amounts during the sampling period (May-August) were somewhat similar totaling 277 mm in 2007 and 254 mm in 2008 though the amounts and timing varied.

Figure 3: 2007 Governor's Camp Monthly Rain Totals

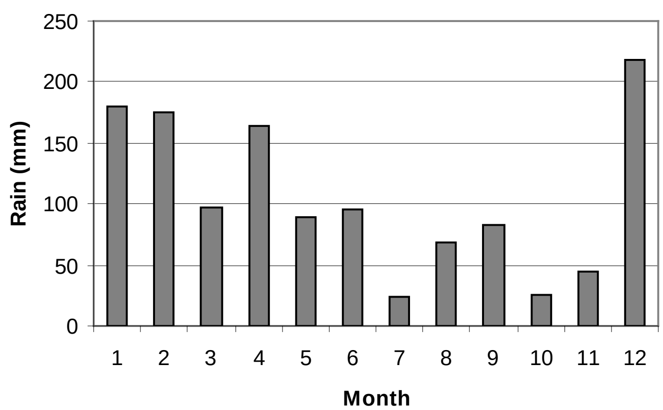
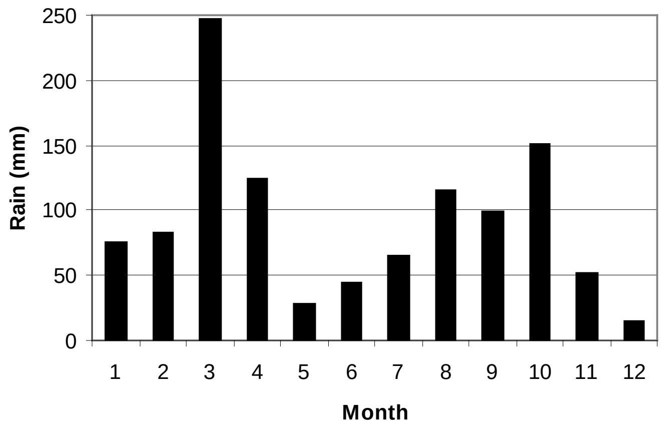


Figure 4: 2008 Governor's Camp Monthly Rain Totals



Though the available data can not provide direct insight regarding water quality correlations, it does provide insight as to the extent of seasonal and annual quantity fluctuations. Additionally, the unpredictable nature of rain, spatial variations and complications associated with collection of precipitation make analysis using a single gauge severely limited. However, daily sums still prove useful when evaluating the effects of isolated events within suitable range of the single rain gauge.

3.3 Geology

Studies indicate that the waters of Kenya are influenced most by geology, climate and anthropogenic activities (Davies 1996). Two soil types compose most of the soils in the Mara River Basin with cambisols in the upper and middle region, and vertisols in the lower downstream part. The cambisols are characterized by structural stability, high porosity, good water retention and moderate to high fertility, all of which make them suitable for agricultural activities. Vertisols are high in clay content and dark in color. Though they have good water holding potential, they require specialized techniques for agricultural use (Mati 2008). The underlying bedrock of the region consists of quartzite, gneisses and schists (Lamprey 2004). The upper watershed is comprised of steep slopes and, historically, was densely forested. However, population growth and agricultural expansion have led to considerable deforestation of this region as land is cleared for farms and forests are depleted of timber for charcoal. The rangelands further south have also seen an expansion of agriculture and pastoral activities. Ultimately, these practices have destroyed riparian zones and contributed to soil compaction both of which result in increased runoff and erosion. Some regions are stressing the importance of best management practices to reduce these effects.

3.4 Livelihood

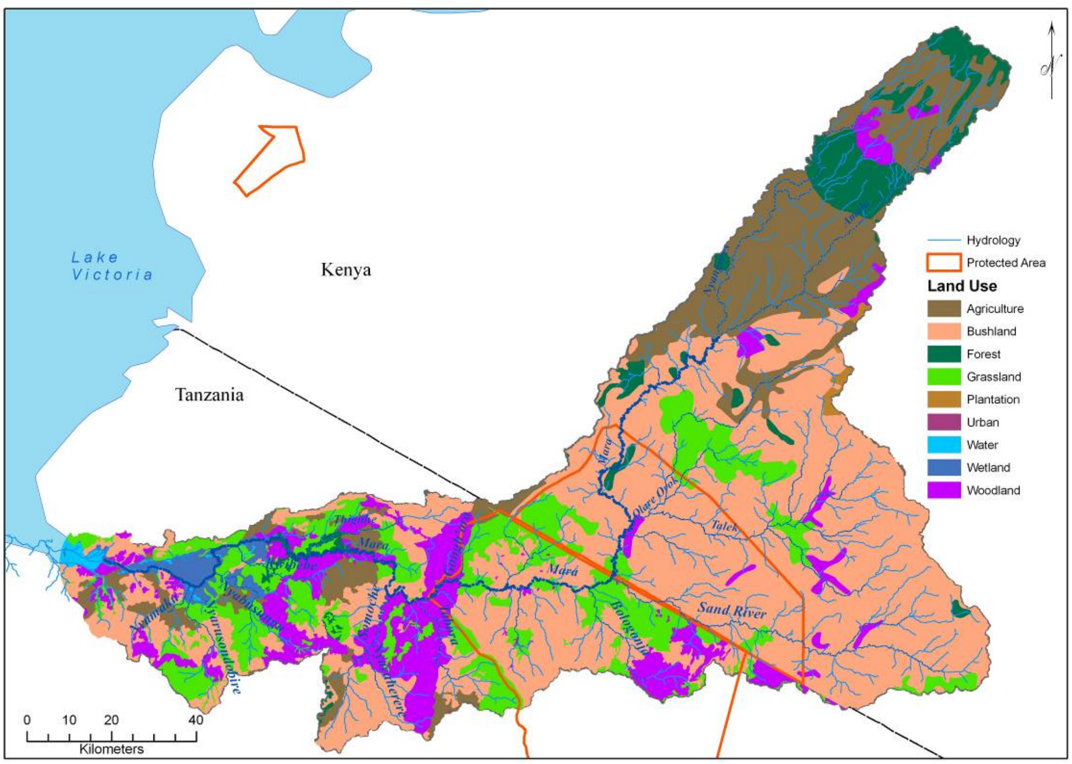
Sixty-two percent of households in the basin are involved in small scale farming though agriculture itself only represents 28% of farmable land (Mati 2008). The highland soils of the Narok district support wheat, barley, maize, potatoes (ALRMP 2009) and tea. Animal husbandry and pastoralism are also significant economic activities throughout the region. The Mara-Serengeti ecosystem hosts the “most diverse combination of grazing mammals in the world” with wildlife and livestock numbers approaching 400,000 (Mati 2005).

The tourism industry is also a substantial socio-economic component. Not only does it serve as a catalyst for ecosystem and wildlife preservation but it provides a venue for the sale of local goods and services. Tourism, in both Kenya and Tanzania, is driven by the unique and numerous wildlife in the region. The migration of wildebeest in to the Mara basin is a critical component in supporting the ecosystem, including vegetation structure and other wildlife populations (Mati 2005).

Issues pertaining to water quality and quantity threaten a collapse of this system should this migration cease (Gereta 2003). Though beneficial, tourism can also impair the region by means of degradation caused by the increase in roads and off-road driving, disturbance to wildlife and increased water supply and sanitation treatment demands.

People in the northern, upstream portion of the basin rely on forest and timber resources as a livelihood. However, the Mara also supports some rare fish species and serves as an important fish breeding area allowing the people in the downstream Musoma region rely on fishing as a source of income (Gereta 2003; Mati 2005). Figure 5, shows current land uses.

Figure 5: Land Use in the Mara River Basin



3.5 Use

The water of the Mara River is crucial to the survival of the people as well as wildlife. Over half of the households in the Mara River Basin rely on its water for domestic and livestock needs (Aboud 2002; Hoffman 2007). The river and its tributaries are used for laundering clothes, personal bathing, consumption and watering livestock. Many of the small-scale farms are rain fed while the large-scale farms are irrigated via extractions from the Mara River. Additional abstractions are made to supply water to towns such as Bomet and as a source of hydropower in the Tenwek region. The Barrick silver mines in Tanzania extract water for the mining processes.

3.6 Policy

In 1982, the Kenyan government, known at that time as the Ministry of Water, initiated routine water quality monitoring of major surface water systems (Davies 1996). In 1999, Kenya National Environment Management Authority (NEMA) was established under the Environmental Management and Coordination Act No. 8 and became active in 2002 as a department in the Ministry of Environment and Natural Resources. In 2003, the Kenya Ministry of Water and Irrigation was formed following a split from the Ministry of Environment and Natural Resources. The intent of this separation was to streamline the administration and development of water resources and to lay the appropriate framework for IWRM (Irrigation 2010). In 2006, the Environmental Management and Co-Ordination (Water Quality) Regulations were established containing policy on the protection of domestic water sources, industrial and effluent discharge and water for agricultural use (NEMA 2006).

Tanzania developed its own approach to IWRM by revising the National Water Policy of 1991 to form a new National Water Policy (NAWAPO), effective in 2002. The new policy is intended to increase participation and integration, as well as to promote sustainability (Doering 2005; Arvidson 2006; URT 2009).

While the NEMA and Tanzanian standards dictate thresholds for primary aquatic chemistry contaminants, some supplementary parameters are not addressed. Where no standard is specified, recommendations instituted by other organizations such as the United States Environmental Protection Agency (USEPA) will be considered (Table 1). NEMA standards do not specifically address soluble reactive phosphorus (SRP) limits, however, the USEPA recommends a level of 0.05 mg L^{-1} for streams that discharge in to a lake or estuary and 0.10 mg L-1 for streams that do not and 0.10 mg L-1 for total phosphorus (TP) (Mueller 2009).

Additionally, no standards exist for dissolved organic carbon but, in general, undisturbed watersheds may range from 1-20 mg L-1 (cite). The US has no national or state standards in place for phosphorus in water but the USEPA does indicate that, though total nitrogen varies, statistically, a range 0.12mg L-1 – 2.2 mg L-1 is appropriate for streams (U.S.EPA 2010).

NEMA standards do not directly address conductivity limits. However, the USEPA indicates that waters in the US may range from 50 to 1500 μS/cm but considers a range of 150-500 μS/cm suitable for fish. Waters with conductivity ranges outside of this may impair aquatic organisms (Weiner 2000).

4. Methodology

4.1 Background

Historically, many approaches for determining the health of an ecosystem were limited to chemical parameters only. However, aquatic ecosystem health is a subjective concept. For example, an aquatic system comprised of treated, palatable water but where the original ecosystem structure has been significantly compromised may be considered healthy from a pathologists standpoint but may not be viewed as favorable from an ecologists perspective (Weiner 2000). Furthermore, in the past, many studies focused solely on the environmental aspects of the system and neglected the complex societal influences and connections, positive or negative.

While the term health and its applicability to ecosystems continues to be debated, the fact remains that the condition of these environments must be maintained at a certain level in order to facilitate benefits and services (Fairweather 1999). Protection of these ecosystems is extremely complex given large numbers of stakeholders, diverse expectations and the highly variable nature of aquatic systems.

Newer approaches emphasize the need for holistic or highly integrated study parameters and approaches. This is evidenced by an increased global recognition of IWRM principles and the development and improvement of approaches such as the Pressure State Response model (PSR), and the U.S. Environmental Protection Agency's Environmental Monitoring and Assessment Program (EMAP) and subsequent Regional Vulnerability and Assessment program (REVA) (Berger 1997; Lazorchak 2000; Smith 2000). Furthermore, these approaches, along with others, reflect a growing emphasis on sustainability and the concept of ecologically sustainable development (ESD) (ANZECC 2000).

The United Nations Environment Programme (UNEP), recognizing water as a crucial component to sustainable development and health, as well as, an integral factor in the industries of agriculture and energy, predicts that without significant improvements in the management of water resources, achievement of the Millenium Development Goals may be compromised

The PSR model, in existence since the mid 20th century, has undergone various modifications and enhancements but the underlying principle remains that certain pressures, natural or anthropogenic, will affect the state of the ecosystem warranting a societal response by means of policy or other management framework (Berger 1997). Approaches of this nature not only exemplify the coupling of science and administration but also begin to emphasize the use of comprehensive; i.e. chemical, biological, sets of study parameters or indicators. Though the PSR model is sometimes criticized for lending itself to linear linkages, the model successfully employs indicators for assessing both ecological and societal conditions (OECD 1993).

The U.S. EPA’s EMAP and REVA programs also incorporate the use of indicators. Together, these programs address the monitoring and evaluate both current and future risk. As defined by the EPA, the EMAP program “is a long term research program focused on developing indicators and unbiased statistical designs” (Lazorchak 2000). EMAP has defined 4 sets of indicators including conditional indicators, stressor indicators, exposure indicators and function indicators (Angradi 2006). Though indicators may not apply to all sites or environments, this approach provides valuable insight in to the larger state of the ecosystem. EMAP data was evaluated using a number of statistical methods, including but not limited to descriptive statistics, variance analysis and empirical estimations (Stoddard, R.M. Hughes et al. 2005).

The REVA program takes the monitoring data of the EMAP program a step further by applying it to a broader, regional scale and incorporating an ecosystem vulnerability aspect. This information can be used in the prioritization of management activities. Though the REVA approach is in the preliminary phase and only a few pilot studies have been conducted, the implications of the method are significant in evaluating the "cumulative risks associated with multiple stressors on multiple resources" (Smith 2000). Vulnerability analysis for REVA involves the use of multivariate statistics, fuzzy distances, weighted sums and weight of evidence (Smith 2000).

Ultimately, these newer approaches strive to not only represent the complexity of ecosystem interactions, i.e., chemical, biological and physical but to also provide better insight in to human – ecosystem linkages. The success of policies or programs aimed to preserve and sustain environmental services hinges on transparency, and the participation of local stakeholders (Hart 2001). The use of IWRM in correlation with comprehensive, indicator driven monitoring and evaluation programs plays a crucial role in facilitating these efforts.

In this study, health was gauged by using a number of quality markers. Unexpected divergence from standards was one indication of poor health. Macro invertebrate numbers and scores also served as an indication of impaired health as did observed disturbance where the disturbance score incorporated the degree of modification to the area, condition of riparian regions and other factors inhibiting proper ecosystem function. Proper functioning allows for pollutant dilution, nutrient assimilation and sediment trapping (Brooks 2003).

4.2 Determination of Status

While some areas and reaches throughout the Mara River Basin have received considerable attention throughout the years (Gereta 1998; Bancy M. Mati1 2005; Mutie 2006; Mati 2008), other areas remain completely unexplored. The aim of this study was to expand and supplement the current understanding of the freshwater resources in the Mara River Basin and, ultimately, to provide a better foundation for decision making, resource management and driving future research endeavors.

Given that water quality and general assessment data is lacking throughout the Mara region, this study strived to provide a broad spectrum of chemical, biological and structural information to develop a characterization of specific reaches throughout the Basin. Compiling a characterization of this nature necessitated using a variety of collection and analytical techniques.

4.3 Determination of Health

All of the collected and compiled data from this study served to satisfy the basic status portion of this study. Determination of health was based deviations from standards and recommendations and then assessing the implications of these deviations on the health of the system. Not all deviations from standards indicate an unhealthy system. For example, low DO in a headwater region does not have the same implications as low levels further downstream. Situations such as this were considered when assessing and interpreting site criteria to evaluate the implications to the health of the system.

4.4 Determination of Vulnerability

Issues associated with land alteration, population growth and modifications to the natural flow regime are currently evident within the Mara River Basin although their extent warrants further investigation. While some results may fall within permissible ranges, the potential for exceeding these thresholds in the future may be high.

As previously mentioned, land alteration and current management practices put many ecosystems throughout the basin at risk. While some best management farming practices are in place this is not universal. Agricultural activities on the steep slopes of the Amala and Nyangores Rivers threaten increased sedimentation downstream. Furthermore, while many of these small-scale farmers are not currently using fertilizer, the potential exists thereby setting the stage for possible nutrient excess downstream. Many of the pastoral regions downstream of this agricultural area already show signs of impaired riparian function (Mati 2008). Expansion of these activities, both spatially and with respect to livestock numbers, will mostly likely result in more wide spread and severe destruction.

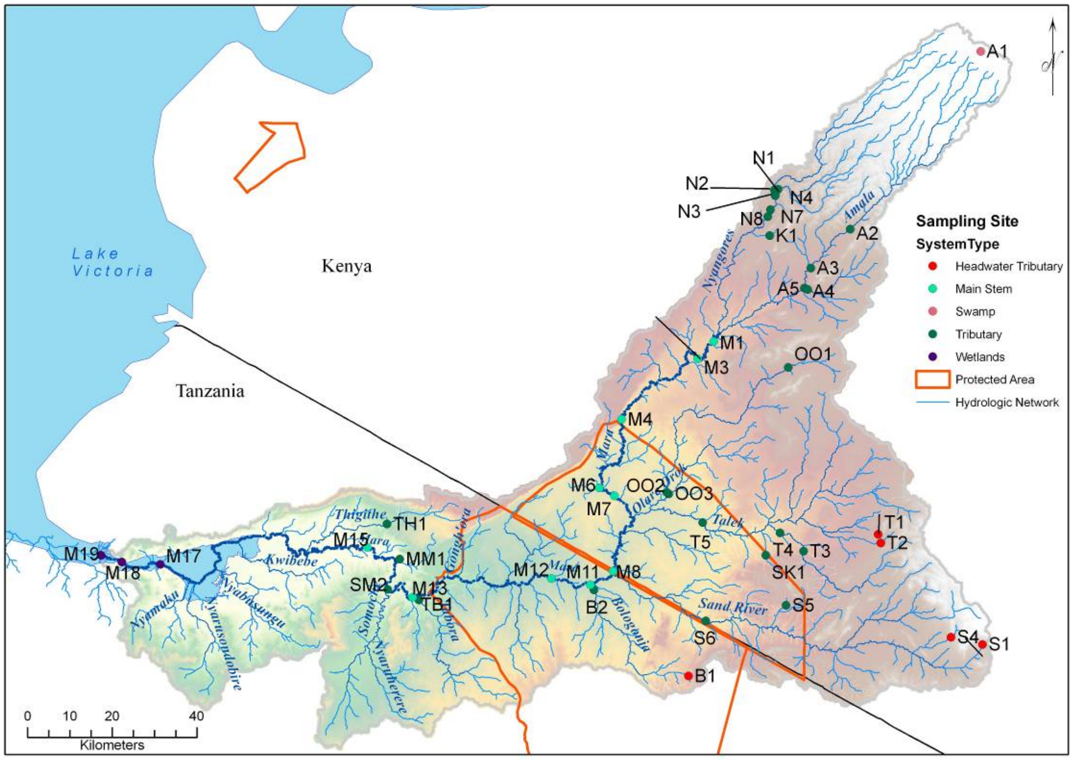
Though water extractions in the basin are fairly widespread, they are not generally substantial in size. Population growth in the area can reach 7.5% per year, eliciting an inevitable increase in consumptive demands personally, domestically and commercially (Mutie 2006). Coupled with deforestation and increasingly erratic precipitation patterns (Kones 2008), effective management is critical given other essential ecosystem services such as pollutant dilution and wildlife dependence. Increases in supply also result in increased treatment, critical to combating the risk of water-borne diseases. Whether a result of decreased flow resulting in stagnant river pooling or the presence of pathogens, the top 3 reported illnesses throughout the Tanzanian portion of the Mara are water related (Gereta 2003). These issues directly apply to the tourism industry as well. As the draw for safaris in the protected regions continues to increase, the potential for additional lodges and increased organic nutrient loads loom. Vulnerability was estimated using health results and incorporating current threats such as deforestation potential, population growth and current landuse.

4.5 Establishment of sampling network

Site selection was based on a number of factors. Previous studies, performed by WWF, the Kenya Ministry of Water and Irrigation, and the Global Waters for Sustainability Program, established approximately 21 sites of particular interest. This study incorporated those existing sites and added roughly 30 additional sites over the course of 2 sampling seasons, Figure 2.

Additional sites were selected based on the ecosystem/land-use type, extent of previous exploration and accessibility. A subset, approximately 33 sites, of the complete 53 site set was repeated in the 2007 and 2008 seasons. A few sites were assessed during only one of those seasons depending on their significance to the larger system. Each site was assigned a system type based on its location, with consideration of other contributing factors. Site descriptions including the associated tributary, assigned system type and sampling season was compiled (Table 2).

Figure 6: Sampling Sites and System Types



4.6 Selection of Parameters

After selecting suitable sites, sampling parameters and equipment were established. As previously noted, the upper reaches of the basin, the Amala and Nyangores in particular, are largely agricultural. This, coupled with the steepness of the region, raises concerns of increased erosion and runoff, subjecting downstream areas to excessive sedimentation and possible pollution due to elevated organic and inorganic nutrient levels.

Pastoralism, present throughout much of the upper main stem Mara, elicits concerns pertaining to riparian degradation, biological contamination and soil compaction. Additionally, the Masai Mara National Reserve in southwestern Kenya, and the Serengeti National Park, in northwestern Tanzania, are among the top tourist destinations in the world. Tourism demands require the use of housing facilities inside and adjacent to these protected areas, elevating the risk of biological pollution.

To better understand the impacts or potential impacts of these activities, a broad spectrum of parameters covering water quality and physical structure were used to assess each site. The water quality component was comprised of *in-situ* chemistry measurements, organic and inorganic nutrients and biological parameters such as fecal coliform (Table 3).

Given that these components are directly affected by their environments, a rapid visual assessment was required to better understand the ecosystem dynamics at each site at that particular time. The visual assessment was modeled after the USEPA's Rapid Bioassessment Protocols and included factors such as water depth, wetted width, channel structure, evidence of impact, i.e. erosion, riparian status and, where discharge was sufficient and the layout of the site permitted, flow was measured (Barbour 1999).

Furthermore, while these parameters are a good indication of the condition at a specific point in time, an aquatic macro invertebrate inventory was conducted in 2008. Aquatic macro invertebrates spend portions or all of their lives in water. They provide insight in to the longer term health of the system and are integral in the food chain of aquatic systems. High macro invertebrate diversity generally occurs in locations where salinity, turbidity and nutrients such as nitrogen and phosphorus are low and dissolved oxygen is high. The collection of macro invertebrates is best conducted along the still areas of the channel, close to the bank and where vegetation may hang over or create recesses. Macro invertebrates are an indicator of past and current water quality. Sedentary invertebrates can give indications of months and even years (Chessman 2003). For unknown reasons, macro invertebrate numbers and diversity in the Mara River Basin have been observed to be low.

4.7 Field Methods

Water chemistry parameters were assessed, *in situ*, using a YSI 556 MPS (Yellow Springs International 556 Multi Probe System). Measurements included temperature, pH, salinity, conductivity (EC), total dissolved solids (TDS) and dissolved oxygen (DO). The pH electrode was calibrated, using a 3 point calibration, every 3 days or after long breaks in sampling. Litmus paper was used as a validation. The DO probe was calibrated prior to each sampling day using the temperature and barometric pressure as measured by the unit.

In addition to the *in-situ* chemistry parameters, samples were collected on site, stored in a cooler, processed and preserved for additional analysis off site. Samples were collected in an HDPE bottle, which was rinsed 3 times with the sample water prior to final collection. The sample was then divided in to three 60ml Nalgene bottles.

The first 60ml bottle was rinsed 3 times with sample before being filled with unfiltered sample water. Sample for the second and third bottles was filtered using a vacuum pump, filter holder and Whatman 45µm cellulose nitrate membranes. The membranes had been previously dried in an oven at 80°C for 24 hours then weighed and recorded. These membranes served 2 purposes in this procedure, the first of which was to provide a filtered sample. Additionally, a specific amount of sample was filtered through the membrane, i.e. 200ml, after which the membrane was removed, dried and stored. The filter was again dried at 80°C and reweighed, producing a total suspended solids (TSS) value in mg TSS mg L^{-1}.

Subsequently, the second and third bottles were rinsed 3 times with the filtrate before being filled. The second bottle was left as is while the third bottle received 2-3 drops of concentrated H_2SO_4 for preservation. All three bottles were kept frozen until time for laboratory analysis.

The remainder of the unfiltered sample was analyzed for turbidity, total suspended solids and fecal coliform bacteria. Turbidity was measured using a Lamotte 2020 Turbidimeter, making sure to shake the sample before pouring into the vial. The presence of fecal coliform was determined using EasyGel Coliscan kits where 5ml of sample was added to the inocculant solution and then poured in to pre-treated petri dishes. The dishes sat at room temperature for 48 hours at which point they were photographed and colonies were counted. Temperature varies throughout the basin but mean temperatures can range from 5ºC to 28 ºC (ALRMP 2009).

Additionally, flow measurements were taken, when feasible. Sites suitable for flow measurement were those with significant discharge and depth and with access to the channel, i.e. from a bridge or boat. For safety reasons, wading in the channel was not an option. Flow was recorded using a General Oceanic 2030 Mechanical Flow meter. The procedure involved recording the initial rotor number, submerging the meter for 60 seconds and recording the final rotor number. The United States Geologic Survey (USGS) stipulates that flow should be measure at 20% and 80% of the water column depth for larger depths and at 60% for lesser depths (Wahl 1995). However, the logistics of this study did not allow for such precise meter placement. A standard speed rotor constant of 26,873 was used to calculate discharge.

A detailed visual assessment was conducted at each site. Notes and photos documented aspects such as the wetted width of the channel, which, in most cases, was measured using a range finder or estimated in the instances where the distance was below the 18 meter threshold. The visual inspection of each site included the type of flow, i.e. riffles, pools or runs and the quantity and quality of the riparian vegetation. While incremental depth measurements would have been ideal, wildlife and other hazards prohibited channel access so water depth was recorded at a suitable distance from the bank. Furthermore, canopy presence, bed material, nearby landuse and any other aspects of note, such as odor, were documented.

The 2008 macro invertebrate survey was conducted using a kicknet, aquarium net, tweezers and Whirl Pak bags. Invertebrates were collected in the channel and along the immediate riparian area and vegetation at each site. Collection times ranged but generally last about 30 minutes. Though the collection techniques differed, the South African Scoring System (SASS) was applied during the analytical phase to better understand trends throughout the basin. The SASS method assigns a quality score relating to the tolerance level of the particular organism. A number of other factors are considered in this method including the habitat extent, quality and the variety of habitat types (Dickens 2002).

4.8 Laboratory Methods

While the in-situ, biological and visual assessment data were completed during the collection campaign, analysis of the organic and inorganic nutrient content required further laboratory analysis. The frozen water samples were thawed and analyzed at 2 labs at the Florida International University. Ammonium, nitrate, nitrite, soluble reactive phosphorus and total phosphorus were measured at the Soil/Sediment Biogeochemistry Laboratory (SBL) of the Southeast Environmental Research Center (SERC) of FIU. Total dissolved nitrogen, total dissolved phosphorus, total nitrogen and dissolved organic carbon were analyzed at the Water Quality Laboratory (WQL) also at SERC/FIU. Standard laboratory methods were used for all analysis (Table 4).

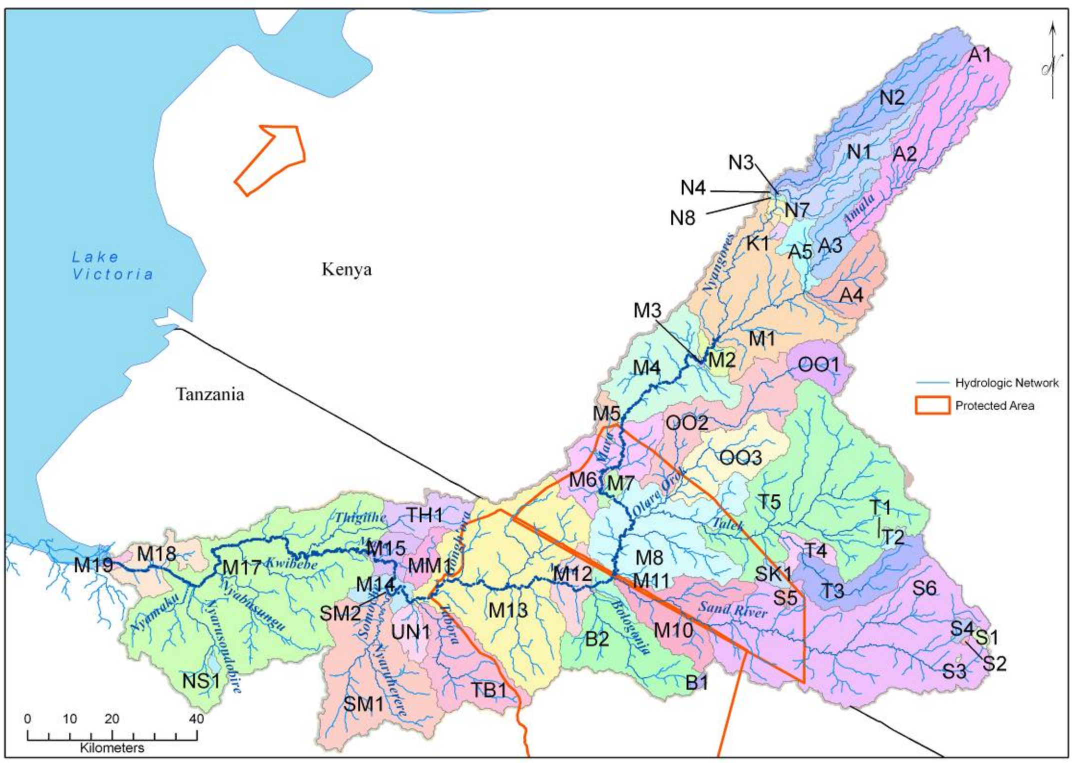
Macro invertebrate samples were preserved in ethanol and labeled per collection site. Winged insects such as dragonflies were pinned to a spreading board. Entomology staff at the Nairobi National Museum, a branch of the National Museums of Kenya, then identified the insects to the Family level. Though the methods used in the 2008 Mara macro invertebrate survey were not identical to the South African Scoring System (SASS), certain components of the approach were used in summarizing the results.

Only aquatic invertebrates were considered in this study; terrestrial invertebrates were excluded. Each taxon was assigned a quality score indicating their tolerance to stressors such as pollution. Lower scores indicate resistant organisms and higher numbers indicate more vulnerable organisms. The tolerance values were summed for each site and divided by the number of taxa, referred to as the Average Score per Taxon (ASPT).

4.9 Geographic Information Systems

In order to put the collected data into the context of the overall system, geographic information system (GIS) software was used to generate spatial and quantitative data. Using ESRI ArcGIS and the ArcHydro extension version 9.2, study units were delineated for each site. The individual units were comprised of the contributing area immediately upstream and adjacent to the site and terminate downstream of the next upstream site (Figure 3).

Figure 7: Mara River Basin Study Units



These individual units were combined to define larger contribution areas to better reflect collective upstream contributions. Comprehensive characterizations of these areas, including total area and land-use percentages were calculated. Each site was designated 1 of 5 system types: swamp (forested), headwater, tributary, main channel or wetland (marsh) based on a combination of stream order and site observation.

Population per study unit on the Kenya side was calculated by intersecting a 1999 population layer with the study units layer. The study units were then summed for a population estimate. No such population layer was available for Tanzania so a table of 2002 population data was used. A layer of the districts, Musoma, Tarime and Serengeti, was used to calculate the population density per district. The districts were intersected and the area multiplied by the population density to calculate population per study unit on the Tanzanian side. Study units that cross the border were again summed for the total Kenyan and Tanzanian population.

The spatial analyst extension of ArcMap was used to determine areas with greater than 30% topographic slope. These raster areas were converted to shapefiles and intersected with the study units to calculate area of steep slope. A populated places layer was used to estimate proximity of sites to towns. Camps within the Masai Mara National Reserve were considered populated places given the potential impacts these activities have on the local ecosystem. The same approach was used to estimate proximity of sites to roads. Additionally, a disturbance value was assigned to each site based on visual observations. Impacted rankings were: 1- less impacted, 2 less/moderately impacted, 3 moderately impacted, 4 – moderately/severely impacted, and 5 – severely impacted.

Although discharge measurements were taken at certain sites, necessary supplemental information such as precipitation was lacking. Given the disconnected and sparse nature of this data, a stream order value generated using ArcHydro served to characterize various flow classifications.

Due to the variability and diversity of sampling sites, 5 categories were established to allow more for more congruent analysis: swamp, wetland, headwater tributary, tributary and main stem (Table 2). Certain discreet sites such as sewage discharge points and on site mining structure sites were not included in this categorization.

Further investigation involved identifying any basic scale trends using x,y scatter plots and regression analysis. In this effort, the analytical data results were paired with the study unit characterization and spatial data to better understand any basin scale or local scale dynamics.

5. Results

5.1 Water Quality Results

5.1.1 In-Situ

Not only are aquatic organisms very vulnerable to changes in pH, the pH of water can dictate the solubility of some compounds or elements, i.e. higher pH can cause ammonium, NH_4, to be converted to the more toxic form, NH_3 (Weiner 2000).

Samples from 2007 ranged in pH from 4.79 at the Enupuiyapi Swamp (A1) to 8.63 Kitaramanka B (NS1). Values for 2008 ranged from 6.48 at Oke Ngalane (T1) to 10.45 at Olchor Lemek (OO1).

Figure 8: pH – Main Stem Mara and Wetlands

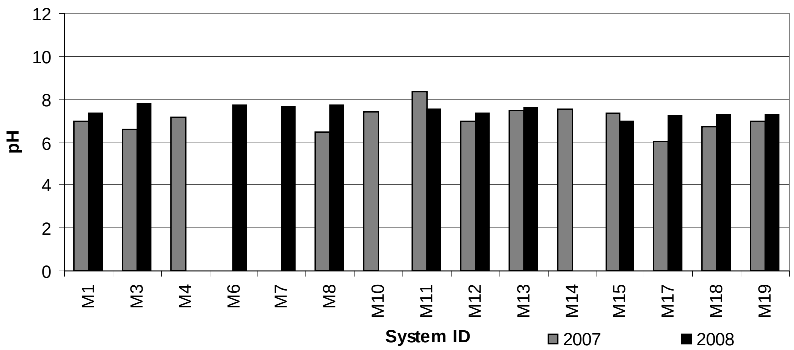
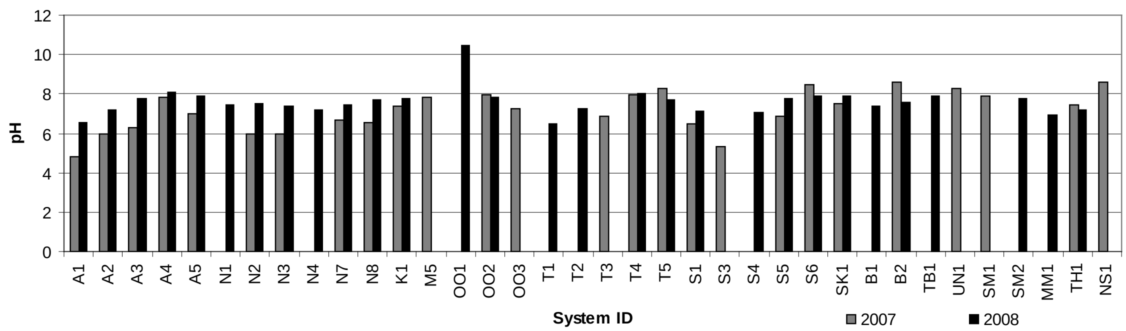


Figure 9: pH – Swamp and Tributaries



Dissolved oxygen, measured in percent saturation, is critical for aquatic life. Dissolved oxygen is consumed by plants at night and is also consumed in the breakdown of decaying organic matter. In particular, it is consumed during times of high biochemical oxygen demand which is fueled by a significant input of biodegradable matter such as the decomposition of dead algal matter after an algal bloom. Low dissolved oxygen can cause suffocation of fish and may result in unusable water due to an inability to oxidize waste.

In 2007, dissolved oxygen ranged from 13.8% at Lyamisanga (M17) to 94.8% at Thighete (TH1). In 2008, dissolved oxygen values ranged from 8.0% at the Enupuiyapi Swamp (A1) to 98.5% at Tabora (TB1).

Figure 10: Dissolved Oxygen – Main Stem Mara and Wetlands

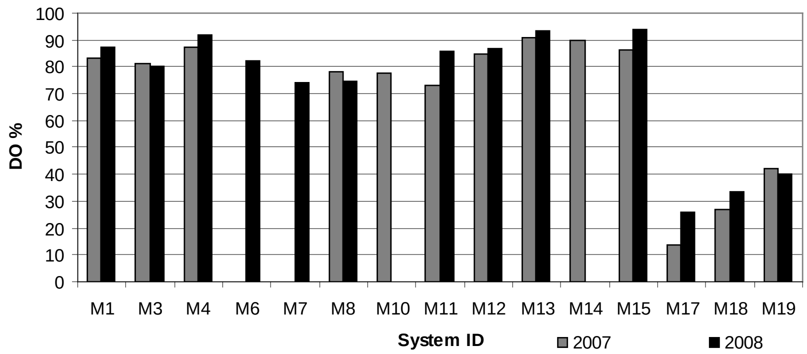
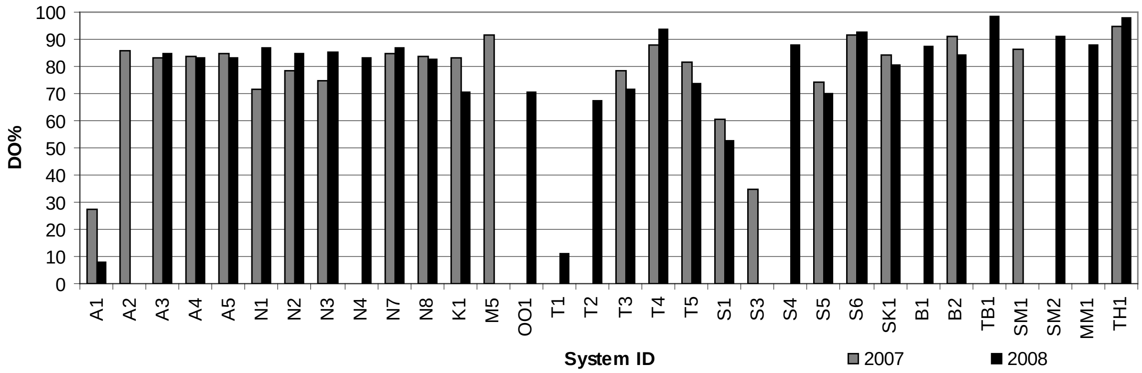


Figure 11: Dissolved Oxygen - Swamp and Tributaries



A YSI 556 MPS water quality unit was used to measure specific conductance, total dissolved solids (TDS) and salinity. Salinity and TDS were derived by the unit using temperature, conductivity, and an additional constant for TDS (Maidment 1993). Specific conductance, salinity and total dissolved solids reflect dissolved salt content and dictate the electrical capacity of the water. Salts in the water can affect taste and, in excess, may create an inhospitable environment for plants and other aquatic organisms.

Conductivity results for 2007 ranged from 22 µS /cm at the Enupuiyapi Swamp (A1) to 2038 µS /cm at Olare Oreko (OO2). The next highest value was 1171 µS /cm at Entiakiak (OO3). Results from 2008 ranged from 31 µS /cm at the Mugango River site

(N2) to 2950 μS /cm along the Olare Orok (OO1). The next highest values were OO2 and OO3 at 2045 μS /cm and 1965 μS cm^{-1}.

Figure 12: Conductivity – Main Stem Mara and Wetlands

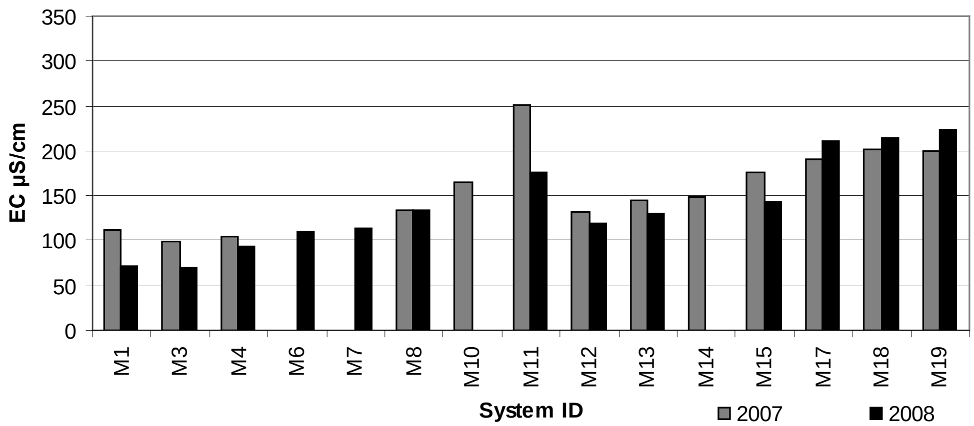


Figure 13: Conductivity – Swamp and Tributaries (low-mid range)

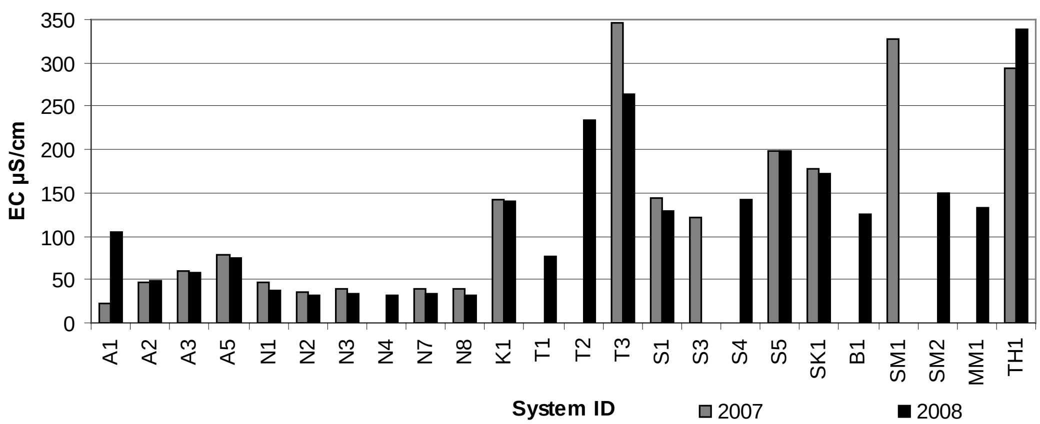
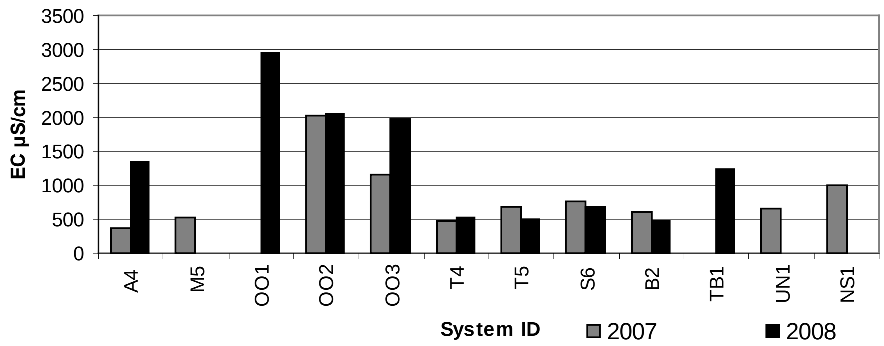


Figure 14: Conductivity – Swamp and Tributaries (high range)



In 2007, total dissolved solids ranged from 0.019 g/L at A1 to 1.466 g/L at OO2. In 2008, TDS ranged from 0.024 g/L at N2 to 2.147 g/L at OO1.

In 2007, salinity ranged from 0.01 ppt at A1 to 1.16 ppt at OO2. In 2008, Salinity ranged from 0.02 ppt at N2 to 1.74 ppt at OO1.

Not only is aquatic life vulnerable to temperature fluctuations but temperature also affects the solubility of compounds and gases. Additionally, temperature influences decomposition rates and plant metabolism which subsequently affects dissolved oxygen demands (Weiner 2000).

Temperature readings taken in 2007 ranged from 12.38 °C at the Enupuiyapi Swamp (A1) to 30.17 °C at the Borogonga Bridge (B2). Temperature results from 2008 ranged from 12.93 °C at the Enupuiyapi Swamp (A1) to 27.8 °C at Entiakiak (OO3).

Turbidity, or the measure of particulate matter suspended in the water column, can cause abrasions to aquatic life, clog gills and suffocate bottom dwelling organisms. Particulate matter facilitates the transport of nutrients and other compounds and also affects light penetration and potentially aquatic plant growth.

Turbidity results for 2007 ranged from 3.98 NTU at Sub Baringo (M5) to 400 NTU at Ochor Orike (S1). Turbidity results for 2008 ranged from 0.14 NTU at the Borogonga River headwaters (B1) to 300 NTU at the Enupuiyapi Swamp (A1).

Figure 15: Turbidity – Main Stem Mara and Wetlands

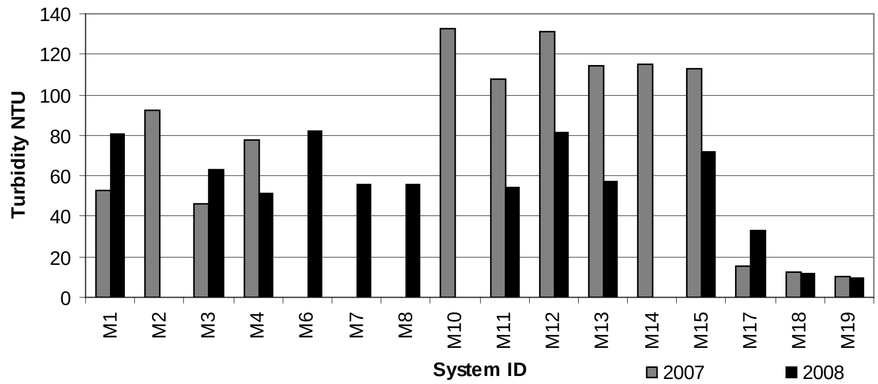
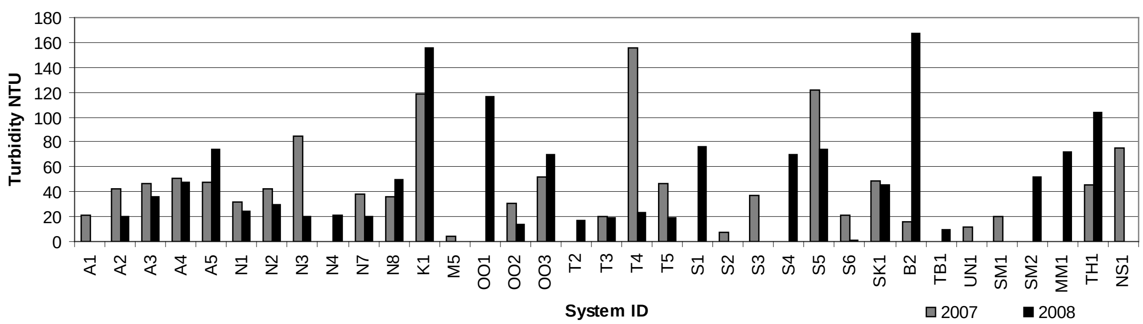


Figure 16: Turbidity – Swamp and Tributaries*



* Subset with higher and lower values removed for graphing purposes

Along the same lines as turbidity, total suspended solids (TSS) are a measure of particulate load. Total suspended solids values for 2007 ranged from 4.5 mg L-1 at Sub Baringo (M5) and Olochro-Ole Tuya (S3) to 417.5 mg L-1 at Ochor Orike (S1). Total suspended solids values for 2008 ranged from 4.4 mg L-1 at the Borogonga River headwaters (B1) to 612.7 mg L-1 at the Enupuiyapi Swamp (A1).

5.1.2 Nutrients

Nitrogen undergoes reversible oxidation and reduction processes as it travels though the environment. Nitrogenous compounds decompose and oxidize to form ammonia. Ammonia, along with other inorganic nutrients, facilitates plant growth. However, in excess, ammonia can be toxic to aquatic life; the NH_3 form is most toxic. Water chemistry components such as pH and temperature affect its form. This study analyzed ammonium nitrogen, NH_4.

In 2007, NH_4 values ranged from 12.92 µg L-1 at BBM2 (M3) to 5530.78 µg L-1 at sewage discharge site (M2). The next highest value, 308.04 µg/L, occurred at Olare Orike (OO2). Ammonium results in 2008 ranged from below detection at 13 sites to 580.3 µg L-1 at the Enupuiyapi Swamp (A1).

Figure 17: Ammonium – Main Stem Mara and Wetlands

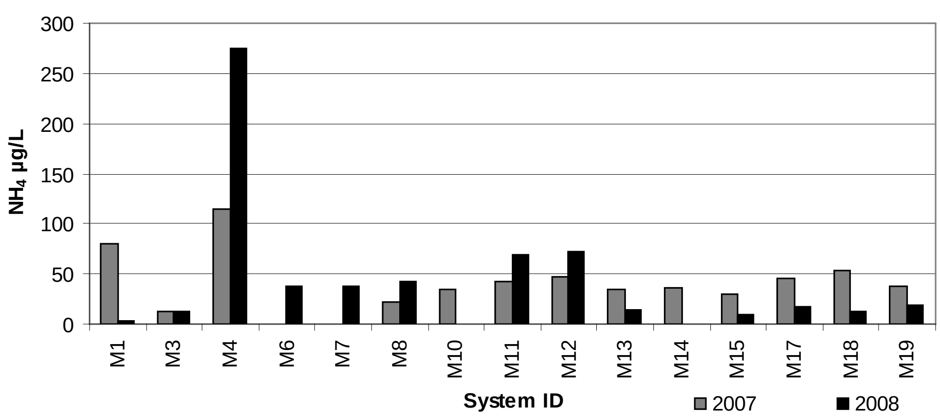
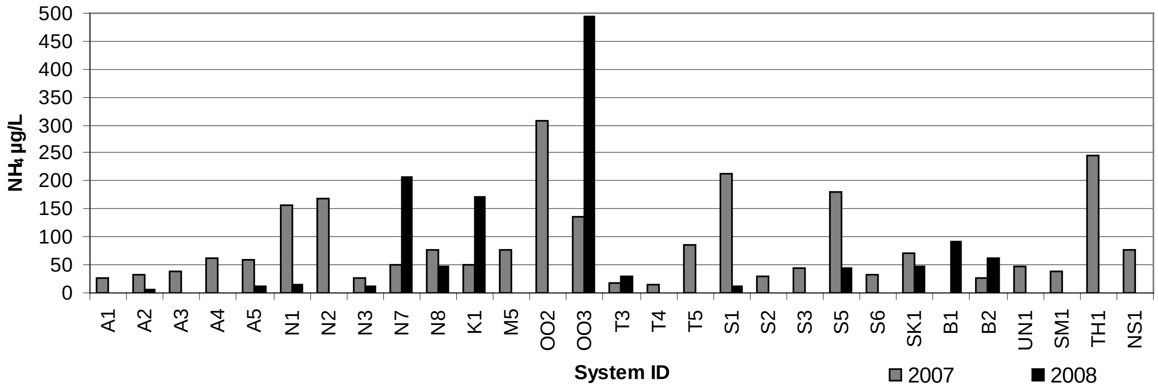


Figure 18: Ammonium – Swamp and Tributaries*



* Subset with higher and lower values removed for graphing purposes

As with ammonia, nitrite (NO_2) is essential for plants but, in excess, may be hazardous to animals and may cause methemologlobinemia in infants (Weiner 2000). Nitrite results for 2007 ranged from below detection at 4 sites to 21.92 μg L-1 at the Bomet Bridge (N8). The next highest value of 20.73 μg L-1 occurred at Nysiet (A4). Nitrite results for 2008 ranged from 0.01 μg L-1 at 1 site (S4) to 27.66 μg L-1 at Sekanani (SK1).

Figure 19: Nitrite – Main Stem Mara and Wetlands

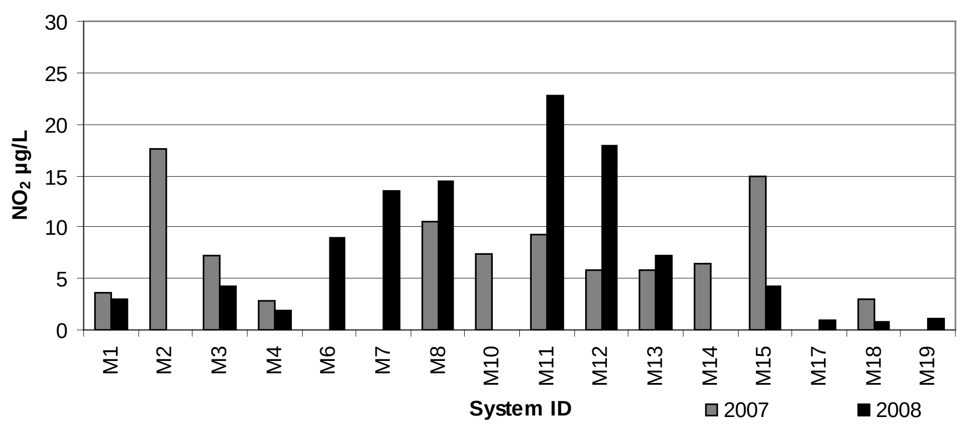
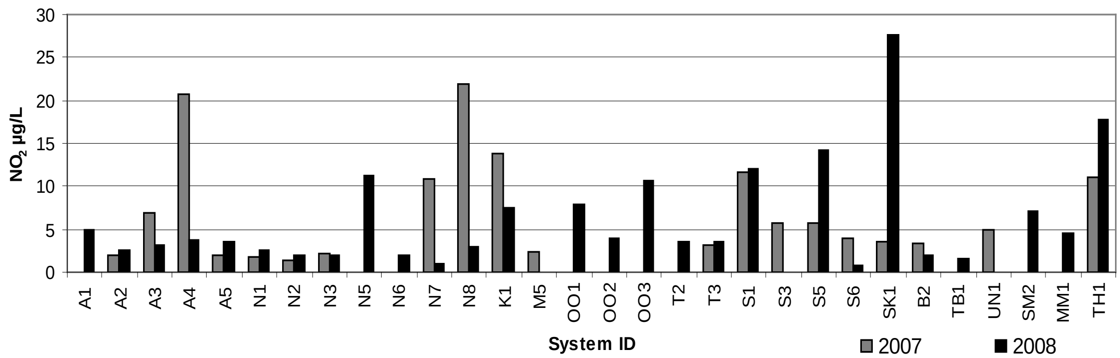


Figure 20: Nitrite – Swamp and Tributaries*



* Subset with lower values removed for graphing purposes

The nitrate (NO_3) results from 2007 ranged from below detection at 6 sites to 5613 μg L-1 at Kagawet (K1). The next highest value of 1189 μg L-1 occurred at the New Mara Bridge (M8). In 2008, NO_3 results ranged from below detection at 1 site the Kirumi Bridge (M18) to 4797 μg L-1 at Thighete (TH1). The next highest value of 1650 μg L-1 occurred at the Borogonga headwaters (B1).

Figure 21: Nitrate – Main Stem Mara and Wetlands

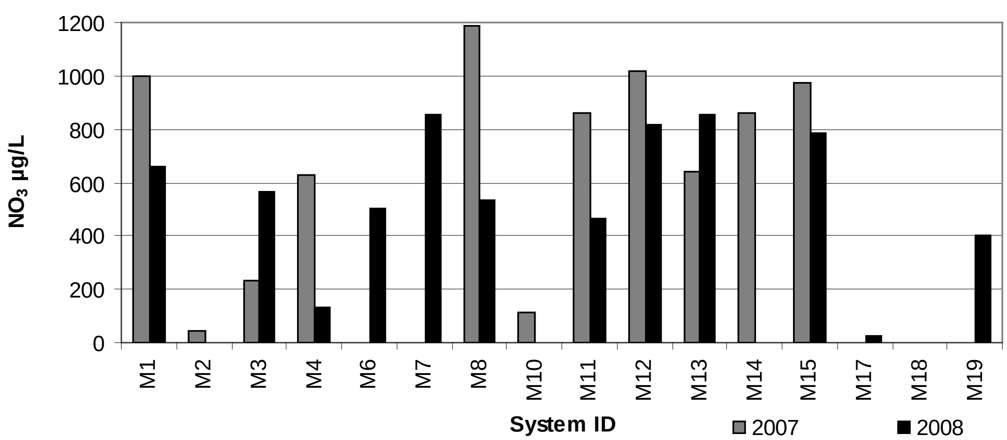
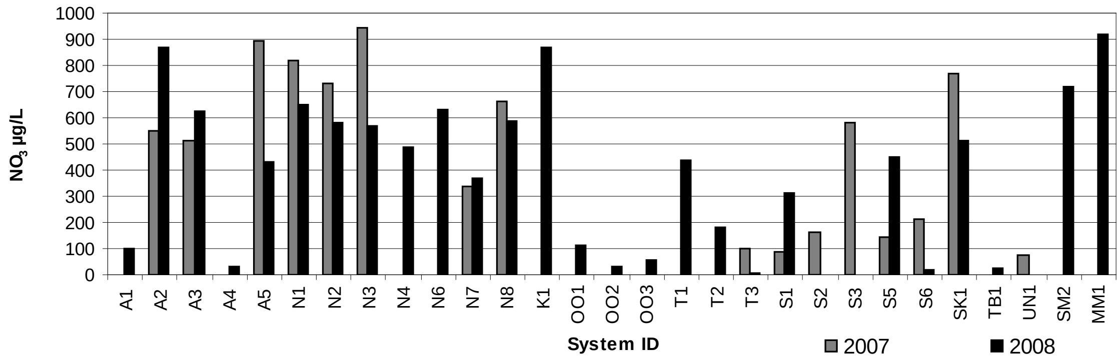


Figure 22: Nitrate – Swamp and Tributaries*



* Subset with high and low values removed for graphing purposes

In 2007, total dissolved nitrogen (TDN) ranged from 0.13 mg L^{-1} at Lyamisanga (M17) to 6.77 mg L^{-1} at Kagawet (K1). Total dissolved nitrogen values for 2008 ranged from 0.17 mg L^{-1} at Siana Springs (T3) and 4.50 mg L^{-1} at the Kones Bridge (N7).

Figure 23: Total Dissolved Nitrogen – Main Stem Mara and Wetlands

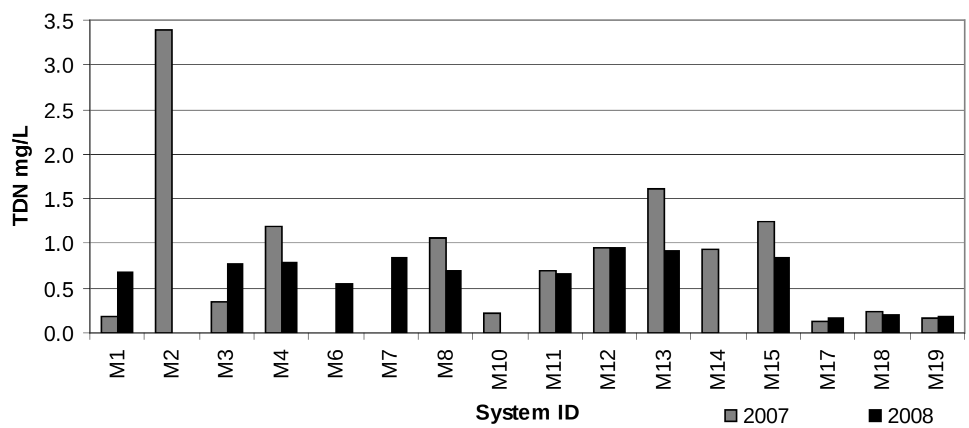
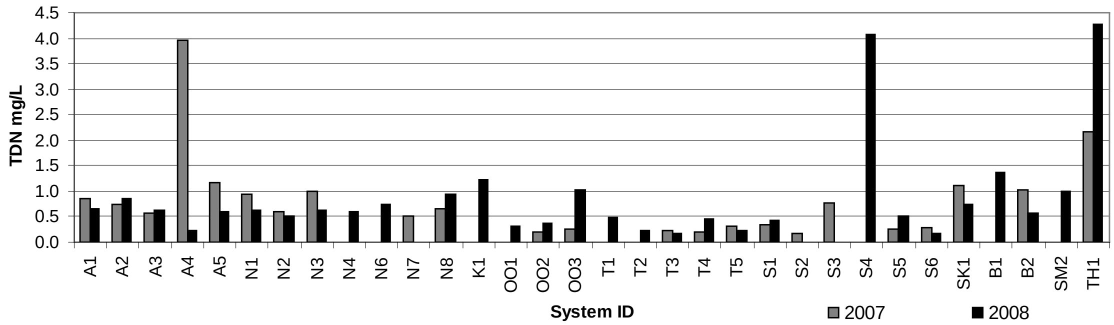


Figure 24: Total Dissolved Nitrogen – Swamp and Tributaries*



* Subset with high and low values removed for graphing purposes

Total nitrogen (TN) values from 2007 ranged from 0.16 mg L^{-1} at Lyamisanga (M17) to 6.34 mg L^{-1} at Sub Baringo (M5). The next highest value was 3.58 mg L^{-1} at Thighte (TH1). In 2008, the 43 ranged from 0.14 mg L^{-1} at Tabora (TB1) to 10.81 mg L^{-1} at the Tenwek Bridge (N4). The next highest value was Thighte (TH1) at 10.16 mg L^{-1}.

Figure 25: Total Nitrogen – Main Stem Mara and Wetlands

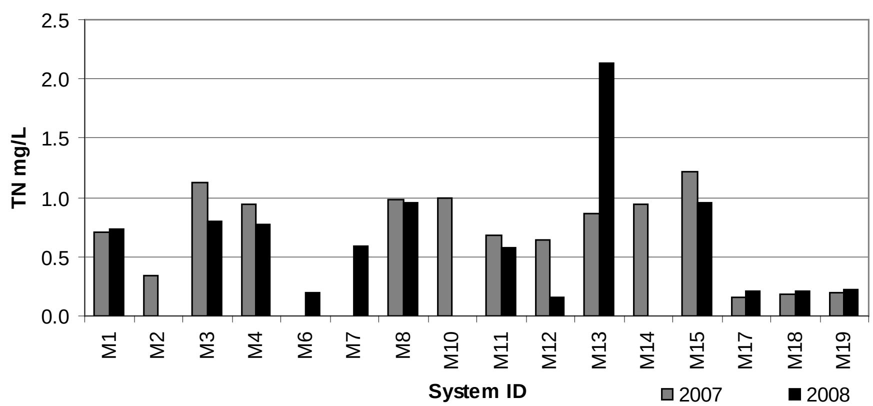
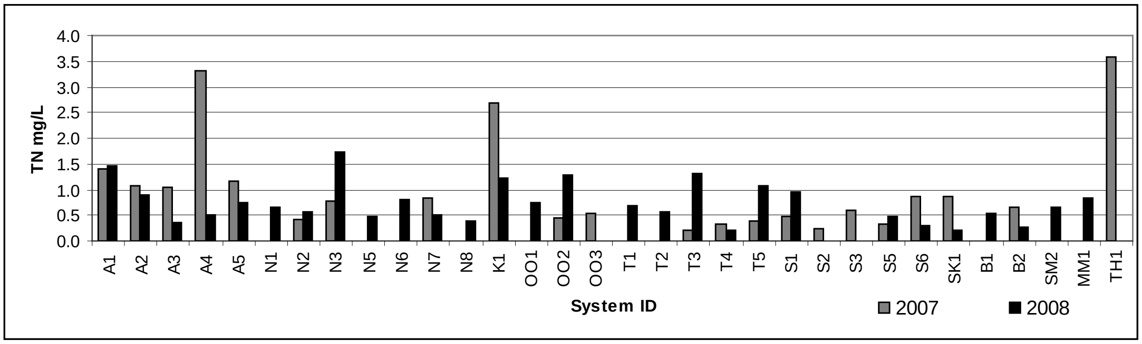


Figure 26: Total Nitrogen – Swamp and Tributaries*



* Subset with high and low values removed for graphing purposes

In 2007, soluble reactive phosphorus (SRP) values ranged from below detection at the Enupuiyapi Swamp (A1) to 688.68 μg L-1 at the sewage discharge site (M2). The next highest SRP value was 281.58 μg L-1 at the Old Mara Bridge (M4). In 2008, 19 of the 45 SRP samples were below detection. Detectable sample values ranged from 0.62 μg L-1 at both the Mara Mouth (M19) and Olooaimutia (S5) to 89.90 μg L-1 at Olchor Lemek (OO1).

Figure 27: Soluble Reactive Phosphorus – Main Stem Mara and Wetlands

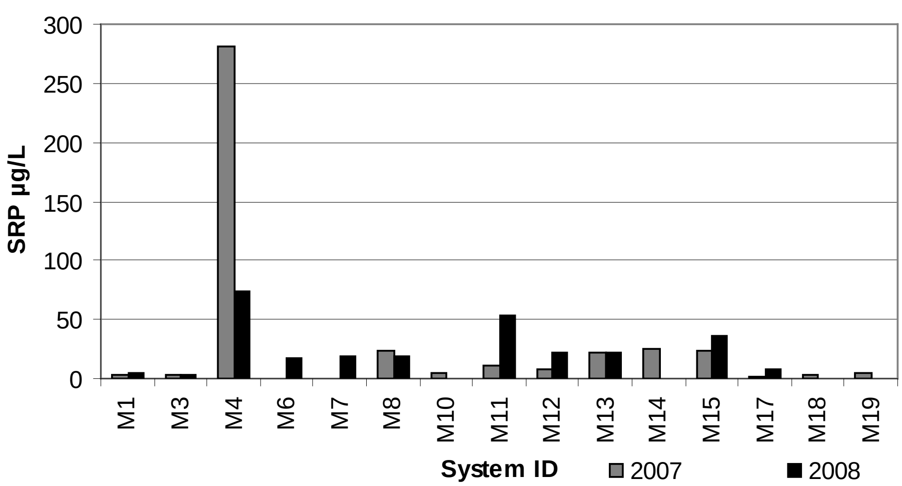
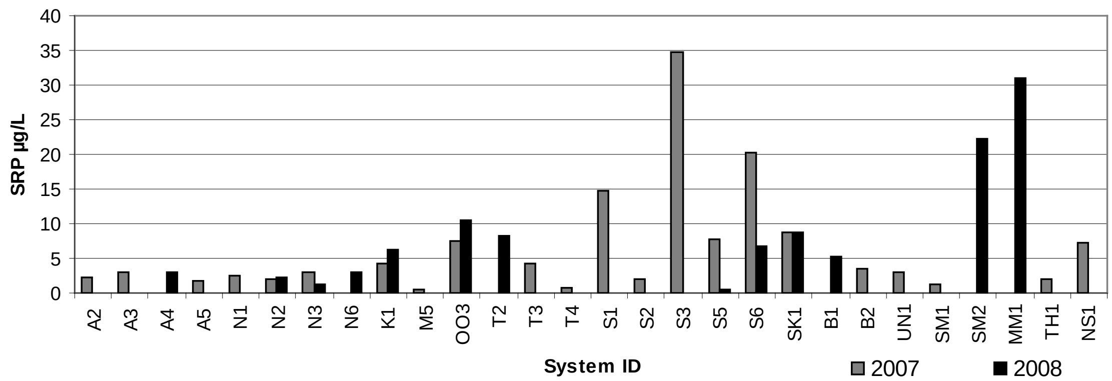


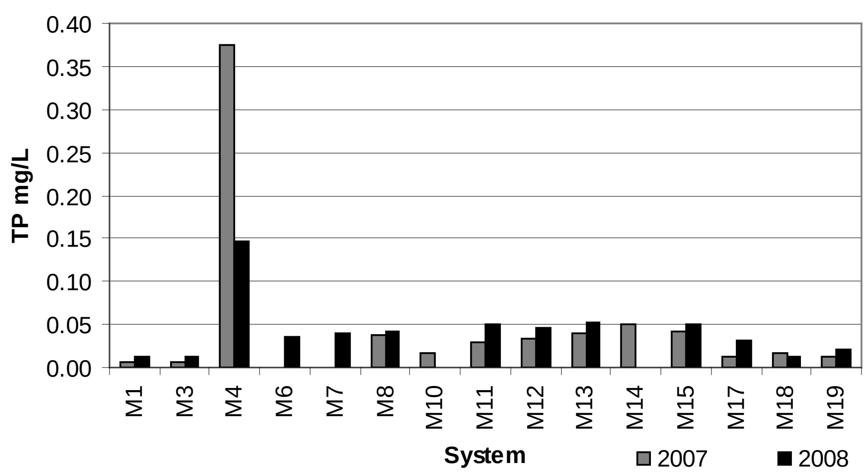
Figure 28: Soluble Reactive Phosphorus – Swamp and Tributaries*



* Subset with high and low values removed for graphing purposes

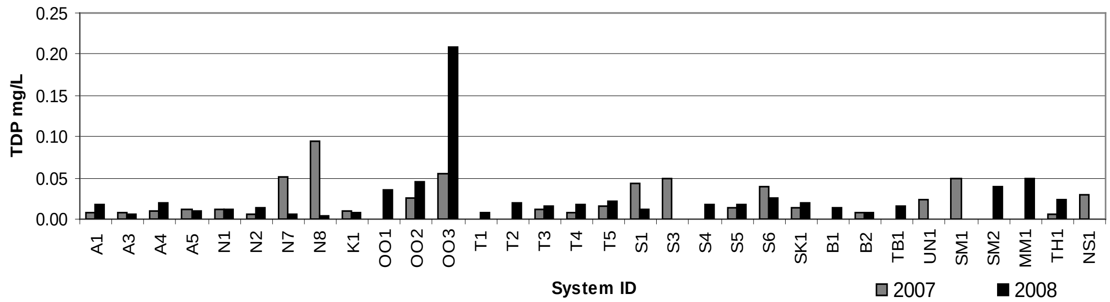
In 2007, total dissolved phosphorus (TDP) values ranged from 0.004 mg L^{-1} at Leshuta (S2) to 1.015 mg L^{-1} at sewage discharge point (M2). The next highest value was 0.374 mg L^{-1} at the Old Mara Bridge (M4). TDP values for 2008 ranged from trace amounts at 21 sites to 5.38 mg L^{-1} at the Tenwek sewage discharge point (N5). The next highest value was 0.21 mg L^{-1} at Entiakiak (OO3).

Figure 29: Total Dissolved Phosphorus – Main Stem Mara and Wetlands*



*M2 removed for graphing purposes

Figure 30: Total Dissolved Phosphorus – Swamp and Tributaries*



* Subset with high and low values removed for graphing purposes

In 2007, total phosphorus (TP) ranged from 4.96 μg L-1 at Leshuta (S2) to 672.70 μg L-1 at the sewage discharge site (M2). The next highest value was 189.10 μg L-1 at the Borogonga Bridge (B2). Total phosphorus results from 2008 ranged from below detection at 2 sites to 317.75 μg L-1 at Lyamisanga (M17).

Figure 31: Total Phosphorus – Main Stem Mara and Wetlands

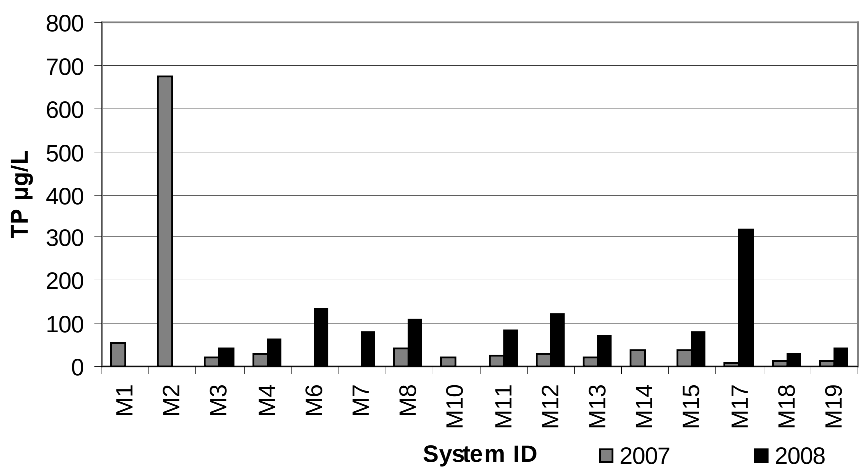
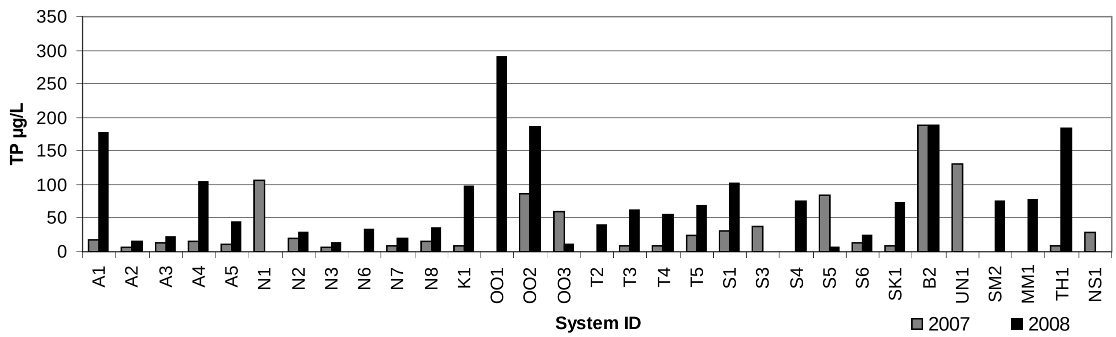


Figure 32: Total Phosphorus – Swamp and Tributaries*



* Subset with low values removed for graphing purposes

In 2007, dissolved organic carbon (DOC) ranged from 0.36 mg L-1 at Olochro Ole Tuya (S3) to 9.62 mg L-1 at sewage discharge point M2. The next highest values occurred at Somanche (SM1) and the Old Mara Bridge (M4). In 2008, values ranged from 0.53 mg L-1 at Oke Ngalane (T1) to 24.88 mg L-1 at Entiakiak (OO3).

Figure 33: Dissolved Organic Carbon – Main Stem Mara and Wetlands

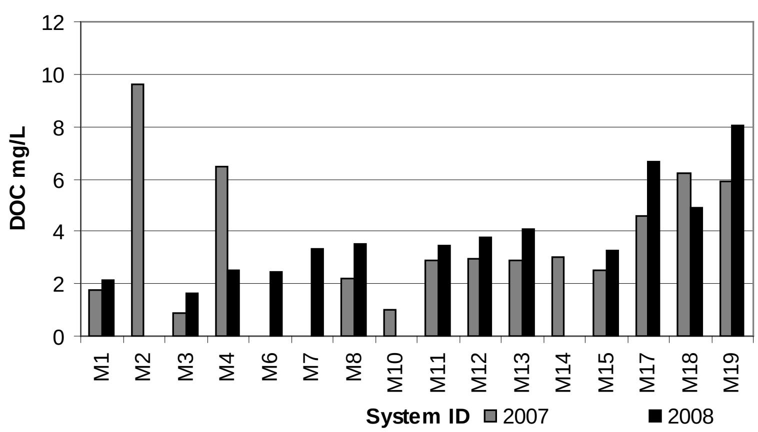
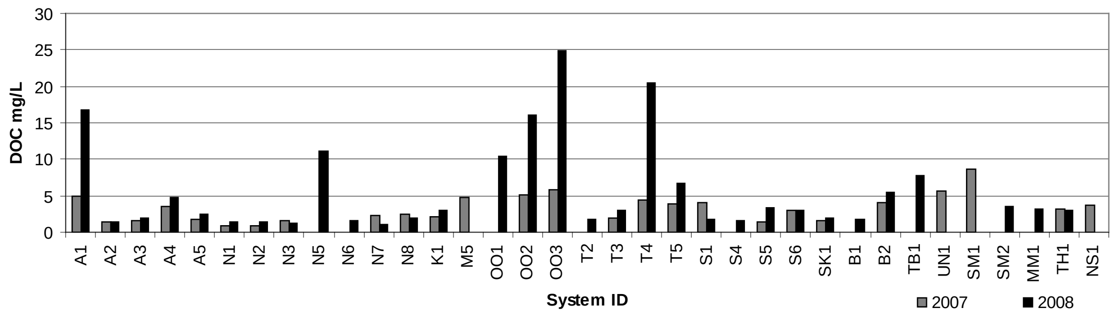


Figure 34: Dissolved Organic Carbon – Swamp and Tributaries*

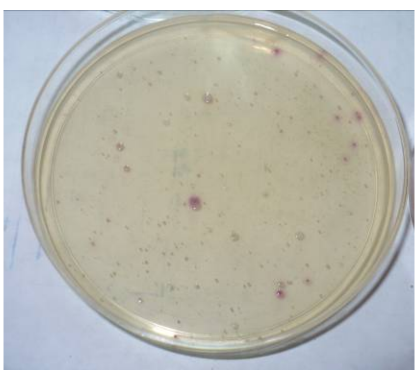


* Subset with low values removed for graphing purposes

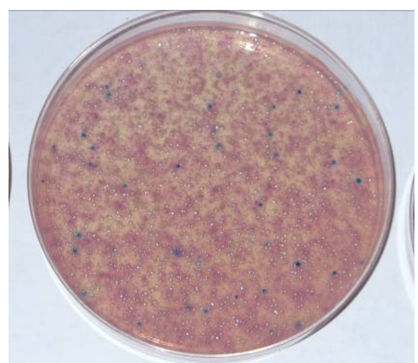
5.1.3 Coliform

Coliform results were inconclusive due to excessive culture growth. A dilution factor should have been used to allow for proper growth and colony formation. In this study, the gel was entirely pink or purple with colonies too numerous to count.

Proper Culture Development



Undiluted Culture Development



5.1.4 Macro Invertebrate Survey

The macro invertebrate ASPT values for 2008 ranged from 3 at Olchor Lemek (OO1) and Mugango Pump Station (N2) to 8 at the Kirumi Bridge (M18) (Table 5).

5.2 Visual Assessment

5.2.1 Flow

Although discharge measurements were taken at certain sites, necessary supplemental information such as precipitation was lacking. Given the disconnected and sparse nature of this data, flow measurements were not incorporated in the final analysis. Stream order, generated in ArcHydro, were used in lieu of flow measurements.

5.2.2 Visual Assessment

As part of the visual assessment, site characteristics pertaining to depth (taken approximately 0.5 meters from the bank), bank height and slope, right bank and left bank riparian condition, type of flow such as run or riffle and site alterations; i.e. pumps or bridges were compiled (Table 6,).

5.2.3 Observed Disturbance

An observed disturbance value was assigned to each site based on the number and extent of alterations; i.e. pumps, sewage discharges, dams, adjacent agriculture (Table 7). This value also reflected erosion and the extent of visible anthropogenic impacts such as riparian trampling and ground exposure due to the presence of livestock. The severity of invasive plant encroachment was also considered in assigning a value to the marsh wetland sites.

5.4 Geographic Information Systems

5.4.1 Characteristics of Contributing Areas

As previously mentioned, the area immediately adjacent to and upstream of each site was delineated as the contributing area or the watershed specific to the site. In all, 53 units were established. The units were summarized comprehensively including the entire upstream contributing area. Summary statistics included area, population, topography/elevation and percent land-use (Table 8).

The contributing area for the Enupuiyapi Swamp (A1) is 100% forest. Landuse percentages upstream of tributary sites vary. The Amala and Nyangores reaches are generally more than half agricultural with the second largest percentage being forest. Both forest and agriculture land uses drop off in the plains regions of the Olare Orok, Talek and Sand Rivers where the landuse is classified largely as bush and grassland. Downstream, in Tanzania, the tributaries are again heavily classified with bush and grassland but also contain significant percentages of woodland.

6. Discussion

6.1 Status

6.1.2 Swamp

Swamps or forested wetlands are essential components of aquatic ecosystems. Along with riparian features, wetlands are integral in controlling the quality and quantity of water entering and passing through the system (Haycock 1996). The aquatic chemistry of swamps is influenced by a number of factors including geology, water balance, plant and soil composition and the anthropogenic forces of the area. Swamps are characterized by wet and dry periods and serve as nutrient sinks as vegetation takes in dissolved inorganic nutrients during the growth process. During dry periods, exposure of the ground to oxygen activates the decomposition process. This decomposition results in the release of minerals and soluble organic nutrients which wash downstream in times of high water, making the swamp a nutrient source as well (Ismail 2005). Swamps also serve as sediment traps.

Due to the sediment trapping nature of swamps, it was expected that TSS and turbidity would be low. Dissolved oxygen was also expected to be low due to the decomposition processes associated with decaying forest and vegetation litter in addition to limited exposure to atmospheric oxygen as an input. Conductivity was also expected to be low considering that the water has not yet traversed a significant amount of rock and channel. Given low oxygen conditions, nitrogen was expected to be present in the ammonium form and dissolved phosphorus was expected to be low expecting that it would already have been assimilated by plants and vegetation. Macro invertebrate numbers and scores were expected to be higher given low salinity and turbidity although low DO and cooler temperatures may be a factor. Discharge was expected to be slow but constant and a less disturbed environment was expected.

As expected, DO and pH were low and NH_4 was the dominant form of nitrogen though NEMA limits were only exceeded in 2008. Somewhat unexpectedly, TSS and turbidity were elevated in 2008, also exceeding NEMA standards. Dissolved phosphorus was low, as expected, but TP levels were elevated in 2008.

Water levels differed significantly between the 2 sampling seasons with a discharge of 0.04 m^3/s in 2007 and too little flow for a discharge measurement in 2008. The site was characterized as less disturbed but deforestation is a significant threat to the entire area. The ASPT score for macro invertebrates was low, most likely a result of DO and temperature.

Though these results were largely expected, the difference between years is of interest. A possible cause for these differences and the unexpected sediment levels might be the drastically reduced water level in 2008, which was considered extreme by local accounts. No discernable flow was observed in 2008, indicating that the system was not flushing thereby allowing for the accumulation of NH_4, TP and sediment at the site. This lower water level also provided little dilution. Furthermore, the dry state of the swamp allowed for livestock encroachment, unseen in the previous year. This increased access may have resulted in more waste inputs and more trampling and dislodging of sediment.

2007

2008

6.1.3 Headwaters

Headwater streams are defined as the point at which sources waters come together to form a discernable channel. It is thought that the “water quality, biodiversity and ecological health of freshwater systems depend on the functions provided by headwater streams” (Lowe 2005). These headwater regions are responsible for maintaining discharge patterns, regulating nutrient and sediment, decomposition of organic material and supporting biodiversity with habitat niches (Lowe 2005).

The contributing areas of headwater sites in the basin are primarily bushland and grassland with high instances of pastoralism, low population density, low flow and recently emergent waters. In some instances, local people have instituted their own forms of protection by means of fencing (S3) and protective structures (T1 and S2).

Oke Ngalane (T1)   Leshuta (S2)

Dissolved oxygen was expected to trend low in recently emergent areas and higher in more established waters. Sites in more forested areas might trend low in pH due to the breakdown of organic material and associated tannic acids. Conductivity and total dissolved solids were expected to be low as the waters were recently emergent and had limited exposure to rock and soils. Total suspended solids and turbidity were expected to be low with the exception of sites with pastoral activities.

Nutrient levels were expected to fall within acceptable ranges. Macro invertebrate numbers and scores were expected to be higher given diverse habitat, low discharge and salinity, and high DO. Headwater sites were expected to have very low discharge. Given low populations densities and distance from populated areas it was expected that they would be fairly undisturbed environments.

As expected, flow in the headwater regions was low such that the Leshuta site (S2) in 2007 did not have enough water for the YSI probe. Therefore no in-situ chemistry readings are available. A low pH reading occurred at the Olochro Ole Tuya site. Low pH was expected at this site given that it was densely forested and had significant vegetation litter.

Olochro Ole Tuya

Dissolved oxygen trended low at Olochro Ole Tuya (S3) due to high organic content, Ochor Orike (S1) possibly due to organic waste inputs and Oke Ngalane due to its spring like nature. Temperature did not appear to be a factor. Otherwise values were in range. Conductivity trended low as expected.

Sites in the headwaters of the Sand River exceeded suspended solids and turbidity limits. The Olare Orike site (S1) was the only site to have received a highly disturbed ranking. This site was densely populated with livestock and had an abstraction pump. The high turbidity and TSS values were most likely a result of livestock trampling and an impaired riparian zone.

Olare Orike

Elevated turbidity and TSS at Olochro Ole Tuya (S3) may have resulted because of the unsettling of sediment by the artificial dam while the results for Olchor Orok Leshuta (S4) may be attributed to lack of significant flow. The Borogonga site (B1) was located in the protection of the Serengeti National Park. Talek site Oke Ngalane (T1) was more spring like with a surrounding marsh area and higher flow was observed at the Pakaitibiao site (T2). These factors may have prevented elevated turbidity and TSS values.

Olochro Ole Tuya

Olchor Orok Leshuta

Olchor Orok Leshuta was also high in total dissolved nitrogen. The riparian area at this site was patch grass with a few trees. TDN may have accumulated to levels beyond vegetation needs given that they system has such low flow and therefore is not allowing nutrients to flush out. Ochor Orike (S1) demonstrated elevated levels of total phosphorus in 2008 only. This sample may have been collected after a rain event which washed particulate in to the channel or dilution in 2007 may have exceeded that of 2008. Macro invertebrate scores for these areas trended mid range, with sites along the Talek River ranking highest. The Talek sites appeared to have more suitable vegetation and demonstrated lower turbidity. Highly disturbed site Ochor Orike (S1) received the lowest score.

Pakiatpiao (T2)

Oke Ngalane (T1)

6.1.4 Tributaries

The tributaries of the Mara River are diverse in their channel structure, flow and surrounding environments. The riparian zone of river channels provides many of the same services as wetlands. Riparian vegetation is vital in "removing and retaining particulates" and can also reduce velocity via the friction provided by the vegetation itself and associated litter (Haycock 1996). Riparian vegetation along the tributaries and main channel of the Mara River are the first line of defense against deforestation, agricultural practices and pastoral activities found throughout the basin.

The tributaries to the north, in Kenya, are mostly permanent and agricultural while the tributaries to the south are mostly ephemeral and pass primarily through rangeland. The Tanzanian tributaries, also largely ephemeral, pass through mining regions, agricultural areas and rangeland.

Studies have indicated that land managed for agriculture passes more nutrients to receiving waters than natural systems. Riparian forests are considered effective nutrient uptake structures (Peterjohn 1984). Samples taken along agricultural tributaries in the Mara Basin were expected to display higher nutrient values. Additionally, given the extent of riparian destruction evident throughout the basin, sediment and turbidity results were also expected to be high at and downstream of these areas. Water chemistry for these sites was expected to fall within acceptable ranges.

Tributaries that pass through the semi arid rangelands were expected to have lower water levels due to the high evaporation rate and high sediment and turbidity values given erosion and riparian destruction attributed to pastoral activities. Nutrient content was not expected to be excessive. However, elevated nutrient levels might be expected at sites where livestock had recently been or were present at the time of sampling. Nutrients may also rate high at and downstream of the Tenwek sewage discharge point. These sites should be higher in dissolved oxygen; therefore nitrogen would be expected to be present in the form of nitrate.

Macro invertebrate assemblages are a product of a number of factors including flow regime, geology and habitat type. It is often difficult to separate the influence of these factors from local land use, such as agriculture (Richards 1997). Therefore, it is difficult to predict how macro invertebrate numbers and scores will reflect the varied land use observed within the tributary sites. None the less, the tributary sites provide good habitat for macro invertebrates given lower velocities, diverse riparian vegetation and varied channel dynamics such as pools and riffles. Chemical parameters such as low salinity and high dissolved oxygen should are also favorable conditions for macro invertebrates(Chessman 2003). Macro invertebrate numbers and ASPT scores are expected to be high at these sites with these characteristics.

Low pH occurred in the upper reaches of the Amala and Nyangores which is most likely attributed to the underlying geology. Though 3 sites displayed high pH values, all but 1, Olchor Lemek (OO1), were very close the NEMA threshold. The pH at this site was extremely high, perhaps from a probe malfunction. As expected, dissolved oxygen was within recommended values, with the exception of Entiakiak (OO3). In this instance, water levels were low enough to allow pooling in the channel thereby decreasing exposure to atmospheric oxygen. OO3 is located in a protected area and therefore not prone to significant biologic inputs as with pastoral regions. Given adequate oxygen levels in 2008, the 2007 reading was most likely a result of circumstances pertaining to flow.

Sites OO1, OO2 and OO3 all ranked high for total dissolved solids, conductivity and salinity. These results suggest that this area is significantly affected by the geology and mineralogy of the region and maybe by the low water levels characteristic of the area. Additionally, these sites are somewhat prone to evaporation.

As expected, suspended solids and turbidity were high throughout the basin. Suspended solids and turbidity patterns bared a strong resemblance. The Amala and Nyangores sites were consistently high, exceeding standards both years. Sites along the border of the MMNR reflected higher values. This area is highly pastoral and more densely populated than other rangelands as the MMNR draws local people for economic opportunities (Gereta 2003). A number of sites downstream of the Serengeti National Park ranked high, all within close proximity to agriculture.

Tenwek sewage discharge point, N5, exceeded the NEMA standard for ammonium, though slight. However, the site immediately downstream of this site, N6, ranked low. Though no standards are in place for total nitrogen or total dissolved nitrogen, a number of sites displayed high total nitrogen and total dissolved nitrogen levels. The sites high in total nitrogen were dispersed. The sites high in total dissolved nitrogen were clustered in the Amala and Nyangores areas, an agricultural region. The Thighete site, high in both TN and TDN, is also located in an agricultural area.

Elevated soluble reactive phosphorus and total dissolved phosphorus values were found along the Nyangores and Olare Orok tributaries. The sites along the Nyangores, Kones and Bomet, have adjacent agriculture and high livestock presence. A high livestock presence was also observed in the upstream region of Olare Orok. All of the Olare Orok sites were characterized by low flow as well which may contribute to the build up of nutrients at these sites.

Kones Bridge (N7)

Bomet Bridge (N8)

Olchor Lemek (OO1)

The sites that displayed high dissolved carbon values, Entiakiak (OO3) and Talek (T4), are characterized as bushland with no agriculture in proximity. Studies indicate that DOC content in rivers is indicative of the catchment and that DOC can be divided into 2 groups, humic substances and more complex compounds. Humic substances may account for 60 – 90% of surface water DOC (Sachse 2005). The high DOC values observed at OO3 and T4 are most likely the result of decaying organic material and low water levels. Excess DOC at OO3 may also be attributed to a hippopotamus (*Hippopotamus amphibious*) pool observed upstream.

Entiakiak (OO3)

Talek (T4)

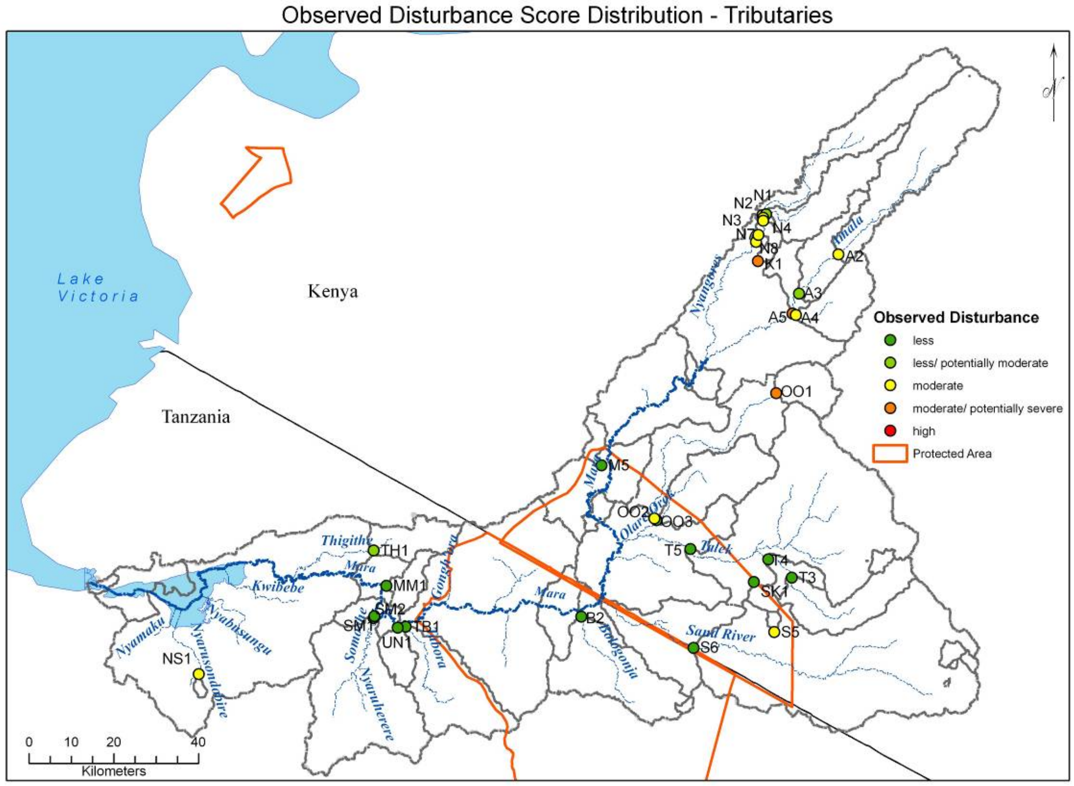
A number of sites ranked high in total phosphorus, including the Borogonga Bridge both years. It is believed that particulate phosphorus is derivative of mineral material. Research indicates that total phosphorus follows total particulate trends, i.e. suspended solids and that the particulates are foremost mineral matter and to a lesser extent organic (Saunders 1988). High TP values at the Borogonga Bridge and elsewhere in the basin may be a result of mineral inputs which accumulate at the site due to lack of flow.

Borogonga (2007) Borogonga Bridge (2008)

Macro invertebrate scores trended mid to high for tributary sites. The Amala and Nyangores tributaries trended mid range with a few lower values while most sites in the Talek and Sand regions trended low. The sites along the Talek and Sand demonstrated lower water levels which may have been a factor. With the exception of the Somanche, sites on the Tanzanian side trended mid range. Tabora (TB1) received the highest score. No correlations between land use and observed disturbance were observed.

Observed disturbance for tributary sites ranged from less disturbed (1) to moderately to potentially severely disturbed (4). Damage from livestock was the most frequent cause for higher disturbance ratings with agriculture coming in second. Sites along the Amala and Nyangores as well as the Oalre Orok trended highest (Figure 35).

Figure 35: Observed Disturbance Score Distribution - Tributaries



6.1.5 Main Channel

The main stem Mara is a compilation of the swamp, headwater and tributary waters as well as runoff from the immediate areas. As previously mentioned, the Mara is often the only source of flowing water in the southern portion of the basin and serves as a last resort for wildlife.

It was expected that the main channel would continue to reflect erosion given agricultural and pastoral practices upstream. Water chemistry parameters were expected to fall within acceptable ranges. Nutrient content was not expected to be excessive though the potential of localized highs were anticipated in and around sewage discharge points, downstream of animal habitats, i.e. hippopotamus (*Hippopotamus amphibious*) pools and potentially reaches with adjacent agriculture. Nitrogen was expected to be present in the form of nitrate.

The main channel was expected to have greater discharge thereby increasing its dilution capacity. Riparian degradation was not expected to be as extensive as tributary areas given lower population densities and the protected status along much of the channel. Therefore the assigned observed disturbance scores were expected to be more 1's and 2's, less and less/potentially moderately disturbed. Macro invertebrate numbers and scores were expected to be low due to lower habitat diversity and faster flow.

Water chemistry results were all within acceptable limits, however, all of the main stem sites exceeded turbidity and total suspended solid standards in both years. Sewage discharge point M2 was the only site high in NH_4. While nitrate was expected to be the dominant form of nitrogen, the low flow level of the source did not allow measurements with the YSI. Most likely, the dissolved oxygen readings would have been low indicating that the NH_4 did not have the opportunity to oxidize into nitrate. This site also displayed high dissolved nitrogen values, though no standards are in place.

Sewage discharge site M2, the Old Mara Bridge site (M4), and the Mara/ Borogonga confluence (M11) exceeded soluble reactive phosphorus limits. Sites M2 and M4 also ranked high in total dissolved phosphorus. These results were expected for the sewage discharge site. M11 only exceeded limits in 2008 while M4 exceeded limits both years, TDP as well. Large numbers of migratory wildlife were observed in the upstream regions of the Borogonga River in 2008, more so that in 2007. This river also demonstrated low water levels. The concentration of animal waste inputs and low dilution ability of the waters most likely resulted in the high levels of SRP observed downstream.

Borogonga Bridge 2008

The reasons for the elevated levels at the Old Mara Bridge are less obvious although livestock is present in this region. Additionally, hippopotamus (*Hippopotamus amphibious*) were observed downstream in 2007. It is possible that there are additional hippopotamus (*Hippopotamus amphibious*) pools upstream of the bridge. High total phosphorus was again observed at sewage discharge point M2 but was also observed at the New Mara Bridge (M8), Oloololo (M6), and the Kogatende Bridge (M12). These levels are most likely a product of mineral inputs from the local environment.

With the exception of the Silibwet Bridge in 2008, discharge along the main channel exceeded that of the tributaries sites. Additionally, only 14% of main stem sites received an observed disturbance value of 3 or above compared to 48% of tributary sites. Sewage discharge point M2 was the only site ranked moderately to potentially severely impacted which was due to the nature of the impact, i.e. sewage, and its intensity in that at times it is potentially undiluted and of serious concern to human health.

Macro invertebrate scores were higher than expected at sites M11, M12 and M13 where scores were above 4. This may be due to the presence of organisms from the Naucoridae Family which is considered to be less tolerant and more susceptible to pollution (Dickens 2002). The Naucoridae Family, known as creeping water bugs, feed on other invertebrates and are common to lentic freshwater regions but can also be found in "sluggish streams" (DEWHA 2008). Though discharge along this reach is more substantial, these bugs were also found in tributaries in the area which may account for their presence in less sluggish areas.

6.1.6 Wetlands

The wetland sites of the Mara were expected to demonstrate lower discharge rates which allows for settling of particulate matter. Therefore, suspended solids and turbidity values were expected to diminish. Dissolved oxygen was expected to be low.

Nutrient levels were expected to be lower due to higher plant density and nutrient assimilation. Nitrogen was expected to be present in the form of ammonium due to low oxygen levels. Macro invertebrate numbers and scores were expected to be higher given more diverse habitat and lower velocities. While the wetland area is under attack by invasive plant species such as the water hyacinth, observed disturbance at these sites was expected to be low. Factors influencing the wetlands are broader in scale and generally reflect collective activities in the upper reaches.

As expected, all 3 sites demonstrated low dissolved oxygen. The Lyamisanga site, M17, displayed low pH which may have been a result of high organic decomposition and elevated tannic acids. This site also exceeded turbidity and total suspended solid limits in 2008. The 2008 sample was taken closer to the bank whereas the 2007 sample was taken more mid channel. The high turbidity and TSS levels were most likely a result of reduced water column mixing and erosion at the access point.

2007 Sampling Point

2008 Sampling Point

Nutrient levels were generally low and within acceptable levels although M17 was high in total phosphorus in 2007. Total phosphorus levels were elevated upstream and seem to reflect mineral inputs of this region. As expected, macro invertebrate scores were high. No specimens were collected at the final site at the mouth of the Mara but the samples taken at the Kirumi Bridge (M18) and Lyamisanga (M17) were the highest in the basin at 8 and 7 respectively. The observed disturbance values for these sites were less/potentially moderate at the Kirumi Bridge and Lyaminsanga and moderately disturbed at the Mara Mouth. The rankings result from the high volume of exotic plants and affects of increased siltation which contributes to the dramatic increase in wetland area (cite Mati).

6.2 Health

6.2.1 Swamp

The Swamp results for 2007 and 2008 were significantly different. Water chemistry results were generally expected and most parameters fell within acceptable ranges. The same can be said for nutrient content. However, the ramifications of the low water level in 2008 were evident. This raises some concern in that the low level was considered extreme by local people. It remains to be seen if this was an isolated occurrence or the beginning of a trend. The overall health of the swamp seems to be intact though deforestation and altered precipitation patterns are cause for concern.

6.2.2 Headwaters

Headwater sites were somewhat diverse. However, given the components of each site, results were generally expected. While the majority of these systems seem to be in good health, results indicate that anthropogenic activities are taking their toll on some, Ochor Orike (S1) in particular. A high level of disturbance was observed at this site in terms of flow alterations and livestock influences. These factors increased sedimentation and diminished flow causing important ecosystem processes to fail. While the Olochro Ole Tuya site (S3) displayed low pH and higher sediment content, potentially affects of the artificial dam, the overall health of that system did not appear to be significantly impaired. While the remaining headwater sites appeared to be in good health these systems are extremely fragile and susceptible to processing failure with small fluctuations in flow and vegetation structure.

6.2.3 Tributaries

With respect to water chemistry, tributary sites overall exhibited good health. Isolated instances of deviation from expected values or standards occurred. Most often these deviations could be attributed to local soils and geology or water level. Suspended solids and nutrient results suggest impaired health in specific regions mostly stemming from agricultural and pastoral activities. This is evidenced by excessive erosion and sediment transport throughout the basin as well as elevated nitrogen and SRP in the agricultural region. Observed disturbance values correlate to these findings. While tributary sites in the Mara River Basin are not universally impaired, results suggest that anthropogenic activities are having some affect on the health of these systems.

6.2.4 Main Channel

The main channel of the Mara River does not appear to be severely impaired. Excessive suspended solids and elevated turbidity were again evident. Elevated nutrient levels are not widespread thereby decreasing the risk of eutrohpication. Though some modifications exist along the main channel, i.e. sewage treatment, extractions for mining, there do not appear to be significant, sustained impacts at this time.

6.2.5 Wetlands

While the wetland sites appear to be in good health with respect to water chemistry, nutrient levels, and macro invertebrates. However, the implications of broad scale issues such as invasive plant and animal species, excess sediment from upstream and surrounding areas and subsequent expansion of the wetlands, push this region to the brink of impairment.

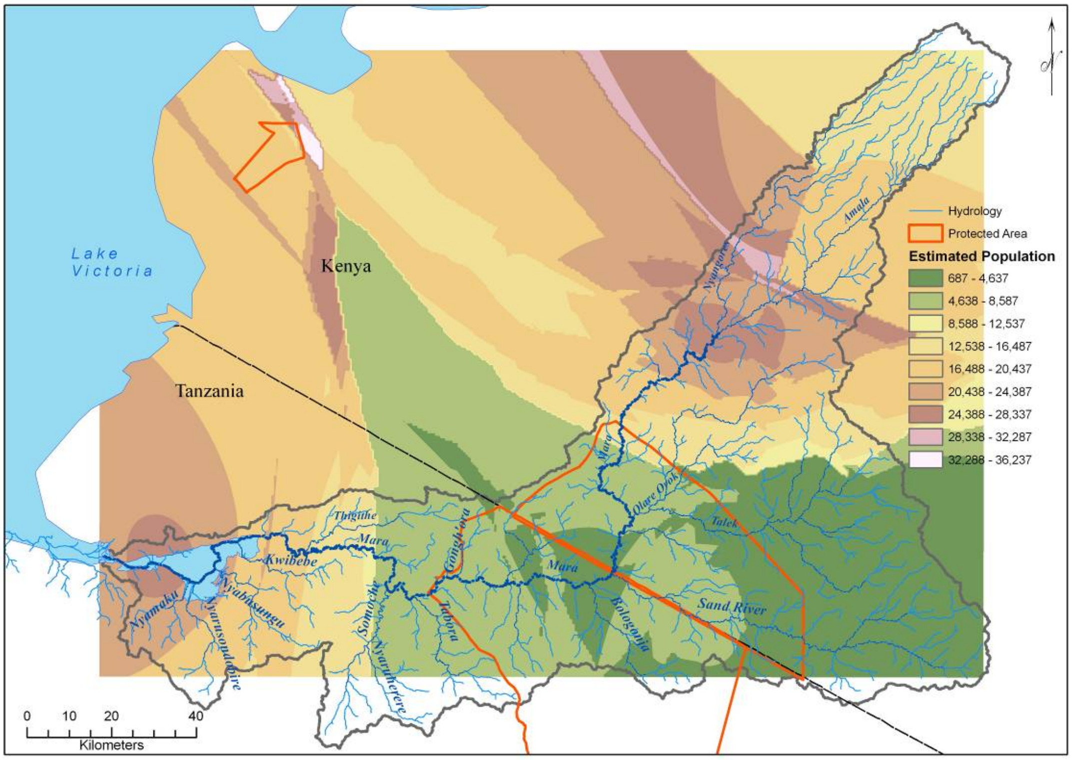
6.3 Vulnerability

The Mara is plagued with numerous local issues, mainly land conversion, nutrient pollution and flow alteration. Additionally, the region faces the universal challenges of population growth and climate change, in this case noticeable deviations from and historic precipitation patterns. While each of these issues has specific impacts and management techniques, they are intimately linked within the larger system.

6.3.1 Population

Population growth rates for Kenya and Tanzania are estimated at ? and ? respectively. Using the populations numbers estimated for each study unit, a surface was generated to interpolate current populations throughout the basin, Figure 36. This figure illustrates the population distribution throughout the basin. As expected the upper and lower portions of the basin are the most densely populated with the tributary headwaters and protected areas being less populated. Population is critical when estimating potential expansion and development vulnerability.

Figure 36: Interpolated Population Distribution



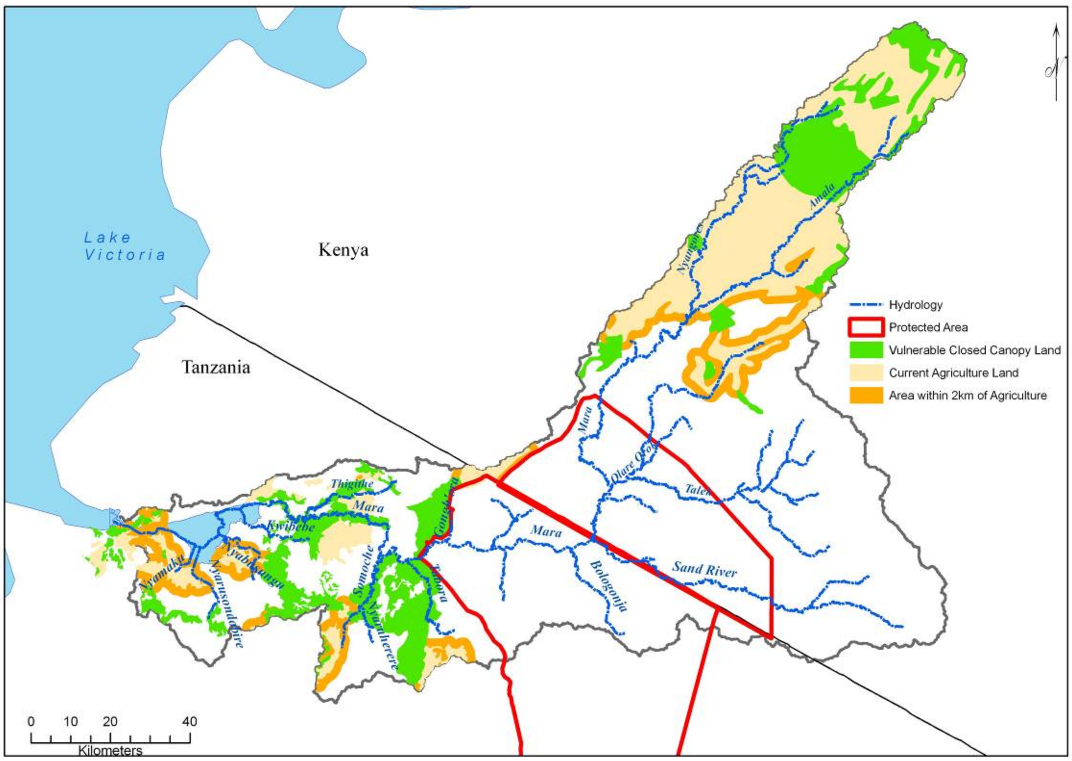
6.3.2 Land Conversion

Cultivated area in the Amala basin alone increased by more than 31% between 1960 and 1991 and these numbers do not even reflect the influx of immigrants to the area between 1999 and 2002 at when the number of households increased by 13%. The rangelands to the south have experienced similar increasing where livestock increased by close to 50% between 1999 and 2002.

Deforestation is evident in both the Mao forest and the region surrounding the Mosirori wetlands in Tanzania. In addition to land conversion, the Enupiuyapi Swamp faces illegal settlements, poaching of timber products and logging,

Land adjacent to agricultural land is inherently vulnerable given the potential for proximate expansion. As seen in Figure 5, fragments of closed canopy land use types, Forest and Woodland, are found throughout the basin. While these remaining forest regions should all be considered vulnerable, those fragments immediately adjacent to agricultural areas are most vulnerable. Figure 37 shows areas vulnerable to land conversion along with land currently characterized as agricultural.

Figure 37: Areas Vulnerable to Land Conversion



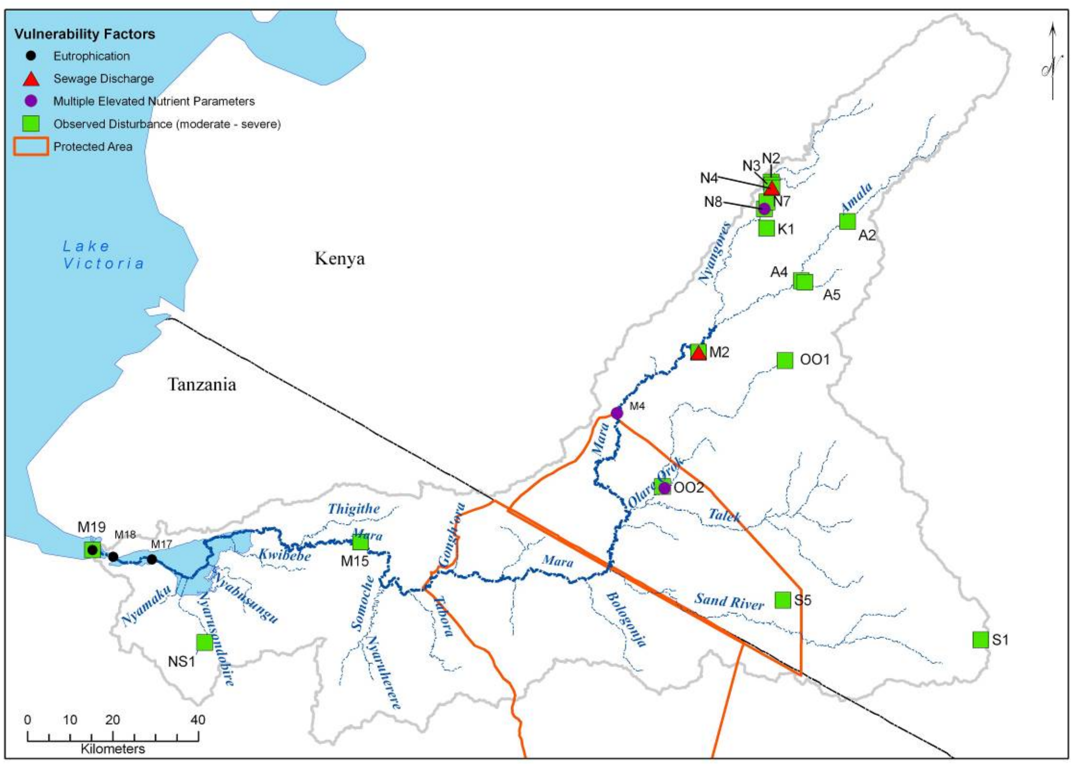
6.3.3 Eutrophication and Biological Contamination

As previously mentioned, diminished riparian zones and sedimentation are evident throughout the basin thereby facilitating the movement of nutrient and disease causing organisms. Though the Mara has continues to flow throughout the year, nearby rivers in Tanzania dry up and pool during the dry season resulting in eutrophic situations (Gereta 1998). The Mara is vulnerable to this given concerns of decreased flow.

Improper agricultural practices upstream, deforestation and damaged riparian structure throughout the basin have resulted in increased sediment load. This is evident in the expansion of the wetland. This sediment may facilitate the movement of excess nutrient, setting the stage for eutrophic conditions.

While results from this study indicate that sewage discharges are, at present, sufficiently diluted downstream, decreased flow and increases in population, both permanent and tourism based, may impair the river's nutrient assimilation capacity. Water treatment facilities throughout the basin are sparse, over capacity or, in some cases, bypassed. The Mara and its tributaries are the sole source of water for many households and wildlife.

Figure 38: Areas Vulnerable to Organic and Inorganic Pollution



6.3.4 Flow Alteration/Climate Change

Permitted abstractions are found throughout the basin. Management and monitoring of these permits is inefficient and weak. Studies indicate the land conversion and deforestation are resulting in fluctuations to historic flow regimes in higher and faster flow peaks. Deforestation and conversion from closed canopy environments to agriculture interferes precipitation development. Furthermore, increased ground exposure facilitates faster runoff and decreases infiltration which also compromises base flow (Mati 2008). As previously mentioned, it is thought that the Mara's baseflow is responsible for maintaining year round flow. The ability of the system to sustain flow is critical especially in instances of severe drought. While environmental flow investigations are underway, the Mara and its tributaries are extremely vulnerable to diminished flow.

6.4 Basin Scale Trends

Some loose correlations were apparent in the 2007 dataset, such as the correlation between pH and percent forest where pH decreased as percent forest increased. Additionally, correlations existed between pH and temperature, dissolved oxygen, conductivity and elevation, whereby pH increased as temperature, dissolved oxygen and conductivity increased and decreased as elevation increased.

Results from 2008 displayed a similar correlation between pH conductivity. A similar correlation between pH and percent forest was apparent when A1 was removed from the dataset. Though higher than the previous year, the pH for the Swamp still fell just above the standard range.

Dissolved oxygen exhibited a positive correlation with pH in 2007 where DO increased as pH increased and when OO2 (high salinity and high DO) was removed from the dataset, the correlation between DO and salinity becomes more apparent. These correlations were not evident in the 2008 dataset.

In both 2007 and 2008 a weak correlation between EC and TP was found where EC increased while TP increased. A similar correlation existed in 2007 with slope, i.e. EC increased as the amount of slope greater than 30 degrees increased. Though stronger in 2008, a positive correlation also existed with dissolved organic carbon in both years. In 2008, somewhat strong positive correlations existed between DOC and EC, Salinity and TDS.

A weak correlation existed between turbidity and NH4. This is most likely due to higher NH4 values at the swamp coupled with an unusually high turbidity reading. The same is true for turbidity and total phosphorus.

No correlations with other chemical, nutrient or physical data were evident in 2007 or 2008 though the expectation was that suspended solids would be highest downstream of agricultural areas.

With respect to the complete dataset, no significant correlations were evident between the ASPT score and nutrient levels, chemistry or level of disturbance. However, weak correlations ($r^2 > 0.10$) were evident between ASPT and system type (ASPT score increased downstream), population (ASPT score increased with increased population), stream order (ASPT score increased as order increased) and elevation (ASPT score decreased with increased elevation). Though weak, these relationships may indicate that the actual physical environment, i.e. flow and temperature, may be more influential than the chemical environment. Although, in most instances, chemical parameters were well within existing standards, potentially concealing their influence.

Overall, basin scale correlations were generally weak. Observed trends reflected… indicating a trend towards more localized trends. However, the nature and scope of the threats to the region, i.e. deforestation, flow alteration and land conversion, might strengthen basin scale relationship in the future.

7. Conclusions

- Turbidity and suspended solids levels are in excess throughout most of the basin
- Anthropogenic activities are associated with impairment of some reaches
- For the most part, the Mara River system is able to assimilate nutrients, inorganic and organic, at present
- Water level/discharge appears to influence water quality
- Eutrophication was not occurring in the wetlands at the time of the study
- Routine monitoring is needed to provide more complete insight into the dynamics of the Mara and its tributaries
- More focused studies are required to understand the reasons behind data results

8. Recommendations

The data from this report are limited in that they are merely snapshots of specific locations at specific points in time. It is recommended that the data from this study be used by water managers to better understand water quality trends in the basin. This data not only serves as a baseline on which to build but may also be used to plan future monitoring programs.

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Table 1: Kenya and Tanzania Water Quality Standards				
Parameter	Kenya	Tanzania	U.S. EPA	Other
pH	6.5 - 8.5			
Dissolved Oxygen		> 6 mg/L		
Conductivity			150-500 µS/cm (recommended: suitable for fish)	
Total Dissolved Solids	1200 mg/L			
Salinity				
Temperature	Max 30 °C (recreational waters)			
Turbidity	50 NTU	30 NTU		
Total Suspended Solids	30 mg/L			
Ammonia	0.5 mg/L			
Nitrate	10 mg/L			
Nitrite	3 mg/L			
Total Dissolved Nitrogen				
Total Nitrogen			2 - 6 mg/L	
Soluble Reactive Phosphorus			0.05 mg/L discharging to lake; 0.10 mg/L open streams	
Total Dissolved Phosphorus				
Total Phosphorus			0.10 mg/L	
Dissolved Organic Carbon				1 - 20 mg/L

(Maidment 1993; U.S.EPA 1997; NEMA 2006)

Table 2: Site Name and Sampling Season									
System	System ID	Site ID	System Type	Years	System	System ID	Site ID	System Type	Years
Amala	A1	Enupuiyapi Swamp	Swamp	2007, 2008	Mara	M13	Tarime/Serengeti	Main Stem	2007, 2008
	A2	Matecha	Tributary	2007, 2008		M14	Mara Mines 2007	Main Stem	2007
	A3	Kapkimolwa (BBM1)	Tributary	2007, 2008		M15	Barrick Mine	Main Stem	2007, 2008
	A4	Nysiet	Tributary	2007, 2008		M17	Lyamisanga	Wetlands	2007, 2008
	A5	Mulot Bridge	Tributary	2007, 2008		M18	Kirumi Bridge	Wetlands	2007, 2008
Nyangores	N1	Mugango River	Tributary	2007, 2008		M19	Mara Mouth	Wetlands	2007, 2008
	N2	Mugango Pump Station	Tributary	2007, 2008	Talek	T1	Oke Ngalane	Headwater Tributary	2008
	N3	Silibwet Bridge	Tributary	2007, 2008		T2	Pakaitibiao	Headwater Tributary	2008
	N4	Tenwek Bridge	Tributary	2008		T3	Siana Springs	Tributary	2007, 2008
	N5*	Tenwek Discharge	Tributary	2008		T4	Talek River II	Tributary	2007, 2008
	N6*	Tenwek Downstream	Tributary	2008		T5	Talek River	Tributary	2007, 2008
	N7	Kones Bridge	Tributary	2007, 2008		SK1	Sekanani	Tributary	2007, 2008
	N8	Bomet Bridge	Tributary	2007, 2008	Sand	S1	Ochor Orike	Headwater Tributary	2007, 2008
	K1	Kagawet	Tributary	2007, 2008		S2	Leshuta	Headwater Tributary	2007
Olare Orok	OO1	Olchor Lemek	Tributary	2008		S3	Olochro-Ole Tuya	Headwater Tributary	2007
	OO2	Olare Orike	Tributary	2007, 2008		S4	Olchor Orok Leshuta	Headwater Tributary	2008

	OO3	Entiakiak	Tributary	2007, 2008		S5	Olooaimutia	Tributary	2007, 2008
Mara	M1	Emarti Bridge	Main Stem	2007, 2008		S6	Sand River	Tributary	2007, 2008
	M2	Sewage Discharge	Main Stem	2007	Borogonga	B1	Borogonga Headwater	Headwater Tributary	2008
	M3	Mara Safari (BBM2)	Main Stem	2007, 2008		B2	Borogonga Bridge	Tributary	2007, 2008
	M4	Old Mara Bridge	Main Stem	2007, 2008	Tabora	TB1	Tabora 2008	Tributary	2008
	M5	Sub Baringo	Tributary	2007	Somanche	SM1	Somance 2007	Tributary	2007
	M6	Oloololo	Main Stem	2008		SM2	Somance 2008	Tributary	2008
	M7	Serena	Main Stem	2008	Mara Mines	MM1	Mara Mines 2008	Tributary	2008
	M8	New Mara Bridge (BBM3)	Main Stem	2007, 2008	Thighte	TH1	Thighte	Tributary	2007, 2008
	M10	Mara/Sand Confluence II	Main Stem	2007	Nyarusondobire	NS1	Kitaramanka B	Tributary	2007
	M11	Mara/Borogonga Confluence	Main Stem	2007, 2008	Unknown	UN1	Tabora 2007	Tributary	2007
	M12	Kogatende	Main Stem	2007, 2008	* Discreet Point - No Study Unit				

Table 3: Water Quality Parameters

Component		*Units*	*Composition*	*Function*	*Issues*
Nitrate	NO^3	µg/L	inorganic: 2nd phase of oxidized ammonia: oxidation of nitrite	required for plant growth	toxic at high levels; can result in oxygen deficiency
Nitrite	NO^2	µg/L	inorganic: 1st phase of oxidized ammonia	required for plant growth	toxic at high levels; can result in oxygen deficiency
Nitrate and Nitrite	N+N	µg/L	inorganic: nitrite plus nitrate	required for plant growth	in excess can cause excessive growth
Total Dissolved Nitrogen	TDN	ppm	dissolved organic and inorganic nitrogen	bio available for plant uptake	in excess can cause excessive growth
Total Nitrogen	TN	ppm	inorganic and organic, dissolved and particulate nitrogen	required for plant growth	in excess can cause excessive growth
Ammonia	NH^4	µg/L	dissolved inorganic; 1st phase of organic nitrogen decomposition	required for plant growth	toxic at high levels; especially unionized form
Soluble Reactive Phosphorus	SRP	µg/L	dissolved, inorganic phosphorus	required for plant growth	in excess can cause excessive growth
Total Dissolved Phosphorus	TDP	ppm	dissolved orthophosphate, soluble reactive phosphorus	required for plant growth	in excess can cause excessive growth
Total Phosphorus	TP	µg/L	inorganic and organic, dissolved and particulate phosphorus	required for plant growth	in excess can cause excessive growth
Dissolved Organic Carbon	DOC	ppm	dissolved organic carbon	indication of organic load	in excess can deplete oxygen content
pH			concentration of H ions measured as a log scale	determines acidity	affects solubility of some compounds; small fluctuations effect wildlife
Dissolved Oxygen	DO	mg/L	dissolved oxygen content	determines decomposition potential	depletion affects wildlife and organic matter decomposition
Salinity	Sal	ppt	dissolved salt content	influences oxygen content	organisms require a specific range
Electrical Conductivity	EC	µS /cm			
Total Dissolved Solids	TDS	g/L			

Temperature		°C	temperature	influences oxygen content, solubility, decomposition and metabolism	organisms require a specific range
Turbidity		NTU	suspended particulate matter	transport of nutrients and organic material	light penetration and subsequent plant growth; abrasion and suffocation of organisms
Total Suspended Solids	TSS	mg/L	suspended particulate matter	transport of nutrients and organic material	light penetration and subsequent plant growth; abrasion and suffocation of organisms

Table 4: Laboratory Instruments and Analysis Methods		
Parameter	Instrument	APHA Methodology #
pH	YSI Mulitprobe System	4500-H^+
Dissolved Oxygen	YSI Mulitprobe System	4500-O G
Conductivity	YSI Mulitprobe System	2510
Total Dissolved Solids	YSI Mulitprobe System	
Salinity	YSI Mulitprobe System	2520 B.
Temperature	YSI Mulitprobe System	2550
Turbidity	LaMotte Portable Turbidity Meter Model 202	2130 B.
Total Suspended Solids	Whatman 45µm cellulose nitrate membrane; microscale	2540 D.
Ammonia	Technicon RFA	4500-NH4 G.
Nitrate	Technicon RFA	4500-NO3 F.
Nitrite	Technicon RFA	4500-NO3 F.
Total Dissolved Nitrogen	Technicon RFA	4500-N C
Total Nitrogen	Technicon RFA	
Soluble Reactive Phosphorus	Technicon RFA	4500-P F.
Total Dissolved Phosphorus	Technicon RFA	4500-P H.
Total Phosphorus	Technicon RFA: digestion	
Dissolved Organic Carbon	Shimadzu TOC-Vcsh	
Flow	General Oceanic 2030 Mechanical Flow meter	

Table 5: Macro Invertebrate Survey					
Site ID	Number of Taxa	ASPT	Site ID	Number of Taxa	ASPT
A1	3	4.00	M13	3	5.33
A2	1	5.00	M15	2	4.00
A3	2	3.50	M17	1	7.00
A4	4	3.50	M18	1	8.00
A5	5	4.60	M19	2	4.00
N1	2	4.00	OO1	1	3.00
N2	4	3.00	OO2	4	4.00
N3	4	4.50	OO3	3	4.33
N4	3	5.67	S1	6	3.67
N5	1	7.00	S4	6	3.83
N7	3	5.00	S5	4	4.25
N8	4	4.00	S6	4	4.50
K1	5	4.40	SK1	5	4.00
B1	4	3.75	T1	1	4.00
B2	1	5.00	T2	4	4.50
BK1	2	5.50	T3	5	3.80
M1	7	4.00	T4	3	3.67
M3	5	3.60	T5	4	4.25
M4	3	4.00	MM1	3	4.33
M8	1	4.00	SM2	4	4.25
M11	3	5.33	TB1	3	6.00
M12	3	4.33	TH1	4	5.50

Table 6: Visual Assessment - Channel							
System ID	Wetted Width		Depth		Water Behavior		Channel
	2007	2008	2007	2008	2007	2008	
A1	1.5	very low	0.5	0.15	medium run, constant flow	pools	vegetation islands
A2	24	18	1.32	low	run ,riffle	run, some riffle, no pool	vegetation islands
A3		9			fast run, riffle	moderate run	
A4	18	7			slow run	run, some pools	vegetation islands, large boulders
A5	24	22	low		run, riffle	run, some riffle	vegetation islands
B1		0.75		0.25		slow run	
B2		57	0.3	1.68	slow run, pools	channelized run, pool	channelized, rock & sand
K1	1.5			0.08	mostly run, some pool	low flow	
M1	18	17			run, some riffle, pools at bank	run, some riffle	
M3		26			fast run	fast run/riffle, some pool at edge	hippo carcass upstream
M4	33	29	1.41	low	run	run, some riffle	exposed rocks
M5	3		0.02		very slow run, pools		bridge will flood
M6							
M7		33		low		moderate run	
M8		33		moderate		fast run	hippo pool upstream
M10							
M11	102	60	0.53	0.43		mostly run, some riffle	boulders, rock in channel, crocodile & hippo in water
M12		83		0.76	very fast run, riffle	run, slow pools along shore	not accessible during high water
M13	32	38	0.1		fast run, riffle & some pool	run, some riffle	vegetation islands
M14	50		0.62		slow run		
M15	32		0.34	extremely low for this time of year	run	slow run	
M17	65		2+		run	run	
M18	128					run	vegetation in channel

M19	128+	128+	2+	2+	river mouth, no discernable flow	river mouth, no discernable flow	
MM1		83				slow run, pools	
N1	12	5	1.09	0.77	slow run	moderate run	sometimes floods
N2	27	25		0.35	run, riffle	run, moderate riffle	
N3	28	23	1.32		pools, riffles, run	run riffle, some pool	
N4		30					silty mud
N7	19	19	1.94		run, some riffle	run, moderate riffle	bank full
N8	18				calm run	moderate/fast run	
NS1	2		0.09		very slow, almost still		
OO1		2		0.31		slow run, appears constant	
OO2	17	17	0.12		run	no run, pools	sometimes floods, vegetation islands
OO3	23	23	0.14		slow run, some isolated pools	some flow, not across road	vegetation islands
S1	1		0.07	low	slow run		also spring in some places
S2					spring		
S3	6		0.1		artificial dam		
S4		3.5-4m		low		slow but constant flow	
S5	6			low	low flow	slow movement but constant	
S6	24	20	0.1	low	channelized run, some pool	slow run, with pools	boulders, sandbars, vegetation
SK1	5				slow flow	slow movement but constant	channelized
SM1	3		0.26		very slow run, pools		
SM2		15		2.5		slow run	rock weir
T1						spring	
T2				0.07			
T3	2	6	0.07		run, some riffle & pools		
T4	18	23	0.18		slow flow	little run, mostly pools	channelized, some vegetation in channel
T5	26	22	0.1		run & riffle, pools downstream	run & riffle, pools downstream	veegetation islands
TB1		12		low			

TH1	5	3	0.3	0.17		run, some pooling along bank	vegetation and boulders in channel
UN1	2		0.11		fast run, riffle & some pool		

Table 7: Visual Assessment - Erosion/Alteration				
System ID	Erosion		Alteration	Substrate
	Right Bank	Left Bank		
A1	increased sediment at low flow, trampling	increased sediment at low flow, trampling		swamp, area soil very red, thick mud
A2	livestock wading	livestock wading	bridge downstream	silty with little/no rock fragments
A3	not evident	not evident	bridge	silt with course rock fragments
A4	livestock wading	livestock wading	bridge	silty
A5	not evident	foot traffic	bridge upstream	silty, muddy w/ unsorted angular rock fragments
B1	not evident	not evident		sandy
B2	not evident	not evident	bridge	rock and sand, many vegetation islands throughout channel
K1	significant with rain	significant with rain	bridge upstream	silty mud
M1	exposed earth, some at bank	at bank	bridge	silty sand
M3	along steep bank area	undercutting		
M4	undercutting	undercutting	bridge	primarily sand with some small pebble/fragments
M5	some undercutting	some undercutting	bridge	
M6				
M7	undercutting	undercutting		sand
M8				sandy
M10				
M11	at exposed ground, undercutting	at exposed ground, undercutting		sand
M12	undercutting, upper bank	undercutting, upper bank	bridge	sandy with some grass and shrubs
M13	at exposed sand	at exposed sand, near cornfield	bridge	bedrock, sand
M14	at site access	at exposed sand		bedrock, sand
M15	along bank, foot traffic, undercutting	undercutting	mining abstraction	bedrock
M17	not evident	not evident	water pump (windmill)	course sand
M18			bridge	course sand
M19	N/A	N/A		
MM1	along steep bank and access point	along steep bank and access point		
N1	not evident	exposed bank, very steep	bridge	Silty, no cobble or rock fragments

N2	not evident	not evident	water pumped to Silibwet Town	Silty, no cobble or rock fragments
N3	minimal	apparent in access area	bridge upstream, pump station rigt bank, car wash	gravel, angular rock fragments
N4	not evident	not evident	hydro electric source, pump to local school	grass
N7	not evident	not evident	bridge downstream	silty sand and mud
N8	not evident	not evident		silty mud with some pebbles
NS1	not evident	not evident	bridge	
OO1	high degree of trampling	high degree of trampling		
OO2	at banks	at banks		silt, bedrock
OO3	some undercut at floodline	some undercut at floodline	road passes though, hippos upstream	channel primarily rock with vegetation interspersed throughout, otherwise loose cobble and fragment and silt
S1	highly trampled	highly trampled	abstraction, pump house	silt
S2	not evident	not evident	protective structure	
S3	not evident	not evident	protective structure	
S4				quartx fragments, sandy silt
S5	trampling	trampling	bridge	small pebbles, course sand
S6	undercut at bank	undercut at bank	bridge	complex flow pattern due to many boulders, flat rocks, vegetation islands and sandbars
SK1	trampling & erosion at road	trampling	road passes though	sand and cobble, divided channel
SM1	not evident	not evident	bridge	
SM2	not evident	not evident		shale banks
T1	not evident	not evident	protected pump tank	marsh
T2	not evident	not evident		course sand
T3	not evident	not evident	road passes though	sand with very small pebbles
T4	undercutting	undercutting	strong livestock odor, bridge nearby	boulders, flat rocks and round cobble
T5	not evident	not evident	bridge	large rock and sand
TB1	access point	minimal	bridge	sand

TH1	not evident	not evident	bridge	bedrock and large cobbles, muddy silt
UN1	not evident	not evident	bridge	

Table 8: Visual Assessment - Riparian				
System ID	Vegetation		Bankd Height & Slope	
	Right Bank	Left Bank	Right Bank	Left Bank
A1	swamp	swamp		
A2	grasses, some shrub, corn field	grasses, some shrub; exposed ground	2m, gradual	3-4m, steep
A3	grass, trees	grass, trees	2m, moderate	2m, moderate
A4	grasses, some shrub	grasses, trampled	2	1.5
A5	some trees, shrubs	grasses at site, some shrub and trees adjacent	3m, gradual	4-5m, steep
B1	grass, trees	grass, trees		
B2	artificial embankment	grass		
K1	grasses, some shrub	grasses, some shrub		
M1	steep, trees and shrub	steep, trees and shrub	steep	steep
M3				
M4	grass, trees & shrub	grass, trees & shrub	4-5m	4-5m
M5	grass & shrub	steeper, grass & shrub		
M6				
M7				
M8			5-6m, steep	5-6m, steep
M10				
M11	grass, shrubs	grass, shrubs		
M12	grass, shrubs	grass, shrub	2m, steep	2m, steep
M13	exposed ground, few shrubs & trees	sand with shrubs & a few more trees	10-12m, steep	10-12m, steep
M14	grass, shrubs	grass, shrubs		
M15	steeper, sandy	grass, shrubs & some trees	5m, steep	5m, steep
M17	invasive water hyacinth	invasive water hyacinth		
M18	invasive water hyacinth	invasive water hyacinth		
M19	invasive water hyacinth	invasive water hyacinth		
MM1	grass, shrubs	grass, shrubs	12m, steep	12m, steep
N1	herbceous and shrub	grass, few trees	2m, gradual	5m, steep
N2	few trees and shrubs	grass		
N3	few trees, herbaceous & shrub	no trees, fewer shrub due to access area	6 m, moderate	2m ,gradual
N4	grass, shrubs, trees	grass, shrubs, trees	steep	steep
N7	more trees, shrubs & grasses	few trees, shrub & grasses	1-2m,	2m, gradual
N8	shrub & tree	no trees, few shrubs, grasses		
NS1	grass, shrubs	grass, shrubs		
OO1	sparse grass	sparse grass	1m	1.5m, steep

OO2	grass, tall shrub	grass	4m, moderateky steep	4m, moderately steep
OO3	high grasses, shrubs	high grasses, shrubs	4, steep	3, steep
S1	shrub	shrub	1.5m, steep	1.5m, steep
S2	trees with canopy	trees with canopy		
S3	trees with canopy	trees with canopy		
S4	grass, exposed ground, some trees	grass, exposed ground, some trees	3m, steeper	1m, gradual
S5	grasses, shrubs	grasss	1m, gradual	1m, gradual
S6	tall grass, few trees	grass	1.5, moderate	1.5 moderate
SK1	grass	grass	2m, steep	2m, steep
SM1	tall grass, shrubs	tall grass, shrubs		
SM2	trees, shrubs and grasses	trees, shrubs and grasses	5m, steep	5m, steep
T1	high grass, high shrubs, trees	high grass, high shrubs, trees		
T2	grass, tall shrubs, acacia	grass, tall shrubs, acacia	1.5, gradual	1.5, gradual
T3	trees, large shrub	tree, shrub adjacent to access point		
T4	grass & shrub	grass & shrub	1-2m, steep	1-2m, steep
T5	grasses, shrub, trees further back	grass	2m, moderate	2m, moderate
TB1	grazed		5m	2m
TH1	grass, trees	grass, trees	3m, steep	3m, steep
UN1	grass, shrubs & few trees	grass, shrubs & few trees		

Table 9: Observed Disturbance				
System ID	Land-use	Protected	Disturbed	Factors
A1	Forest	No	less	abstraction, deforestation, livestock
A2	Agriculture	No	moderate	agriculture encroachment, erosion, livestock
A3	Agriculture	No	less/ potentially moderate	exotic vegetation, livestock
A4	Agriculture	No	moderate	agriculture, erosion, livestock
A5	Agriculture	No	moderate/ potentially severe	erosion, livestock
B1	Woodland	Yes	less	
B2	Grassland	Yes	less	
K1	Agriculture	No	moderate/ potentially severe	erosion, livestock
M1	Bushland	No	less/potentially moderate	erosion
M10	Grassland	Yes	less	erosion/ incising
M11	Grassland	Yes	less	erosion/ incising
M12	Grassland	Yes	less	erosion/ incising
M13	Bushland	Partial	less	agriculture, livestock
M14	Bushland	No	less	agriculture, erosion, livestock
M15	Agriculture	No	moderate	abstraction, agriculture, erosion, livestock
M17	Wetland	No	less/potentially moderate	abstraction, burning, exotic vegetation
M18	Wetland	No	less/potentially moderate	agriculture, exotic vegetation
M19	Water	No	moderate	exotic vegetation, siltation, quantity
M2	Bushland	No	moderate/ potentially severe	pathogens
M3	Bushland	No	less/potentially moderate	abstraction, erosion
M4	Bushland	No	less	erosion, livestock
M5	Bushland	Partial	less	abstraction, erosion
M6	Bushland	Yes	less	
M7	Bushland	Yes	less	possible toxins, erosion
M8	Grassland	Yes	less	erosion/ incising
M9	Grassland	Yes	less	erosion/ incising
MM1	Grassland	No	less	agriculture, livestock
N1	Agriculture	No	less/ potentially moderate	abstraction, flooding, riparian encroachment,
N2	Agriculture	No	moderate	abstraction, livestock
N3	Agriculture	No	moderate	agriculture, car wash, livestock

N4	Agriculture	No	moderate	abstraction, siltation
N5	Agriculture	No	moderate	pathogens
N6	Agriculture	No	moderate	abstraction, pathogens
N7	Agriculture	No	moderate	abstraction, agriculture, erosion, flooding, siltation
N8	Agriculture	No	moderate	abstraction, car wash, erosion, livestock
NS1	Woodland	No	moderate	agriculture, livestock
OO1	Agriculture	No	moderate/ potentially severe	erosion, livestock
OO2	Bushland	Partial	moderate	erosion
OO3	Bushland	Partial	less	erosion
S1	Bushland	No	high	livestock
S2	Bushland	Yes - by Ministry	less	
S3	Bushland	Community protected	less	
S4	Bushland	No	less	livestock
S5	Bushland	Border	moderate	livestock
S6	Bushland	Border	less	
SK1	Bushland	No	less	abstraction, erosion, livestock, sand harvesting
SM1	Woodland	No	less	livestock
SM2	Bushland	No	less	agriculture
T1	Bushland	Locally (also physically)	less	
T2	Bushland	No	less	agriculture, livestock
T3	Grassland	No	less	car washing, livestock, sand harvesting
T4	Bushland	No	less	erosion, livestock, sand harvesting
T5	Bushland	No - at border	less	abstraction, flooding, livestock
TB1	Woodland	No	less	livestock
TH1	Grassland	No	less/potentially moderate	agriculture, livestock, potential toxins
UN1	Woodland	No	less	livestock

Table 10: Study Unit Population, Elevation and Percent Landuse												
System ID	Elevation (meters)	Population	Area km^2	% Agriculture	% Bushland	% Forest	% Grassland	% Plantation	% Urban	% Water	% Wetland	% Woodland
A1	2922	0	0.01	0%	0%	100%	0%	0%	0%	0%	0%	0%
A2	1972	37136	540	59%	0%	37%	0%	0%	0%	0%	0%	4%
A3	1875	67527	699	63%	0%	34%	0%	0%	0%	0%	0%	3%
A4	1819	28369	204	69%	12%	1%	0%	4%	0%	0%	0%	15%
A5	1811	120806	992	68%	2%	24%	0%	1%	0%	0%	0%	5%
N1	1976	29516	266	37%	0%	46%	0%	0%	0%	0%	0%	16%
N2	1975	32305	394	56%	0%	38%	0%	0%	0%	0%	0%	6%
N3	1975	62306	661	49%	0%	41%	0%	0%	0%	0%	0%	10%
N4	1996	64285	666	49%	0%	41%	0%	0%	0%	0%	0%	10%
N7	1911	73415	690	51%	0%	39%	0%	0%	0%	0%	0%	10%
N8	1908	76101	697	51%	0%	39%	0%	0%	0%	0%	0%	10%
K1	1932	3681	13	100%	0%	0%	0%	0%	0%	0%	0%	0%
OO1	1877	2408	135	18%	69%	0%	0%	13%	0%	0%	0%	0%
OO2	1532	6787	544	19%	58%	1%	18%	3%	0%	0%	0%	0%
OO3	1532	2864	310	1%	53%	2%	44%	0%	0%	0%	0%	0%
M1	1692	325181	2456	64%	8%	21%	0%	0%	0%	0%	0%	6%
M2	1685	326319	2511	62%	10%	21%	0%	0%	0%	0%	0%	6%
M3	1683	326360	2514	62%	10%	21%	0%	0%	0%	0%	0%	6%
M4	1599	354598	2978	56%	18%	20%	1%	0%	0%	0%	0%	5%
M5	1578	505	41	0%	88%	12%	0%	0%	0%	0%	0%	0%
M6	1534	357000	3323	50%	26%	18%	1%	0%	0%	0%	0%	5%
M7	1525	357235	3358	50%	26%	18%	1%	0%	0%	0%	0%	5%
M8	1484	383756	6493	27%	52%	10%	6%	1%	0%	0%	0%	4%
M10	1470	407305	8337	21%	59%	8%	7%	0%	0%	0%	0%	5%
M11	1449	414723	8811	20%	58%	7%	8%	0%	0%	0%	0%	6%
M12	1415	416927	8952	20%	58%	7%	8%	0%	0%	0%	0%	6%
M13	1223	449809	10473	18%	57%	6%	12%	0%	0%	0%	0%	7%
M14	1190	463473	11327	17%	56%	6%	12%	0%	0%	0%	0%	9%
M15	1175	470535	11500	17%	56%	6%	12%	0%	0%	0%	0%	9%
M17	1144	581882	13440	17%	51%	5%	15%	0%	0%	0%	1%	11%
M18	1140	593917	13544	16%	51%	5%	15%	0%	0%	0%	1%	11%
M19	1138	595376	13561	16%	51%	5%	15%	0%	0%	0%	2%	11%
T1	1907	0	0	0%	100%	0%	0%	0%	0%	0%	0%	0%
T2	1947	226	22	0%	100%	0%	0%	0%	0%	0%	0%	0%
T3	1737	3246	268	0%	87%	0%	2%	0%	0%	0%	0%	11%
T4	1663	4165	335	0%	82%	0%	8%	0%	0%	0%	0%	10%
T5	1556	13579	1615	0%	88%	0%	7%	1%	0%	0%	0%	4%
SK1	1701	514	36	0%	100%	0%	0%	0%	0%	0%	0%	0%
S1	2179	81	11	0%	100%	0%	0%	0%	0%	0%	0%	0%
S2	2270	20	3	0%	100%	0%	0%	0%	0%	0%	0%	0%
S3	2110	10	1	0%	100%	0%	0%	0%	0%	0%	0%	0%

S4	2155	256	24	0%	100%	0%	0%	0%	0%	0%	0%	0%
S5	1812	138	11	0%	100%	0%	0%	0%	0%	0%	0%	0%
S6	1582	19698	1487	0%	88%	1%	6%	0%	0%	0%	0%	5%
B1	1714	148	9	0%	30%	0%	64%	0%	0%	0%	0%	6%
B2	1453	6716	419	0%	50%	0%	24%	0%	0%	0%	0%	26%
TB1	1233	5879	367	7%	31%	0%	38%	0%	0%	0%	0%	23%
SM1	1208	10997	687	8%	51%	2%	10%	0%	0%	0%	0%	29%
SM2	1205	11003	687	8%	51%	2%	10%	0%	0%	0%	0%	29%
MM1	1186	3413	80	0%	34%	0%	27%	0%	0%	0%	0%	39%
TH1	1300	7096	151	2%	76%	0%	3%	0%	0%	0%	0%	20%
NS1	1222	887	10	0%	37%	0%	0%	0%	0%	0%	0%	63%
UN1	1236	1349	84	0%	2%	0%	19%	0%	0%	0%	0%	79%

Appendix 1: Water Chemistry 2007											
System ID	System Type	Date	TSS mg/L	Turbidity NTU	Conductivity µS/cm	TDS	Temperature ℃	Salinity ppt	DO %	Do mg/L	pH
A1	Swamp	8/2/2007	23	21	22	0.02	12.4	0.01	27.3	2.89	4.8
A2	Tributary	7/5/2007	37	43	46	0.04	15.6	0.03	85.7	8.52	6.0
A3	Tributary	7/16/2007	40	47	60	0.05	14.6	0.03	83.4	8.47	6.3
A4	Tributary	7/6/2007	61	51	380	0.29	17.6	0.21	83.9	7.99	7.9
A5	Tributary	7/5/2007	59	47	78	0.06	16.6	0.04	84.6	8.25	7.0
B2	Tributary	7/27/2007	24	16	610	0.36	30.2	0.27	90.9	6.84	8.6
K1	Tributary	7/4/2007	121	119	142	0.10	19.3	0.07	83.4	7.67	7.4
M1	Main Stem	7/6/2007	58	53	112	0.08	18.1	0.06	83.1	7.83	7.0
M2	Main Stem	7/18/2007	197	93							
M3	Main Stem	7/18/2007	97	46	99	0.08	16.8	0.06	81.2	7.87	6.6
M4	Main Stem	7/10/2007	60	78	105	0.08		0.06	87.5	8.14	7.2
M5	Tributary	7/10/2007	4	4	534	0.36	23.0	0.27	91.7	7.89	7.8
M8	Main Stem	7/20/2007	88		133	0.10	20.4	0.07	78.2	7.03	6.5
M10	Main Stem	7/27/2007	181	133	165	0.11	23.4	0.08	77.6	6.55	7.4
M11	Main Stem	7/27/2007	131	108	251	0.16	25.1	0.12	73.2	6.04	8.3
M12	Main Stem	7/27/2007	171	131	132	0.09	24.4	0.06	84.9	7.1	7.0
M13	Main Stem	7/26/2007	136	114	145	0.10	23.5	0.07	91	7.79	7.5
M14	Main Stem	7/26/2007	120	115	148	0.10	23.4	0.07	89.8	7.65	7.6
M15	Main Stem	7/25/2007	134	113	176	0.12	23.4	0.08	86.3	7.34	7.4
M17	Wetlands	7/24/2007	13	15	191	0.13	21.8	0.10	13.8	1.21	6.0
M18	Wetlands	7/24/2007	13	12	201	0.13	23.6	0.10	26.7	2.27	6.7

M19	Wetlands	7/24/2007	13	10	199	0.13	23.5	0.10	42.2	3.57	7.0
N1	Tributary	7/3/2007	33	32	46	0.04	17.2	0.02	71.4	6.86	0.0
N2	Tributary	7/3/2007	32	42	35	0.03	16.2	0.02	78.6	7.74	6.0
N3	Tributary	7/2/2007	128	85	40	0.03	16.4	0.02	74.6	7.31	6.0
N7	Tributary	7/4/2007	38	39	39	0.03	15.2	0.02	84.5	8.46	6.7
N8	Tributary	7/4/2007	31	36	40	0.03	15.6	0.02	83.9	8.35	6.5
NS1	Tributary	7/28/2007	119	75	995	0.61	28.5	0.46			8.6
OO2	Tributary	7/8/2007	48	30	2038	1.47	20.0	1.16	74.3	6.7	8.0
OO3	Tributary	7/8/2007	91	52	1171	0.81	22.1	0.62	53.6	4.65	7.2
S1	Headwater Tributary	8/3/2007	418	400	145	0.11	19.1	0.08	60.6	5.6	6.5
S2	Headwater Tributary	8/3/2007	18	7							
S3	Headwater Tributary	8/3/2007	5	37	121	0.09	19.1	0.06	34.9	3.2	5.4
S5	Tributary	7/9/2007	140	122	198	0.14	24.1	0.10	74	6.67	6.8
S6	Tributary	7/9/2007	29	21	755	0.47	28.0	0.35	91.8	7.18	8.5
SK1	Tributary	7/11/2007	68	49	178	0.13		0.10	84	7.95	7.5
SM1	Tributary	7/26/2007		20	327	0.20	23.9	0.15	86.4	6.84	7.9
T3	Tributary	7/9/2007	23	20	347	0.23	23.1	0.17	78.4	6.71	6.9
T4	Tributary	7/11/2007	248	156	470	0.34	19.2	0.26	88	8.12	8.0
T5	Tributary	7/9/2007	65	47	691	0.50	19.4	0.38	81.6	7.49	8.3
TH1	Tributary	7/25/2007	30	46	293	0.19	24.6	0.14	94.8	7.87	7.4
UN1	Tributary	7/28/2007	10	12	667	0.47	21.5	0.35			8.3

Appendix 2: Water Chemistry 2008											
System ID	System Type	Date	TSS mg/L	Turbidity NTU	Conductivity µS/cm	TDS mg/L	Temperature °C	Salinity ppt	DO %	DO mg/L	pH
A1	Swamp	6/15/2008	613	300	105	0.09	12.9	0.06	8.0	0.85	6.6
A2	Tributary	5/30/2008	9	20	48	0.04	16.9	0.03			7.2
A3	Tributary	6/8/2008	35	36	58	0.04	16.9	0.03	84.6	8.21	7.8
A4	Tributary	6/8/2008	78	48	1350	0.95	21.1	0.73	83.2	7.38	8.1
A5	Tributary	6/9/2008	117	74	74	0.05	19.4	0.04	83.1	7.64	7.9
B1	Headwater Tributary	6/30/2008	4	0	126	0.08	25.6	0.06	87.5	7.16	7.4
B2	Tributary	7/1/2008	322	167	465	0.32	22.9	0.23	84.2	7.22	7.6
K1	Tributary	6/9/2008	313	156	141	0.10	22.1	0.07	70.6	6.16	7.8
M1	Main Stem	6/10/2008	103	81	72	0.05	18.4	0.04	87.5	8.21	7.4
M3	Main Stem	6/10/2008	101	63	69	0.05	19.7	0.04	80.1	7.33	7.8
M4	Main Stem	6/4/2008	82	52	93	0.07	21.5	0.05	91.9	8.09	
M6	Main Stem	6/4/2008	250	82	110	0.07	23.8	0.05	82.4	6.97	7.8
M7	Main Stem	6/4/2008	100	55	114	0.08	24.2	0.05	74.1	6.22	7.6
M8	Main Stem	6/4/2008	105	56	134	0.09	25.2	0.06	74.5	6.12	7.8
M11	Main Stem	7/1/2008	85	55	176	0.12	24.5	0.08	85.6	7.13	7.6
M12	Main Stem	6/30/2008	117	81	120	0.08	24.3	0.06	86.8	7.26	7.4
M13	Main Stem	6/28/2008	98	57	131	0.09	24.7	0.06	93.6	7.80	7.6
M15	Main Stem	6/27/2008	116	72	143	0.09	25.3	0.07	94.1	7.74	7.0
M17	Wetlands	7/2/2008	51	33	211	0.14	24.8	0.10	25.7	2.13	7.3

M18	Wetlands	7/2/2008	16	12	215	0.14	24.6	0.10	33.5	2.79	7.3
M19	Wetlands	7/2/2008	14	10	223	0.14	25.0	0.10	40.0	3.37	7.3
MM1	Tributary	6/28/2008	100	72	132	0.09	23.2	0.06	88.1	7.53	6.9
N1	Tributary	7/5/2008	26	25	38	0.03	15.8	0.02	86.8	8.62	7.4
N2	Tributary	7/5/2008	39	30	31	0.02	16.5	0.02	84.5	8.25	7.5
N3	Tributary	7/5/2008	26	20	33	0.03	15.9	0.02	85.2	8.44	7.4
N4	Tributary	7/4/2008	23	21	32	0.03	15.8	0.02	83.0	8.24	7.2
N5	Tributary	7/4/2008	45	30							
N6	Tributary	7/4/2008	23	23	32	0.03	16.4	0.02	87.1	8.52	7.1
N7	Tributary	7/5/2008	24	21	33	0.03	16.6	0.02	86.7	8.45	7.5
N8	Tributary	6/9/2008	53	50	32	0.03	17.1	0.02	82.5	7.96	7.7
OO1	Tributary	5/29/2008	189	116	2950	2.15	19.4	1.74	70.6	6.40	10.5
OO2	Tributary	6/3/2008	31	13	2045	1.27	27.6	0.98			7.8
OO3	Tributary	6/4/2008	116	70	1965	1.22	27.8	0.96			
S1	Headwater Tributary	6/13/2008	137	76	130	0.09	21.0	0.07	52.8	4.70	7.1
S4	Headwater Tributary	6/13/2008	149	69	142	0.10	19.4	0.07	87.7	8.08	7.0
S5	Tributary	6/5/2008	116	74	199	0.15	17.2	0.11	70.2	6.74	7.8
S6	Tributary	6/2/2008		2	686	0.50	19.6	0.38	92.4	8.43	7.9
SK1	Tributary	6/5/2008	72	45	172	0.12	19.9	0.09	80.5	7.32	7.9
SM2	Tributary	6/28/2008	66	52	150	0.09	27.5	0.07	91.1	7.20	7.8
T1	Headwater Tributary	6/13/2008		1	76	0.05	22.9	0.04	11.2	0.95	6.5
T2	Headwater Tributary	6/13/2008	28	17	234	0.16	21.8	0.12	67.5	5.92	7.2
T3	Tributary	6/5/2008	22	19	263	0.17	24.2	0.13	71.4	5.98	
T4	Tributary	6/6/2008	33	24	538	0.35		0.26	93.5	7.70	8.0
T5	Tributary	6/2/2008	22	19	492	0.33	23.5	0.24	73.5	6.24	7.7
TB1	Tributary	6/28/2008	13	9	1238	0.77	27.3	0.59	98.5	7.89	7.9
TH1	Tributary	6/27/2008	124	104	338	0.23	22.4	0.17	98.1	8.46	7.2

Appendix 3: Nutrients 2007											
System ID	System Type	Date	NH_4 µg/L	NO_3 µg/L	NO_2 µg/L	TDN ppm	TN ppm	SRP µg/L	TDP ppm	TP µg/L	DOC ppm
A1	Swamp	8/2/2007	26.36	0.00	0.00	0.84	1.41	0.00	0.01	16.74	5.03
A2	Tributary	7/5/2007	31.54	553.00	1.95	0.74	1.07	2.27	0.01	7.44	1.38
A3	Tributary	7/16/2007	37.42	512.00	6.94	0.57	1.06	2.89	0.01	12.40	1.53
A4	Tributary	7/6/2007	62.90	5068.00	20.73	3.97	3.31	0.10	0.01	14.88	3.54
A5	Tributary	7/5/2007	58.14	892.00	2.02	1.16	1.17	1.65	0.01	12.09	1.69
B2	Tributary	7/27/2007	27.90	0.00	3.35	1.03	0.65	3.51	0.01	189.10	4.09
K1	Tributary	7/4/2007	49.04	5613.00	13.75	6.77	2.68	4.13	0.01	9.92	2.05
M1	Main Stem	7/6/2007	80.26	999.00	3.54	0.19	0.71	3.51	0.01	53.94	1.73
M2	Main Stem	7/18/2007	5530.78	41.00	17.60	3.39	0.33	688.68	1.01	672.70	9.62
M3	Main Stem	7/18/2007	12.92	234.00	7.18	0.34	1.12	2.58	0.01	19.84	0.86
M4	Main Stem	7/10/2007	114.42	631.00	2.90	1.20	0.94	281.58	0.37	27.28	6.44
M5	Tributary	7/10/2007	76.34	6.00	2.44	0.22	6.34	0.41	0.01	17.36	4.70
M8	Main Stem	7/20/2007	22.16	1189.00	10.46	1.07	0.99	23.66	0.04	40.92	2.20
M10	Main Stem	7/27/2007	34.90	111.00	7.34	0.22	0.99	5.06	0.02	21.08	0.99
M11	Main Stem	7/27/2007	42.88	863.00	9.30	0.70	0.68	10.64	0.03	24.18	2.89
M12	Main Stem	7/27/2007	47.64	1018.00	5.82	0.96	0.65	8.47	0.03	27.90	2.98
M13	Main Stem	7/26/2007	35.18	643.00	5.77	1.61	0.86	22.11	0.04	20.46	2.88
M14	Main Stem	7/26/2007	35.46	859.00	6.44	0.94	0.94	25.52	0.05	35.65	2.99
M15	Main Stem	7/25/2007	30.00	975.00	14.87	1.24	1.22	23.04	0.04	35.65	2.51
M17	Wetlands	7/24/2007	45.82	0.00	0.00	0.13	0.16	2.27	0.01	9.92	4.57
M18	Wetlands	7/24/2007	54.08	1.00	3.02	0.25	0.18	3.51	0.02	10.54	6.24
M19	Wetlands	7/24/2007	37.14	0.00	0.00	0.16	0.19	4.44	0.01	13.95	5.88
N1	Tributary	7/3/2007	155.58	816.00	1.82	0.94		2.58	0.01	105.40	0.86
N2	Tributary	7/3/2007	168.46	730.00	1.47	0.59	0.42	1.96	0.01	18.91	0.94
N3	Tributary	7/2/2007	26.22	946.00	2.18	0.99	0.76	2.89	0.01	6.20	1.56
N7	Tributary	7/4/2007	50.30	339.00	10.78	0.51	0.85	163.47	0.05	8.06	2.23
N8	Tributary	7/4/2007	77.46	661.00	21.92	0.64		174.01	0.09	15.50	2.54
NS1	Tributary	7/28/2007	78.02	18.00	4.34	0.47	0.27	7.23	0.03	28.21	3.75

OO2	Tributary	7/8/2007	308.04	0.00	0.00	0.20	0.46	221.75	0.03	87.42	5.05
OO3	Tributary	7/8/2007	135.14			0.26	0.54	7.54	0.06	60.45	5.90
S1	Headwater Tributary	8/3/2007	212.84	85.00	11.60	0.35	0.47	14.67	0.04	31.93	4.12
S2	Headwater Tributary	8/3/2007	29.86	162.00	2.55	0.17	0.24	1.96	0.00	4.96	1.01
S3	Headwater Tributary	8/3/2007	45.82	584.00	5.63	0.78	0.60	34.82	0.05	37.82	0.36
S5	Tributary	7/9/2007	181.62	142.00	5.78	0.27	0.34	7.85	0.01	85.25	1.38
S6	Tributary	7/9/2007	33.08	215.00	3.95	0.30	0.87	20.25	0.04	13.95	2.92
SK1	Tributary	7/11/2007	71.72	767.00	3.47	1.10	0.88	8.78	0.01	8.99	1.67
SM1	Tributary	7/26/2007	39.80	0.00	0.91	0.23	0.17	1.34	0.05	10.23	8.64
T3	Tributary	7/9/2007	17.54	98.00	3.23	0.23	0.20	4.13	0.01	8.99	1.95
T4	Tributary	7/11/2007	13.76			0.20	0.32	0.72	0.01	8.68	4.38
T5	Tributary	7/9/2007	87.12			0.31	0.39	0.10	0.02	25.11	3.85
TH1	Tributary	7/25/2007	246.58		11.04	2.15	3.58	1.96	0.01	8.06	3.09
UN1	Tributary	7/28/2007	45.96	75.00	5.03	0.27	0.31	2.89	0.02	131.75	5.61

Appendix 4: Nutrients 2008											
System ID	System Type	Date	NH_4 µg/L	NO_3 µg/L	NO_2 µg/L	TDN ppm	TN ppm	SRP µg/L	TDP ppm	TP µg/L	DOC ppm
A1	Swamp	6/15/2008	580.30	103.00	4.94	0.65	1.45	0.00	0.02	177.32	16.82
A2	Tributary	5/30/2008	6.86	867.00	2.53	0.85	0.89	0.00	0.01	15.19	1.47
A3	Tributary	6/8/2008	0.00	625.00	3.14	0.61	0.37	0.00	0.01	22.63	1.94
A4	Tributary	6/8/2008	0.00	33.00	3.84	0.21	0.50	3.10	0.02	103.23	4.82
A5	Tributary	6/9/2008	12.60	432.00	3.52	0.61	0.75	0.00	0.01	44.64	2.49
B1	Headwater Tributary	6/30/2008	92.54	1650.00	0.61	1.38	0.55	5.27	0.01	4.03	1.74
B2	Tributary	7/1/2008	61.46	41.00	1.94	0.57	0.27	0.00	0.01	188.48	5.44
K1	Tributary	6/9/2008	170.66	871.00	7.58	1.22	1.24	6.20	0.01	98.27	3.09
M1	Main Stem	6/10/2008	3.92	658.00	2.95	0.68	0.74	4.03	0.01	0.00	2.14
M3	Main Stem	6/10/2008	12.04	568.00	4.31	0.77	0.79	3.41	0.01	40.92	1.62
M4	Main Stem	6/4/2008	275.38	130.00	1.94	0.79	0.78	74.09	0.15	61.07	2.50
M6	Main Stem	6/4/2008	37.52	503.00	9.02	0.54	0.20	17.67	0.04	134.23	2.46
M7	Main Stem	6/4/2008	37.38	856.00	13.45	0.84	0.59	19.53	0.04	78.74	3.35
M8	Main Stem	6/4/2008	43.12	536.00	14.39	0.70	0.95	18.29	0.04	107.88	3.54
M11	Main Stem	7/1/2008	68.60	467.00	22.72	0.66	0.58	52.70	0.05	83.70	3.45
M12	Main Stem	6/30/2008	72.38	817.00	17.93	0.95	0.16	22.32	0.05	121.83	3.75
M13	Main Stem	6/28/2008	14.56	857.00	7.29	0.91	2.14	22.32	0.05	69.44	4.08
M15	Main Stem	6/27/2008	10.08	784.00	4.24	0.85	0.95	36.27	0.05	79.98	3.26
M17	Wetlands	7/2/2008	17.50	28.00	0.99	0.17	0.21	8.37	0.03	317.75	6.64
M18	Wetlands	7/2/2008	12.88	0.00	0.72	0.21	0.21	0.00	0.01	28.52	4.88
M19	Wetlands	7/2/2008	18.90	402.00	1.13	0.19	0.22	0.62	0.02	39.99	8.01
MM1	Tributary	6/28/2008	6.86	916.00	4.54	0.19	0.85	31.00	0.05	78.43	3.16
N1	Tributary	7/5/2008	14.14	652.00	2.53	0.62	0.64	0.00	0.01	0.00	1.42
N2	Tributary	7/5/2008	0.00	581.00	2.01	0.51	0.57	2.17	0.01	29.45	1.39
N3	Tributary	7/5/2008	12.46	569.00	1.90	0.63	1.74	1.24	0.00	14.26	1.23
N4	Tributary	7/4/2008	3.92	486.00	1.80	0.59	10.81	0.00	0.00	10.85	1.55
N5	Tributary	7/4/2008	568.40	25.00	11.31	0.18	0.49		5.38		11.20

N6	Tributary	7/4/2008	11.20	633.00	2.02	0.75	0.80	3.10	0.01	32.55	1.66
N7	Tributary	7/5/2008	207.90	369.00	0.97	4.50	0.52	0.00	0.01	20.15	1.05
N8	Tributary	6/9/2008	47.60	587.00	2.91	0.93	0.40	0.00	0.00	34.72	1.92
OO1	Tributary	5/29/2008	0.00	110.00	7.90	0.31	0.75	89.90	0.04	290.78	10.39
OO2	Tributary	6/3/2008	0.00	34.00	3.86	0.38	1.29	0.00	0.04	186.62	16.09
OO3	Tributary	6/4/2008	493.22	59.00	10.62	1.04		10.54	0.21	10.54	24.88
S1	Headwater Tributary	6/13/2008	13.30	313.00	11.99	0.43	0.97	0.00	0.01	101.06	1.74
S4	Headwater Tributary	6/13/2008	0.00	18.00	0.01	4.08	0.19	0.00	0.02	75.02	1.67
S5	Tributary	6/5/2008	44.52	448.00	14.27	0.51	0.47	0.62	0.02	7.13	3.28
S6	Tributary	6/2/2008	0.00	21.00	0.83	0.18	0.28	6.82	0.03	24.49	2.94
SK1	Tributary	6/5/2008	48.02	511.00	27.66	0.73	0.21	8.68	0.02	72.23	1.97
SM2	Tributary	6/28/2008	7.70	720.00	7.02	1.00	0.66	22.32	0.04	75.95	3.57
T1	Headwater Tributary	6/13/2008	0.00	439.00	1.13	0.49	0.68	0.00	0.01	0.00	0.53
T2	Headwater Tributary	6/13/2008	0.00	184.00	3.56	0.24	0.56	8.37	0.02	39.06	1.71
T3	Tributary	6/5/2008	29.54	8.00	3.49	0.17	1.33	0.00	0.02	61.38	2.92
T4	Tributary	6/6/2008	0.00	22.00	1.88	0.45	0.21	0.00	0.02	56.42	20.46
T5	Tributary	6/2/2008	0.00	42.00	2.12	0.24	1.08	0.00	0.02	67.58	6.67
TB1	Tributary	6/28/2008	0.00	26.00	1.67	0.18	0.14	0.00	0.02	11.78	7.70
TH1	Tributary	6/27/2008	0.00	4797.00	17.75	4.28	10.16	0.00	0.02	183.83	3.03